EVALUATION AND IDENTIFICATION OF SINGLE-CROSS MAIZE HYBRIDS FOR USE IN TESTER DEVELOPMENT

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DISSERTATION ABSTRACT

Development of testers from new inbred lines that are high yielding and high discriminating abilities in diverse environments, and in stress conditions is very important in maize breeding in southern and eastern Africa. Genetic gain decreases when new lines are combined with old testers. It is, therefore, important to develop new testers that perform better in harsh environmental conditions to replace the old single-cross testers; CML 312 x CML 442 (heterotic group A) and CML 444 x CML 395 (heterotic group B). These are currently dominating the maize breeding programmes at the Agricultural Research Council (ARC) and most of the National Agricultural Research stations (NARS) in eastern and southern Africa. The objectives of this study were therefore; i) to identify elite single-cross hybrids suitable for further evaluation as potential testers in development of three-way cross hybrids, ii) to determine the correlations between grain yield and secondary traits in single-cross maize hybrids, and iii) to estimate phenotypic and genetic variance components, heritability and genetic advances for yield and its related components in single-cross maize hybrids. The trials were established under three different environments which are: random drought (RD), optimum environment (OPT) and low nitrogen (Low N) at ARC Potchefstroom and Cedara using alpha lattice 0, 1 design (32 x 5). The single-cross hybrids used in this study were obtained from CIMMYT Zimbabwe and they belong to two different heterotic groups as follows;, heterotic group A with 160 entries among which 155 were experimental single-cross hybrids and five were check entries and heterotic group B with 160 entries among which 157 were experimental single-cross hybrids and three were hybrid checks.

High significant differences ($P< 0.01$) among single-cross hybrids were observed on days to 50% anthesis (AD), grain yield (GY), ear height (EH), and ears per plant (EPP) in heterotic group B under optimum environment. Hybrid 139 had a mean yield of 8.65 t/ha, which was higher than the average grain yield of 6.22 t/ha. Days to 50% anthesis (AD), anthesis-silk interval (ASI), plant height (PH), and EH varied significantly ($p<0.01$) among single-cross hybrids in the low nitrogen environment. Hybrid 65 had a mean yield of 4.04 t/ha, which was higher than the average yield of 2.29 t/ha. Days to 50% anthesis were slightly higher in low nitrogen environment than in optimal environment. Hybrid 92 had a mean yield of 7.53 t/ha, which was higher than the average yield of 4.77 t/ha in random drought environment. As in heterotic group B, significant variations were observed in heterotic group A, in random drought and optimum environments. Grain yields of 9.44 t/ha and 6.42 t/ha for maize hybrids 134 and 52 were higher than average mean yields of 6.75 t/ha and 3.43 t/ha from optimum and random drought environments, respectively. Hybrids with higher trait values than the average may be advanced for further use in breeding in their respective environments. Maize single-cross hybrids 1, 23, 127, 15, 122, 8, 134, 109, 34, and 31 from heterotic group A and 69, 81, 65, 97, 92, 40, 117, 58, 101, and 44 from heterotic group B were selected for further use in breeding. The hybrids had consistently higher mean yields across the environments.

Significant, positive and negative correlations were observed among secondary traits in all environments. Yield (t/ha) was positively correlated with cob length (CBL), EH, field weight (FW), grain weight (GW) and shelling percentage (SP). It was however, negatively correlated with days to 50% silking (SD) and days to 50% anthesis (AD). A breeding programme aimed at improving CBL, EH, FW, GW and SP and reducing traits SD and AD may indirectly result in improvement of maize yields in random and optimum environments. High genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for ASI, yield t/ha, PH and ear height therefore, and selection can be done. Improvement of maize yield based on AD and ASI selection would be successful due to their high broad sense heritability estimates. The genetic advance observed in this study were high and therefore some trait values can be increased in the next generation through selection.

DECLARATION

I, Barnaba Makavu declare that:

1. The research reported in this dissertation, except where otherwise indicated, is my original research.

2. This dissertation has not been submitted for any degree or examination at any other University.

3. This dissertation does not contain other person's data, pictures, graphs, or other information, unless specifically acknowledged as being sourced from other persons.

4. This dissertation does not contain other person's writing unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:

   a. Their words have been re-written, but the general information attributed to them has been referenced

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5. This dissertation does not contain text, graphics or tables copied and pasted from the internet, unless specifically acknowledged, and the source being detailed in the dissertation and in the references sections.

Signed.

Makavu!

Barnaba Makavu

As the candidate's supervisors, we agree to the submission of this dissertation:

Sibiya

Dr. Julia Sibiya (Main supervisor)

Dr. Kingstone Mashingaidze (Co-supervisor)

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- I dedicate this work to my mother and my father, Rebeca Andrea Msambili and Mr. Lameck Makavu for their prayers for their only child.
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LIST OF ABBREVIATIONS

AD	Days to 50% anthesis
ARC	Agricultural research council
ASI	Anthesis-silking interval
CIMMYT	International Maize and Wheat Improvement Centre
CML	CIMMYT maize line
DH lines	Double haploid lines
EH	Ear height
EP	Ear position
EPP	Number of ears per plant
F1	First generation hybrid
FW	Field weight
FWH	Four-way cross hybrids
GA	Genetic advance
GAM	% genetic advances as mean percentage
GCV	Genetic coefficient of variation
GLS	Grey leaf spot
GV	Genetic variation
GW	Grain weight
H	Broad sense heritability
HTG A	Heterotic group A
HTG B	Heterotic group B
LN	Low Nitrogen
m. a.s.l	Metres above sea level
MSV	maize streak virus
NARS	National agricultural research stations
NCLB	North corn leaf bright
NE	Number of ears per plant/plot (prolificacy)

NP	Number of plants
OPV	Open pollinated varieties
PCV	Phenotypic coefficient of variation
PH	Plant height
RL	Root lodging
SC	Single-cross
SD	Days to 50% silking
SP	Shelling percentage
TWH	Three-way cross hybrids
VG	Genetic variance
VP	Phenotypic variance
W	absorbed soil water by plants
WUE	Water use efficiency
HI	Harvest index

CHAPTER ONE

GENERAL INTRODUCTION

1.1 Meaning of testers and their potential in maize (*Zea mays* L.) breeding

A tester is a discriminatory agent in a wide range of either populations, inbred lines, genotypes or on hybrids for selection (Rawlings and Thompson, 1962). It is used to test combining ability of an inbred line and hybrids, and in evaluation of breeding values of the genotypes in a population. Testers combine well and give maximum information on the performance of the tested lines when used with other combinations or when grown in other environments. They were reported to maximize genetic gains and expected mean yield of the population produced from random mating among selected genotypes (Allison and Curnow 1966; Hallauer 1975) cited by Hallauer et al., 2010).

In maize breeding programmes, testers are used to evaluate and screen various inbred lines based on the environmental conditions that are prone to drought and diseases. In eastern and southern Africa, farmers are facing great challenges in increasing maize yield during drought, low nitrogen conditions, and diseases such as maize streak virus (MSV), maize lethal necrosis (MLN), grey leaf spot (GLS), and northern corn leaf blight (NCLB) among others. All these point to the need for developing new testers that can test for adaptation to stress environments for yield improvement.

1.2 Development of new three-way cross hybrid testers

Evaluation and identification of elite single-cross maize hybrids to be used as potential testers in three way-cross hybrids is crucial in maize breeding programmes and seed business. A high seed producing single-cross is used as a female parent and crossed with an inbred line in three-way cross hybrid development. Three-way hybrids have been reported to be statistically the most important second hybrids after single-cross in terms of yield potential. They produce yields that are above those of double cross hybrids and open pollinated varieties (OPVs) (Forrest Troyer, 1996). Development of maize hybrids from three-way crosses started in the 1960s and to date, maize hybrids like CML 312 x CML 442 (heterotic group A) and CML 444 x CML 395 (heterotic group B) developed by CIMMYT are still being used as single-cross testers in developing countries.

1.3 Maize single-cross hybrids' tolerance to drought and low nitrogen conditions

Drought is the main constraint limiting maize yields in the tropics (Araus et al.,2008 ;Baker, 1989, 2008). Climate change is expected to increase the occurrence of extended dry periods in tropical areas (Lobell et al., 2008), with a general decrease in the availability of water resources for agricultural use. Consequently, decreased crop productivity is also anticipated, increasing the risk of famine (Bänziger and Araus, 2007). In sub-Sahara Africa (SSA), drought affects many people's lives since maize is the staple crop. Sometimes eastern and southern Africa experience droughts which result in food shortages, making it difficult to compensate by importing food (Araus et al., 2008). Drought-tolerant maize will, therefore, significantly play a part in alleviating the problem of extreme poverty and hunger in SSA. Low nitrogen (N) stresses on maize can cause yield reduction of about 60% due to reduction of photosynthesis and many other physiological process in the maize crop. A yield loss of 60% to 62% compared to optimum conditions was reported by Bänziger and Lafitte (1997) and Weber et al. (2012). Photosynthesis reduction is caused by the reduced leaf area development, accelerated leaf senescence and reduced rate of photosynthesis. It is estimated that 50% of all leaf N is involved in photosynthesis. Leaf senescence due to a short supply of N begins with the bottom leaves because the plant relocates N from the bottom older tissue to the younger leaves and grains (Blum, 1988).

1.4 Opportunity for plant breeding

Maize is the third most important cereal crop in the world after rice and wheat. However, yield in the SSA region is still low. This is because there is still low exploitation of the genetic gains from the new lines identified since old testers still dominate the breeding programmes in Sub-Saharan Africa.

The Republic of South Africa and other countries in eastern and southern Africa mostly depend on inbred lines from CIMMYT for the three-way cross programmes. The following are the lines mostly used; CML 312, CML 444, CML 442 and CML 395. The most commonly used single-cross testers for three-way crosses are: CML 312 x CML 442, and CML 444 x CML 395. These testers have been used for a long time and now the genetic gains are low when they are used with new lines. Therefore, if new testers crossed new inbred lines, there could be high genetic gains. There is a need, therefore, of evaluating new single-crosses for use as female parents in development of three-way hybrids. Single-cross testers crossed by ARC and NARS for early screening are CML 312/CML 442 heterotic group A and CML 395/CML 444 in heterotic group B. Understanding the single-cross hybrid performance is important in the development of testers for three-way cross hybrids.

1.5 Problem statement

There was a yield decrease estimate of 4.21 t/ha in 2012/13 compared to yield of 4.96 t/ha realized in 2008/09 and yield of 4.49 t/ha estimated for 2011/12 (Araus et al., 2008; FAO, 2013). This is mainly because of the drought conditions that occurred during the growing season which impacted negatively on the yields. In addition, SSA breeding programmes are still dominated by the use of old testers. For example, South Africa and other countries in eastern and southern Africa mostly depend on lines from CIMMYT to the extent that for the three-way programmes, most national programmes rely on the use of single-cross (SC) hybrids CML 312 x CML 442, and CML 444 x CML 395 as testers. These testers have been used for a long time and limited genetic gains are expected when crossed with new lines.

The study aimed at developing single-cross testers that are stress tolerant, with high yielding capacity and stability across the environments, which can replace the old testers. The study also aimed at evaluating the agronomic performance of the single-cross hybrids under different environments. The identified single-cross hybrids would provide reliable discriminating testers under stress conditions and improved selection for the development of three-way hybrids.

1.6 Research overall goal

The overall goal of this study was to develop new single-cross hybrid testers using new inbred lines developed in partnership between ARC and CIMMYT, Zimbabwe, which are high yielding and stable across environments, and stress tolerant to replace the currently used testers made from old inbred lines.

1.7 Specific objectives

The specific objectives of the study were:

- To identify the elite single-cross hybrids suitable for further evaluation as potential testers for three-way cross hybrids.

- To determine the correlations between grain yield and secondary traits in single-cross maize hybrids.
- To estimate the phenotypic and genetic variance components, heritability and genetic advances for yield and its related components in single-crosses of maize hybrids.

1.8 Research hypotheses

The following hypotheses were tested:

- There are elite single-cross hybrids suitable for further evaluation as potential testers for development of three-way cross hybrids.
- There are high correlations between grain yield and secondary traits in single-cross maize hybrids.
- There are high phenotypic and genetic variances, and heritability among maize single-cross hybrids that can be exploited in breeding high yielding maize hybrids.

1.9 Dissertation Outline

This dissertation comprises the introduction and four main chapters as follows:

Chapter 1: General Introduction
Chapter 2: Literature review
Chapter 3: General materials and methods
Chapter 4: Identification of elite maize single-cross hybrids suitable for further evaluation as potential testers in three-way cross hybrids
Chapter 5: Determination of the correlations between grain yield and secondary traits and estimation of genetic parameters in single-cross maize hybrids
Chapter 6: General overview of the research findings

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CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature on maize (*Zea mays* L.) crop evaluation in optimum, random drought and low nitrogen conditions. It also explains the theory of inbred lines, maize heterotic groups, maize testers, and maize hybrids. Current efforts on breeding for drought and low N environments are explained. Drought has significant effects on the maize crop from vegetative growth stage, flowering stage to grain filling where it affects the physiological process of the plant and hence photosynthesis which is the food machinery process of maize crop (Byrne et al., 1995; Farooq et al., 2009). Drought stress can cause reduction in growth and y loss in yield (Chenu et al., 2009). Low nitrogen stress causes yield loss (Bänziger and Lafitte, 1997; Bänziger et al., 2006). The yield loss due to drought and low nitrogen can be up to 80% (Bänziger et al., 2006).

2.2 Origin of Maize

Maize is believed to have originated from the Mesoamerica region, probably in the Mexican highlands, from where it spread rapidly to other parts of the world. Domestication is believed to have started around 6,000 to 10,000 years ago (Matsuoka et al., 2002; Hufford et al., 2007). Maize spread around the world after the discovery of the Americas in 15th century, particularly in temperate regions (Randolph, 1959; Farnham et al., 2003). During the domestication of maize, every region in which it has been cultivated over the centuries has produced a selection of maize cultivars or landraces. Farmers have maintained and improved these varieties and are adapted to local requirements and characteristics (Paliwal et al., 2000).

Maize can be grown in a number of environments (Farnham et al., 2003) from 58^o N to 40^o S. Generally, tropical maize is grown between 30^oN and 30^oS, sub-tropical maize between 30^o and 34^o both north and south, temperate maize beyond 34^o latitudes. Maize grows in a range of altitudes from sea level to 3,800 m a.s.l and with growing seasons between 42 and 400 days. This ability to be grown in a wide range of environments is due to the high diversity in morphological and physiological traits.

2.3 Taxonomy of maize

The maize species and their chromosomes number is presented in table 2.1. The genus *Zea* belongs to the tribe Andropogonease in the subfamily *Panicoideae* in the family *Poaceae* (USDA, 2005). There are currently 86 recognized genera within the Andropogononeae tribe (USDA, 2005). There are five species included in the genus *Zea.* Species of have 2n=20 chromosome number except for the Z. *perrennis* (perennial teosinte with 2n=40) (Ellneskog-Staam et al., 2007).

Table 2.1: Maize species and their chromosome numbers (USDA, 2005).

S/N	**Species**	**Chromosome number**
1	*Zea diploperennis*	2n=20
2	*Zea luxurians*	2n=20
3	*Zea mays* L.	2n=20
4	*Zea nicaraguensis.*	2n=?
5	*Zea perennis.*	2n=40

Zea spp*. mays* is the only cultivated species; the other species are wild grasses referred to as teosintes. In addition to the basic A chromosome complement, maize plants may contain one or more supernumerary chromosomes, called B chromosomes, which do not pair with A chromosomes during meiosis (McMullen et al., 2009). Maize genome is large, being somewhere between 2.3-2.7Gbp^b (Arumuganathan and Earle, 1991) with a total gene number of between 42,000 and 56,000 genes.

2.4 Importance of maize

Maize is one of the oldest cultivated grains and one of the most productive crop species with a global average yield of more than 4.9 t/ha (Tollenaar and Lee, 2002 ; Edgerton ,2009). It can be directly consumed as food at various developmental stages from young maize to mature grain. A high proportion of maize produced is used as stock feed, e.g. 40% in tropical areas and up to 85% in developed countries (Trostle, 2008; Ranum et al., 2014). Maize stalks are fed to livestock as animal fodder after the grain has been harvested. For example, in Zimbabwe annual requirement is divided by the following ratio; 64% for human consumption, 22% for livestock and poultry feeds and 14% for other industrial uses (Mashingaidze, 2006).

Maize can be processed for a range of uses both as an ingredient in food or drinks, e.g. corn syrup in soft drinks or maize meal, or for industrial purposes. Maize is the major source of starch worldwide, and is used as food ingredients, either in native form or chemically modified (Ranum et al., 2014). Maize starch can be fermented into alcohol, including fuel ethanol, while the paper industry is the biggest non-food user of maize starch. The oil and protein are often of commercial value as by-products of starch production and are used in food manufacturing.

2.5 Production constraints

Maize production has a number of challenges from abiotic to biotic factors. Abiotic stress factors include low N, drought, and heat. All these factors limit the yield of maize in sub-Saharan Africa (SSA) (Mashingaidze and Mataruka, 1992; Zerihun et al., 2013).The yield obtained from small and medium scale farmers is about 1.5 to 2 t/ha which is lower than 5.3 t/ha reported in 2014 (FAOSTAT, 2014;Tittonell and Giller, 2013). These low yields are due to a number of factors such as moisture stress, diseases, and low nitrogen (Heisey and Mwangi, 1996; Jones and Thornton, 2003; Chenu et al., 2011).

2.6 Maize hybrids

Hybrid seed began with maize in the 1920s and was extended to vegetables and flowers; and more recently, rice and some forage crops. A hybrid is a filial 1 (F1) generation seed that is constituted by crossing two or more inbred lines, clones, pure lines or hybrids in a particular order from different heterotic groups. Hybrids exploit heterosis (hybrid vigour) that results from crossing parents that are genetically diverse and from distant heterotic groups. Hybrid cultivars are used mostly for allogamous crops such as maize and sunflowers (Shull, 1910; Pešek and Baker, 1969).

Important hybrid cultivars show expression of heterosis and efficiency of seed production (cost, labour, time). Heterosis expression needs to be sufficient to overcome the cost of development and hybrid seed production. Crosses are made within a heterotic group to develop superior inbred lines within the group. These inbred lines are crossed to testers from other heterotic groups to determine specific combining ability (Hallauer et al., 2010).

Superior inbred lines from dissimilar heterotic groups are crossed to produce hybrids. Several 100s or 1000s of hybrids are evaluated each year to identify the most superior hybrid(s) for commercial release based on their performance and target area of adaptation (maturity, stress, environment etc.) (Sprague and Tatum, 1942; Forrest Troyer, 1996). Hybrid seed is also produced by growing female and male rows (female and male are inbred lines from dissimilar heterotic group) and de-tasselling (removing male inflorescence from female plant rows). Manual or mechanical tools are used to de-tassel prior to pollen shed to avoid selfing among female inbred lines. Generally, ears from female rows are harvested and they constitute the hybrid seed.

2.7 Inbred lines

An inbred line is a pure line that is generated after many generations of selfing a line selected from a population. Inbred lines are then used for crossing in particular combinations to generate hybrids. If an individual plant is heterozygous at a locus, approximately seven generations of self-pollination are needed until nearly all the progeny generated from that single plant are homozygous. After seven consecutive generations of self-pollination, more than 99% of the progeny are expected to be homozygous at any one locus (Crow, 1998). Inbred lines usually look weak, dwarf, thin, low yielding and less vigorous compared to the hybrids because of inbreeding depression especially in allogamous crops. In many cases hybrid yield exceeded that of the varieties from which the hybrid was derived. Furthermore, inbred lines have high uniformity (Crow, 1998).

2.8 Types of hybrids

2.8.1 Single-cross hybrids

Each seed produced from crossing two inbred lines has an array of alleles from each parent. Those two arrays will be different if the inbred are genetically different, but each seed contains the same female array and the same male array. Thus, all plants of the same single-cross hybrid are genetically identical. At every locus where the two inbred parents possess different alleles, the single-cross hybrid is heterozygous. In many cross-pollinated crops such as maize, single-cross hybrids (F1) are commercially marketed as the first generation of selection (Miranda et al., 2008). The single-cross hybrids were commercialized in 1970s. The yield of the single-cross hybrids is higher since the inbred lines are of different heterotic pool and thus parents show high heterosis in hybrid combinations (de Souza Guimarães et al., 2007; Miranda et al., 2008).This type of hybrid often has challenges with hybrid seed production. This is because the female line is an inbred line and exhibits inbreeding depression, the seed yield from the two inbred lines is always low (Crow, 1998).

2.8.2 Double cross hybrids

A double or four parents cross hybrid can be produced by crossing two single-cross F1 hybrids each formed from two inbred lines. Each of the resulting individuals in the double cross generation will be genetically distinct. This is the hybrid progeny from a cross between four unrelated inbred lines. The inbred lines are first crossed in pairs and their hybrids are crossed to produce the double cross hybrid (Crow, 1998) as indicated in equation 2.1.

$$A \text{ x } B = AB \text{ x } \overset{\overset{C \text{ x } D}{\downarrow}}{CD} = ABCD \text{ . …………….equation 2.1}$$

The first double cross hybrid was grown in the United States in the 1930s and 1940s. Typically, A and B are closely related and C and D are also closely related, but neither A nor B are closely related to C or D. Unlike a single-cross hybrid, plants of a double-cross hybrid are not genetically uniform (Crow, 1998).

2.8.3 Three-way cross hybrids

Crossing the single-cross F1 to a third parent (inbred line) and self-pollinating the resulting three-way hybrid creates a three-way cross population. In this cross the third parent contributes 50% of the alleles to the three way hybrid, therefore, should generally always be one of the best parents. A three-way cross is useful if one of the parents is less desirable and one or two are more desirable. In commercial seed, the single-cross is considered to be one with very high yielding capacity and the line crossed must be the best in pollen production. The F1 hybrid from a cross between a single-cross and a third inbred line (Crow, 1998) is shown in equation 2.2.

A x B = AB x C = (AB) x C ………………equation 2.2

2.9 Testers

In any plant breeding programme, especially maize breeding, developing and evaluating testers is important since testers will facilitate assessment and selection of genotypes based on general and specific combining ability. This is very important for breeding programmes for hybrid production. A good tester must be stable across environments such as low nitrogen environments (Deitos et al., 2006; Souza et al., 2010). Testers have been used in maize breeding programmes to form heterotic groups, assess the combining ability and to identify superior hybrid combinations. In addition, information about performance and combining ability of lines can be useful for further selection in early generations, with a good prediction of performance in advanced generations. The success of a maize breeding programme depends on the choice of the most appropriate testers to select superior lines with a significant reduction of costs and labour. Ideal testers should allow great expression of genetic variability in their progeny (Russell, 1961). Recessive homozygous lines and populations with low frequency of favourable alleles should be successful testers because they are effective in identifying new lines with high frequency of favourable genes (Russell, 1961; Smith 1986; Hallauer et al., 2010b).

The use of testers with a high frequency of favourable alleles allows identification of the best crosses, that is, the ones with the highest specific combining ability with those testers. CIMMYT and most many NARS institutions in eastern and southern Africa use old single-cross testers CML312/CML44 and CML395/CML44 which have shown low genetic gains from the new developed inbred lines. Therefore, there is a need for developing new testers using inbred lines.

2.10 Maize heterotic groups

Heterotic groups are vital in any breeding programme. Theoretically, crossing of parents from different heterotic groups results in hybrid vigour than crossing parents from the same heterotic group. Heterotic groups indicate that plants are from related population or from unrelated groups which when crossed show similar combining ability and heterotic response (Bayoumi et al., 2008; Hallauer et al., 2010b).

Globally heterotic groups are different depending on the regions or specific breeding programme. For example, U.S Corn Belt used RYD x LSC, while in Europe they have Flint x Dent heterotic groups (Doebley et al., 1988).Tropical and subtropics promising heterotic groups are ETO x Tuxpeno, Suwan I x Tuxpeno, Cuban flints x Tuxpeno, and Caribbean Flints X Tuxpeno (Bayoumi et al., 2008). CIMMYT uses a narrower heterotic grouping which classifies inbred lines into either heterotic group (HTG) A or B and AB. As a result, CIMMYT has three heterotic groups A, B and AB exemplified by; HTG AB group - CML440, CML 559, CML 558, CML557; HTG B group – CML 441, CML 577, CML 576, CML 575, and HTG A group - CML 447, CML 573, CML 572 (CIMMYT, 2015).

Agricultural research council has its own heterotic grouping for its breeding programmes. These are HTG K, CB, I 137TN, M37 W, SS, NSS, and the three CIMMYT HTG A, AB, and B. Molecular marker assisted selection has facilitated identification of the maize heterotic groups, and genetic diversity has also been determine using modern breeding tools (Dreisigacker et al., 2005).

2.11 Secondary traits for maize grain yield under drought stress conditions

Drought is the most limiting abiotic factor to maize yield performance. It causes poor ear and kernel setting and induces early leaf senescence during grain filling (O'Neill et al., 2006). Additionally, reduction in production may come from an energy and nutrient consumption of drought adaptive responses, such as increase in root growth under drought (Bänziger et al., 2006).

Maize under drought stress undergoes many physiological processes such as sustaining its photosynthesis during the grain filling stage resulting in an increase in dry matter. Occurrence of drought during kernel formation results in decrease in kernel number.(O'Neill et al., 2006; Araus et al., 2008). Selection under drought stress can be done through indirect selection using the secondary traits, because selection based only on grain yield is insufficient due to a low heritability under stress (Monneveux et al., 2008). To remedy this, secondary traits are selected instead of direct yield selection. The secondary traits genetically associated with grain yield under drought in the target environment should be genetically variable, highly heritable, easy to measure, and stable over time (Monneveux et al., 2008). The high heritability of the secondary trait under stress conditions indicates that the trait is less affected by the environment (Araus et al., 2008). It is important that the selective traits are not associated with poor yields under unstressed conditions and are related to productivity rather than survival mechanisms. Furthermore, the measurement of the secondary trait should be cheaper than the measurement of grain yield. Monneveux et al. (2008) came to the conclusion that some long established secondary traits (i.e. anthesis-silking interval) have become less important, while others have become more relevant. To counteract the steady reduction in genetic gain over time it is necessary to identify alternative traits or novel strategies.

2.12 Breeding for high yields

One of the major objective of any breeding programme is to increase grain yield. Grain yield is a complex trait controlled by several traits (grain weight, grain rows per ear, ear length, ear diameter and prolificacy) influenced by genotypic and environmental factors. Therefore, selection for desirable genotypes should be made based on grain yield as well as other yield components that could influence the yield (Menkir and Kling, 2007; Rahman et al., 2007).

2.13 Breeding and screening for maize under abiotic stress

Maize production in sub-Saharan Africa is limited by abiotic factors such as drought and low soil fertility which lead to food insecurity and poor economic growth in the region (Bänziger et al., 2006). There are several strategies put in place to improve maize tolerance to drought and low soil fertility. These include studying the maize crop behaviour during flowering and also using secondary traits in analysing crop performance.

2.13.1 Effects of drought in maize production

Maize production in sub-Saharan Africa shows variability through time that is attributed to abiotic stresses (Bolanos and Edmeades, 1996). Among these abiotic stresses, drought is the most important, limiting maize production in eastern and southern Africa. Drought stress may increase due to global climatic changes and the displacement of maize to marginal environments by high value crops and partly due to reduction in soil organic matter, leading to reduction in soil fertility and water holding capacity (James, 2007). This fertility and water availability varies greatly in many farmers' fields especially in the tropics and requires a torelant variety that can withstand a wide range of drought stress and nitrogen availability (Weber et al., 2012). Therefore, breeding for crop improvement against drought stress is more useful than the use of agronomic practices (Lobell et al., 2011).

Most tropical maize is produced under rain-fed conditions and many of the maize varieties grown in eastern and southern Africa are susceptible to drought (Blum, 1988). Given the high cost of irrigation, production of maize by smallholder farmers will continue to depend on the limited rainfall and the success in cropping will depend on breeding as well as better crop management techniques.

Maize crop under drought conditions can show physical symptoms of the stress. For instance, the following changes can be noted; firstly change in colour from green to green-grey, secondly rolling of the lower leaves. At the same time stomata close coupled with sharp photosynthesis reduction resulting in slow growth (Silva et al., 2007; Hammer et al., 2009). When the drought stress exceeds 7-10 days prior to flowering, it causes slow growth of the ear compared to tassel. Also, drought causes delay in silk emergence relative to pollen shed, giving rise to prolonged interval between pollen shedding and silk extruding. This anthesis-silking interval can be used to predict drought-induced yield reduction. At the same time leaf senescence begins at the base of the plant and spreads to the ear. Severe stress at flowering may lead to the complete abortion of ears and the plant becomes barren. Drought-affected ears typically have fewer kernels that will be poorly filled if drought extends throughout grain filling (James, 2007).

2.13.2 Effects of low nitrogen in maize production

Low N stresses on maize can cause yield reduction of about 60% due to a reduction of photosynthesis and many other physiological process in maize crop. A yield loss of 60% to 62% compared to optimum condition was reported by Bänziger and Lafitte (1997) and Weber et al. (2012). Photosynthesis reduction is caused by the reduced leaf area development and accelerated leaf senescence. It is estimated that 50% of all leaf N is involved in photosynthesis. Leaf senescence due to a short supply of N begins with the bottom leaves because the plant relocates N from the bottom older tissue to the younger leaves up the plant and to the grain (Blum, 1988). An increase in the root/shoot ratio and delayed pollen shedding and silk emergence when stress is severe is also observed (Blum, 1988). The delay in silking is relatively more than the delay in pollen shedding resulting in long ASI especially when the N stress coincides with flowering. This delay in silking is correlated with barrenness (Bänziger et al., 2007). Under these conditions tolerant genotypes can be identified. Correlation between genotype performance under low N and well fertilized conditions diminishes with an increase in severity of stress. This means that there is no relationship between genotype performances under well fertilized environments and environments severely stressed with N (Bänziger and Lafitte, 1997; Weber et al., 2012).

2.14 Breeding maize for tolerance to drought

When breeding for drought tolerant genotypes, breeders target genetic and management strategies that improve grain yield in water-limited environments through the knowledge of three important parameters. These parameters are; i) the amount of water which plants absorb from the soil (W), ii) the efficacy at which the absorbed water is converted from biomass (WUE), and iii) harvest index (HI), that is the ratio of grain formed to the total biomass (Blum, 2009). During the process of selection, breeders must take these parameters into account (Araus et al., 2002; Blum, 2009). Breeders must select for genotypes with roots that go deeper into the soil with no soil hard pan and extract water from deep wet zones. Current researchers suggest that breeding for deeper roots for drought tolerance is important rather than an increase in root biomass, and variation for root depth occurs among genotypes (James, 2007). Apart from the obvious step of irrigation, other growing practices can alter substantially. Good weed control and the managed variation in plant density are practices that control the amount of water available for transpiration.

2.15 Breeding strategies for low nitrogen environments

Many breeding programmes are prioritizing development of low N tolerant varieties aiming for the tropical areas especially the sub-Saharan Africa soils. Low N tolerant genotypes are characterized by staying green for a longer period of time (Bänziger and Lafitte, 1997). For effective identification of low N tolerant genotypes, breeding strategies make use of selections under conditions of severe low N stress. Over the past 20 years, researchers at CIMMYT have improved maize germplasm for drought and low N tolerance using an approach that is probably unique. Large populations were screened under carefully managed drought or low N stresses so that genetic variation for tolerance was revealed to the greatest extent possible. The selection gains realized have been considerable — 100 kg/ha/yr under stress conditions (Bänziger et al. 1998; Bolaños et al. 1993; Byrne et al. 1995; Chapman and Edmeades 1999)

2.16 Heritability

Heritability is statistically defined as the proportion of phenotypic variance attributable to genetic variance (Falconer and Mackay 1996). According to Anholt and Mackay (2009) and Mohsin et al. (2009) heritability has big significance in plant breeding since it predicts the expression of the phenotype as a guide to its breeding value. It is the heritability which determines how much of the phenotype would be passed onto the next generation.

Heritability measures the extent to which the phenotypic and breeding value corresponds. It is mostly used to calculate the expected response to selection especially for quantitative traits in a population (Mohsin et al., 2009).

Heritability is divided into two categories; i) broad sense heritability, which is defined as the proportion of phenotypic variability that is due to the overall genetic effects in a population (Robinson et al., 1949; Hanson et al., 1956; Li et al., 2015) and ii) narrow sense heritability, which is defined as the proportion of the total phenotypic variance that is associated with the additive effects of genes transmitted from parents to progenies (Rao and Gu, 2008). The heritability percentage can be categorized as low, moderate and high as explained by Robinson et al. (1949) as follows: low = 0 – 30%, moderate = 30 – 60%, and high = > 60%. Heritability is affected by genetic or by environmental variation. Low environmental effects result in high heritability which means that the genetic variance will be higher than the environmental variance. A low heritability could be attributed to influence of genotype by environment interaction (Ghimire and Timsina, 2015). Ojo et al. (2006) reported broad sense heritability estimates of 99.95% for grain yield in optimum environments, suggesting that genetic variation was higher than the environmental variation for grain yield and it was thus possible to conduct effective selection for genetic improvement. On the other hand, Mohamed (2016) reported 0.00% heritability under stress conditions, implying no direct selection of grain yield would be possible. This is why secondary traits are required to increase efficiency for grain yield selection.

2.17 Genetic gains

The extent of genetic advance (GA) to be expected by selecting about five percent of the genotypes is calculated by using the following formula given by GA = k.H.σp; where, k = selection intensity, σp = phenotypic standard deviation, H= broad sense heritability (Robinson et al., 1949). According to Sleeper and Poehlman (2006), selection intensity depends on the percentage of the population selected. The GA as percent of mean can be categorized as low, moderate and high as suggested; low = 0 - 10%, moderate = 10 - 20% and high = > 20% (Johnson et al., 1955). In plant breeding, genetic advancement is very important for making selection of the best performing genotypes.

2.18 Summary

This literature review has highlighted that, regardless of maize being one of the major staple crops in Sub-Saharan countries, its yield is low. Improvement of maize yield requires development of maize hybrids that perform better in stressed environmental conditions. Development of such genotypes requires substantial development of testers that perform well in such environmental conditions. Testers that are used are old and they have lost most of their genetic potential particularly when exposed to drought and low nitrogen conditions. The current study therefore, focused on evaluating diverse single-cross maize hybrids to identify the potential hybrids that can be used in tester development under drought and low nitrogen conditions of eastern and southern African countries.

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CHAPTER THREE

GENERAL MATERIALS AND METHODS

3.1 Planting materials

Seeds of single-crosses were obtained from CIMMYT Zimbabwe and classified into heterotic groups A and B. Each heterotic group comprised of 160 entries of single-cross maize hybrids (Appendix 3. 1 to Appendix 3. 2**)**. Heterotic group A include Tuxpeno, Kitale, Stiff Stalk Synthetic (BSSS), N3 (more dent type) while heterotic group B includes ETO, Ecuador 573, Lancaster Sure crop and SC (more flint type). CIMMYT developed broad heterotic groups A and B for use in its lowland tropical, subtropical and highland breeding programmes (CIMMYT, 2001).Heterotic groups were initially identified based on how lines performed in crosses, for example AxB crosses were superior than AxA and BxB, with A and B representing divergent germplasm source (Hallauer, 1997). Crosses made between inbred lines from the same heterotic groups generally exhibit low heterosis that crosses between lines from divergent heterotic groups (Vasal et al., 1992).Heterotic groups are therefore used to facilitate the exploitation of maximum heterosis (hybrid vigour) in crosses. 3.2

3.2 Experimental site and evaluation environments

This study was conducted in South Africa at Potchefstroom (latitude 26.7145°S and longitude 27.0970°E; altitude 1321 m.a.s.l) and at Cedara research station (latitude 29.54’S; longitude 30.26’E; altitude 1066 m.a.s.l.) during the season of 2015/2016.

The evaluation environments were categorised into three; optimum (Opt) environment at Potchefstroom and Cedara, random drought (RD) at Potchefstroom and low nitrogen environment at Cedara.

Table 3.1: Description of the study locations during 2015/16 growing season

Site	Env	Season	Lat	Long	Alt (m.a.s.l)	AR (mm)	TMin (^{0}C)	TMax (^{0}C)	Soil Type	Irrigation
Potchefstroom	Opt; RD	S	26	27	1321	532	14	29	Sandy loam	Sprinkler
Cedara	Opt; LN	S	29	30.	1066	736	11	25	Clay loam	Rainfed

Opt= optimum; RD= random drought; LN= low Nitrogen;S = summer; m.a.s.l. = meters above sea level.AR annual rainfall, Env=Environment, long=longitude, lat=latitude, alt = altitude; TMin=minimum temperature, TMax=maximum temperature

3.2.1 Optimum environment

At ARC Potchefstroom and Cedara, the crops were fully irrigated and fertilized to avoid any kind of stresses from occurring. Under optimum moisture conditions, trials received optimal fertilization and supplementary irrigation. Lime Ammonium Nitrate (LAN) 3:2:1 (33) was applied as a basal fertilizer at a rate 150 kg ha^{-1}, an additional 150 kg N ha^{-1} was applied as topdressing at four weeks after planting. The sprinkler irrigation was used to apply water to each block once a weak for four hours (5 mm h^{-1}), except at Cedara where trials were under rain-fed conditions.

3.2.2 Random drought

The random drought trial was Potchefstroom. Screening for drought tolerance was achieved under random drought stress conditions with no supplementary irrigation, but irrigation was only applied at the beginning of the season to establish a good plant stand. Fertilization was applied as in optimum moisture conditions. Rainfall was poor during the season. This technique of imposing moisture stress in maize fields was suggested by Zia et al., (2013).

3.2.3 Low nitrogen environment

The low nitrogen environment was at Cedara research station. Screening for low N tolerance was achieved in fields that had been previously depleted of nitrogen by growing unfertilized, non-leguminous crops (oats, wheat and sorghum) at high density for several seasons (five years) and removing the crop biomass after each season. For managed low N blocks, triple super phosphate (46% P_2O_5) and Potassium Chloride (61% KCl) were applied at planting at a rate of 25 kg P_2O_5 ha^{-1} and 25 kg KCl ha^{-1} with no further top dressing. There was no irrigation supplement, therefore, the trial was under rain-fed conditions.

3.3 Experimental design

An alpha lattice 0,1 with number of blocks (s=32) per replication, Block size (k=5) and replication (r=2) was used (Patterson and Williams, 1976).The plots (320 plots) were planted in single row plots with 0.75 m spacing between row and 0.25 m within rows and plot length was 4 m. Two seeds were planted per station and then after four weeks, seedlings were thinned to one seedling per station.

3. 4 Management practices

Planting was done using a jab planter on 04/12/2015 and 08/12/2015 for the different environments. The management was done according to the objectives of the trial. The fields were kept free from weeds, pests and diseases. Pesticides and herbicides were applied to control pests and weeds, respectively. The maize crops were irrigated and well fertilized for the optimum environment to avoid any kind of stress. Fertilizer was applied using hand placement. Random drought experiments were irrigated until two weeks prior to flowering.

The trial blocks were kept free of weed throughout the season by application of herbicides. Dual gold with active ingredient ethyl methazaco, was applied in the field at rate of 4.5 l/ha as a pre-emergence treatment and then three weeks later Servian as post emergence herbicide was applied. Herbicides were applied using a 500 l spray tank with a 10 m wide boom with 20 nozzles mounted on a tractor. Then from seven weeks after planting, weeds were removed from the field using hand hoes.

Pesticides were applied to control pests like maize stalk borer by hand applying Beta-cyfluthrin 25 g/l every 10 days. Pests like cutworm (*Agrotis ipsilon*) were controlled using 2.5g/l Lambda-cyhlothrin, which was hand applied (30 cm from crop row) at a rate of 100 ml/ha in 200 l of water.

3.5 Data collection

Field data were collected for the following traits; number of days to 50% silking, number of days to 50% anthesis, plant and ear height, field weight and grain weight, cob length, crop stand, stem and root lodging, ears per plant, ear position and yield at 12.5% adjusted moisture content. The collected data were imported and estimations were done using the field book excel sheet (Silva et al., 2007; Vivek et al., 2007).

Plant height (PH) was measured from the ground level to the point of insertion of the flag leaf (cm). Ear height (EH) was measured from the ground level to the insertion of the highest ear in the stem (cm). Ear aspect (EA) was rated on a scale from 1 to 5, where 1= good and 5 = bad. Flowering date was determined by counting the number of days to 50% tasselling, and 50% silking (SD). Number of plants (NP) was counted per each genotype/plot. Stem lodging (SL) was determined by counting the number of plants broken below the upper ear at harvest. Number of ears (NE) or ear prolificacy was calculated as total number of ears per genotype/plot.

A grain moisture meter (model: LDS-1G) was used to measure the percentage moisture content in the grain (MC %); grain yield (GY) in tons/ha was determined using the following equation:

Yield (t/ha) = GY (kg) x ((100-MC %)/(100-12.5)) x Area factor x P/1000.....equation 3.1

Where, area factor = 10000/ (row length x number of rows x row width), SP is shelling percentage (weight shelled/Weight unshelled) x 100.

Cob length and diameter were measured using a ruler and micrometre screw gauge, respectively. Ears per plant (EPP) were determined as the ratio of number of ears per plot to the number of plants per plot.

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CHAPTER FOUR

IDENTIFICATION OF ELITE SINGLE-CROSS HYBRIDS SUITABLE FOR FURTHER EVALUATION AS POTENTIAL TESTERS FOR THREE-WAY CROSS HYBRIDS

Abstract

High yielding single-cross testers with good discriminatory features across the low nitrogen (LN), random drought (RD), and optimum (Opt) conditions are useful genetic resources for plant breeding. Testers made from the old inbred lines fail to exploit genetic gains from new inbred lines and new introduced germplasm in breeding programmes. The objective of this study was to identify new single-cross testers to replace CML312/CML442 (heterotic group A) and CML395/CML444 (heterotic group B), currently being used in the maize breeding programmes at ARC and other national programmes in southern and eastern Africa. A total of 160 single-cross hybrids each from heterotic group A (HTG A) and heterotic group B (HTG B) were evaluated across the Opt, LN and RD conditions, using an alpha lattice design. Highly significant differences ($P < 0.01$) among single-cross hybrids were observed for days to 50% anthesis (AD), grain yield (GY), ear height (EH), and ears per plant (EP) in HTG B under Opt environment. Hybrid 139 (8.65 t/ha) had higher grain yield than the average yield of 6.22 t/ha. Days to 50% anthesis, anthesis-silk interval (ASI), plant height (PH), and ear height (EH) varied significantly ($p<0.01$) among the single-cross hybrids in low nitrogen environment. Hybrid 65 (4.04 t/ha) yielded higher than the average yield of 2.28 t/ha. Days to 50% anthesis were slightly higher in LN than in Opt environment. Single-cross hybrid 92 (7.53 t/ha) yielded higher than the average yield of 4.77 t/ha in RD. As in heterotic group B, significant variation was observed in HTG A, in RD and Opt environments. Grain yields of 9.45 t/ha and 6.42 t/ha for maize hybrids 134 and 52 were higher than the average mean yields of 6.75 t/ha and 3.43 t/ha for Opt and RD environments, respectively. Hybrids with higher mean yield compared to the average mean yield are usefully genetic material to be advanced for further breeding in their respective or across the environments. Maize single-cross hybrids 1, 23, 127, 15, 122, 8, 134, 109, 34, and 31 in heterotic group A and 69, 81, 65, 97, 92, 40, 117, 58, 101, and 44 in heterotic group B were selected for further breeding as they showed consistently high yield across environments.

4.1 Introduction

Testers are genotypes with good general combining ability (GCA) and fit well in defined heterotic groups which are used for discriminating good genotypes from weak ones in breeding. In a plant breeding programme, testers can be used to determine heterotic patterns of the inbred lines, and to evaluate the breeding values of the inbred lines in population improvement. Testers can be inbred lines, single-cross hybrids or heterogeneous materials. Rawlings and Thompson (1962) recommended that a good tester should be precise in discriminating among the good from the bad genotypes and should provide information that classifies the merit of lines and maximizes genetic gain. In general, a good tester should be poor in the traits for which the lines are to be analysed but should have broad adaptation to the target environments. There is a need for developing new testers to cater for diverse environments.

Basing on the availability of testers, type of materials under test and type of hybrids for which the lines are to be used, breeders can decide which tester to use. Testers can be categorised as broad based or narrow based testers. Broad based testers can be used in selection for general combining ability (GCA), while narrow based testers are the ones which can be used in selection of specific combining ability (SCA). In addition, breeders can choose the type of tester to use by looking at commercial hybrid development programmes that use inbred parents with proven hybrid performances. Pedigree information of the genotypes which have been tested for a long time and their performances and parent's performance, if known, is very important to breeders in making choices of what testers to use. Testers are not static, they always change depending on the objectives of the breeding programme. In addition, the testers should be highly adapted to a wide range of environments (Hallauer and Miranda , 1988).

The aim of this study was therefore to identify elite single-cross hybrids which are to be used as single-cross maize hybrid testers under stress conditions.

4.2 Materials and methods

The materials and methods used are described in chapter 3. Only the statistical analysis which is unique to this chapter is described below.

4.2.1 Statistical Analysis

The collected data were recorded and organized in Microsoft Excel 2013. Both the genotypes and genotypes by environment interaction effects were estimated across the environment following the model below:

$Y_{ijkl}=\mu+E_i+R(E)_{j(i)}\ IB(RE)_{bkj}+G_k+GE_{ik}+e_{ijkl}$;………..equation 4.1

where μ is the overall mean, R(*E)j(i)* is the effect of the *jth* location, R(*E) kj* is the effect of the k^{th} replicate within the i^{th} location, *IB(RE)* is the effect of the incomplete block within the k^{th} replicate in the j^{th} environment, G_i is the effect of the i^{th} genotype, and GE_{ik} is the interaction effect of the i^{th} genotype with the j^{th} location and e_{ijkl} is the residual effect.

Mean, standard deviation (SD), coefficient of variation (CV), analysis of variance (ANOVA), and heritability (H) were calculated using GenStat 17th edition. One way and two way analyses were carried out as suggested by Payne (2009). Means were compared using Duncan's multiple range tests at 0.05 level of probability and F values as described by Rahmani et al. (2014). Broad sense heritability (H) was estimated using the formula:

$H = \delta^2g/ [(\delta^2g + \delta^2gxe/E + \delta^2e/rE)\ x100$……………………........................equation 4.2

where H represents heritability in the broad sense, σ^2g represents estimates of genetic variances, δ^2gxe represents estimates of genotype x environment interactions variance, σ^2e represents residual variances, E=number of environments, r= number of replications, σ^2_e = residual variances, σ^2_{gxe}= Genotypes x environment interactions variances (Li et al., 2015).

$\delta^2p=\delta^2g + (\delta^2gxe) + (\delta^2e)$……………..equation 4.3

Genetic variance was calculated using the formula:

$\delta^2_g = (MS_g - MSgxe)/r$……………………………… equation 4.4

Where MSg =mean sum square of genotype; MS_{gxE} = mean sum square of genotype by environment interaction and σ^2_e mean sum square of residual.

Variance due to genotype by environment interaction were determined using the following formula

$\boldsymbol{\delta^2_{gxe}}= (Ms_{gxe}-Ms_e)/r$-- equation 4.5

Where MS_{ge}=mean square genotype by environment interaction, Ms_e=mean square residual, r=number of replications and δ^2_{gxe}= Variance due to genotype by environment interaction

Phenotypic variance formula $\delta^2p = (\sigma^2g + \sigma^2gxe + \sigma^2e)$………… equation 4.6

4.3 Results

4.3.1 Performance of maize single-cross hybrids for the heterotic group B evaluated across the three environments

Table 4.1 summarises the analysis of variance when 160 maize single-cross hybrids were evaluated across random drought (RD), low nitrogen (LN) and optimum (Opt) environments. Maize single-cross hybrids differed significantly in grain yield ($P<0.001$), days to 50% anthesis (AD) $P<0.01$, ear height (EH) ($P<0.001$), field and grain weight at ($P<0.001$) and ($P<0.001$) respectively, number of ears (NE) were significant different ($P<0.01$), days to 50% silking were significantly different ($P<0.05$). Number of plants (NP), Anthesis-silking interval and shelling percentage were non-significant different across environments. (Table 4.1). Environments were significantly different ($P<0.001$) for all measured variables. However, the interaction of environment and entries were not significantly different for all measured variables except EH (Table 4.1).

Table 4. 1: Mean squares and significant tests of grain yield and yield related traits for heterotic group B across three environments

SOV	d.f.	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	GY
Env	2	131842.63***	196.31***	59345.80***	2.91***	4.95***	2.20***	63.70***	305.36***	73611.80***	141292.42***	0.54***	615.08***
Env.Rep	3	155.46***	0.31^{ns}	2122.20***	0.10	2.14***	1.18***	37.35**	375.25***	4334.30***	138.33***	0.02^{ns}	8.13***
Env.Rep.Bl	314	20.47***	4.00^{ns}	360.60***	0.07	0.34***	0.20***	15.66***	7.18^{ns}	991.00***	26.98***	0.02^{ns}	1.52***
Entry	159	17.83**	4.80^{ns}	283.80***	0.10**	0.32***	0.20***	12.75**	8.38*	787.60ns	23.76*	0.02^{ns}	1.51***
Env.Entry	287	12.96^{ns}	4.04^{ns}	183.40*	0.07	0.16^{ns}	0.11*	8.89^{ns}	6.65^{ns}	508.60	17.61^{ns}	0.02	0.85^{ns}
Residual	194	12.36	4.19	135.80	0.08	0.14	0.09	8.31	6.37	659.10	18.41	0.03	0.81
δ^{2}entry		1.22	0.19	25.10	0.01	0.04	0.02	0.97	0.43	69.75	1.54	0.00	0.16
δ^{2}entry*env		0.30	0	23.80	0	0.01	0.01	0.29	0.14	0	0	0.00	0.02
δ^{2}Residual		12.36	4.19	135.80	0.08	0.14	0.09	8.31	6.37	659.10	18.41	0.03	0.81

***= significantly different at 0.001 probability level; AD = days to 50% anthesis; ASI= anthesis-silking days interval, SD=Days to 50% silking, EH= ear height, EP ear per plant, SP= shelling percentage, GW= grain weight, FW= field weight, NP = number of plants per plot, PH= plant height and NE number of ear per plot. BL=Bloc and GY=grain yields (t/ha).

Appendix 4.5 summarises the mean responses of tested maize single-cross hybrids across the environments. Yield ranges of 2.3 to 5.6 t/ha were recorded. Maize single-cross hybrids 69, 81, 65, 97, 92, 40, 117, 58, 101 and 44 were the best ten selected genotypes from heterotic group B

Table 4. 2) shows genotypes listed that had significantly larger yield compared to the average yield of 3.9 t/ha (P<0.01.) Poor performers are also showed. The higher yields were supported by days to 50% silking, days to 50% anthesis, grain weight, field weight, number of ear per plant (Appendix 4.5). Some genotypes had grain yield slightly higher than the average mean, while other were below the average. However, the performances of their yielding components were average.

Days to 50% silking (SD), AD, ASI, GY, EH, and PH, EP, SP, CBD, CBL, KNCB, FW, GW and yield differed significantly (P< 0.01) among maize single-cross hybrids in optimal environment. NE and NP do not differ significantly (Appendix 4.1 and 4.2). Maize single-cross hybrid 139 had a mean of 8.65 t/ha significantly larger than the average mean of 6.22 t/ha. Similarly, variation of the yielding components was observed in low nitrogen environment. In this environment, maize single-cross hybrid 65 had a mean of 4.04 t/ha larger than the average yield of 2.28 t/ha (Appendix 4.1 and 4.2). As in other environments, variation in yield and yielding components were observed in a random drought environment. In this environment, maize single-cross hybrid 92 had a mean of 7.53 t/ha which was higher than the average mean of 4.77 t/ha (Appendix 4.1 and 4.2).

Table 4. 2: Best 10 and bottom 10 maize single-cross hybrids for heterotic group B across environments

SN	Entry	GY	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP
1	40	5.00	92.83	1.00	89.89	0.99	1.75	1.35	12.67	13.00	171.00	96.00	0.75
2	44	4.81	93.33	1.17	88.78	0.88	1.33	1.03	12.00	13.67	156.10	93.50	0.77
3	58	4.93	89.50	1.33	94.61	1.06	1.51	1.22	15.50	14.00	166.70	94.67	0.80
4	65	5.10	92.67	0.83	95.83	0.91	1.69	1.25	13.50	15.00	163.50	93.50	0.74
5	69	5.57	95.17	0.83	96.83	0.94	1.76	1.34	12.50	13.67	172.90	96.00	0.76
6	81	5.19	91.50	-0.17	100.72	0.96	1.64	1.28	13.83	14.67	172.10	91.33	0.78
7	92	5.05	92.83	1.17	85.61	0.98	1.69	1.31	13.50	14.17	162.80	94.00	0.77
8	97	5.08	93.17	1.67	88.06	0.86	1.29	0.98	11.33	13.50	164.60	94.83	0.76
9	101	4.84	92.50	0.33	84.28	0.87	1.59	1.23	12.17	14.17	156.40	92.83	0.78
10	117	4.99	94.17	1.67	90.72	0.96	1.77	1.33	13.33	14.50	162.90	95.83	0.76
11	1	2.87	96.33	0.33	78.89	0.77	0.91	0.70	10.17	13.67	141.80	96.67	0.73
12	2	2.27	95.83	2.00	68.78	0.81	0.79	0.52	8.50	11.50	123.00	97.83	0.72
13	3	2.63	95.33	1.17	68.28	0.83	0.86	0.63	9.50	13.00	125.20	96.50	0.75
14	8	2.95	95.83	1.83	80.50	0.71	1.03	0.76	8.83	14.67	150.70	90.83	0.78
15	15	2.39	95.33	4.67	76.11	0.56	0.72	0.52	5.83	13.50	140.40	94.83	0.72
16	16	2.51	92.67	0.33	75.50	0.62	0.83	0.57	6.83	12.17	136.60	100.00	0.70
17	18	2.74	93.33	1.17	76.89	0.98	1.05	0.72	9.17	11.67	137.00	97.50	0.71
18	26	2.93	96.67	0.67	61.28	0.81	0.90	0.69	8.67	11.50	116.80	95.33	0.79
19	64	2.37	98.00	-1.17	64.89	0.96	0.69	0.52	7.50	10.00	134.70	93.33	0.75
20	138	2.96	91.17	2.50	77.17	0.53	0.82	0.54	7.17	14.17	142.10	93.67	0.67

Entry number 1-10 were the genotypes that performed better across the environments, the other genotypes, 11 - 20 were the poor performers across the environments.

4.3.2 Performance of maize single-cross hybrids for the heterotic group A, evaluated across two environments (random drought and optimum environment)

Table 4.3 summarises the analysis of variance for 160 maize single-cross hybrids in heterotic group A evaluated under random drought (RD), and optimum (Opt) environments. Significant differences (P<0.01) were observed for days to 50% anthesis, number of plants, number of ear and days to 50% silking. A significant variation was also observed for ear height, field weight, and grain weight (P<0.001). Non-significant differences were observed for the following traits; anthesis-silking interval, ear position, shelling percentages and grain yield. Environments varied significantly (P<0.001) for all measured variables. The interaction of the genotypes and entry was highly significant (P<0.001) for EH and PH.

Table 4.3: Mean squares and significant tests of yield and yield related traits for heterotic group A across two environments

SOV	d.f.	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	GY
Env	1	11919.76***	159.00***	40296.05***	1.86***	19.27***	15.19***	53.48**	185.98***	150374.00***	14697.64***	0.15***	146.36***
Env.Rep	2	12.96	0.23	2055.20***	0.16	1.43***	0.90	35.81	168.40	3967.80***	10.08	0.02	7.41***
Env.Rep.Bloc	124	54.64***	4.88	651.13***	0.11	1.00***	0.62	27.12	15.71	1950.20***	70.30***	0.01	4.08***
Entry	159	14.29***	4.07^{ns}	155.00***	0.05^{ns}	0.30***	0.19***	11.32**	9.07***	280.40*	17.06***	0.01^{ns}	1.42^{ns}
Env.Entry	159	15.73	3.81	158.95***	0.03	0.21^{ns}	0.14	9.21	10.55^{ns}	352.90***	19.91	0.01*	1.13^{ns}
Residual	194	9.20	3.56	87.46	0.04	0.18	0.12	7.41	6.06	202.20	11.73	0.01	1.16
δ^2entry		0.00	0.07	0.00	0.00	0.02	0.01	0.53	0.00	0.00	0.00	0.00	0.07
δ^2entry*env		3.27	0.12	35.75	0.00	0.01	-0.02	0.90	2.25	75.35	4.09	0.00	-0.02
δ^2Residual		9.20	3.56	87.46	0.04	0.18	0.12	7.41	6.06	202.20	11.73	0.01	1.16

***= AD = days to 50% anthesis; HP = plant height, SD =Days to 50%silking, ASI=Anthesis-silking interval, EP =ear position, FW= field weight, GW= grain weight, NE=Number of ear, NP=number of plants SP=shelling percentage of plant, GY= grain yields (t/ha).

Table 4.4 summarises the mean response of the best ten and ten poor maize single-cross hybrids across the optimum (Opt) and random (RD) drought environments. Yield ranges of 0.2 to 4.3 tonnes/ha were recorded. Maize single-cross hybrids 1, 8, 15, 23, 31, 34, 74, 122, 127 and 134 were the best ten selected genotypes (Table 4.4), that had significantly larger yields as compared with the average yield of 2.6 t/ha. Their higher yields were supported by good performance of yield components (Table 4.4). Other genotypes had grain yield that was below the average indicated in Table 4.4

Table 4.4: Best 10 and bottom 10 maize single-cross hybrids for heterotic group A across environments

SN	Entry	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	YD
1	1	78.25	0.75	106.08	0.96	2.17	1.71	15.75	16.25	190.90	79.00	0.78	4.32
2	8	75.50	1.00	101.00	1.13	2.00	1.58	16.00	14.25	170.20	76.50	0.79	4.01
3	15	76.00	1.00	109.42	1.08	2.09	1.65	15.25	14.50	191.50	77.00	0.78	4.17
4	23	80.50	1.00	104.58	0.93	2.26	1.72	12.75	13.25	188.20	81.50	0.72	4.21
5	31	78.75	2.00	88.92	0.96	1.90	1.49	16.00	16.75	174.40	80.75	0.78	3.73
6	32	79.50	0.25	78.50	0.63	1.25	1.02	9.75	15.75	153.10	79.75	0.84	2.66
7	74	82.75	1.25	93.17	0.79	1.85	1.45	12.25	15.50	173.40	84.00	0.77	3.62
8	122	75.50	2.00	100.50	0.92	2.08	1.61	14.00	15.25	183.20	77.50	0.77	4.01
9	127	78.25	0.50	96.58	0.89	2.00	1.63	12.00	13.25	177.70	78.75	0.80	4.20
10	134	78.00	2.75	91.25	0.97	2.02	1.59	13.75	14.25	159.00	80.75	0.79	3.96
11	2	83.00	2.00	88.17	0.60	0.74	0.58	7.00	13.25	147.60	85.00	0.67	1.46
12	3	80.75	0.50	102.33	0.97	1.28	0.96	13.25	13.75	173.50	81.25	0.73	-0.20
13	26	83.00	2.00	85.67	0.73	0.75	0.59	9.00	13.00	154.90	85.75	0.77	1.44
14	52	81.50	1.50	78.92	0.83	0.35	0.26	6.00	10.00	154.30	83.00	0.73	0.65
15	66	80.25	0.75	85.75	0.69	0.91	0.55	10.50	15.50	177.20	81.00	0.64	1.10
16	67	85.00	-0.50	73.00	0.65	0.54	0.43	8.00	12.25	155.60	84.50	0.78	1.06
17	85	84.25	1.00	87.25	0.63	0.89	0.59	10.75	17.50	148.10	85.25	0.65	1.30
18	91	83.75	1.75	79.17	0.50	0.63	0.48	7.00	14.00	147.30	85.50	0.73	1.17
19	100	82.50	3.00	79.50	0.77	0.67	0.50	8.25	11.75	149.00	85.50	0.77	1.21
20	137	83.00	0.00	90.08	0.75	0.65	0.53	5.50	9.00	152.30	83.00	0.80	1.37

Entries 1 – 10 performed best across the environments while genotypes 11 – 20 were the least in performance across the environments

4.4 Discussion

4.4.1 Grain yield across the environments

Significant variation in grain yield among maize single-cross hybrids across the environment revealed the genetic variation portrayed among the tested genotypes. The existence of the genetic differences among the genotypes was confirmed by the variation in the average grain yield among heterotic group A (2.56 t/ha) and heterotic group B (4.0 t/ha). Presence of the genetic differences among maize genotypes is the bases for selection of the suitable maize single-cross hybrid to be used as a tester across or in the particular environment. The differences could be attributed to variations in the extent of adaptability of the genotypes in each or across the environment. The idea is supported by the significant differences observed among few traits most of traits showed non significance differences therefore selection across sites can be done easily (Tables 4.1 and 4.3). Variation in grain yield performances within and across the environments due to the influence of environments, genetic and or interaction of the two has also been reported in an earlier study conducted by Presterl et al. (2002).

Low grain yield of 2.30 and 4.77 t/ha recorded from the low nitrogen and random drought respectively in heterotic group A showed inability of the environments to support maize genotypes due to lack of the required plant growing conditions that are available in the optimum environment (6.22 t/ha). Similar observations have been reported by Lafitte and Edmeades (1994), Bänziger and Lafitte (1997) and Presterl et al. (2002).

High yield above average reported in some maize single-cross hybrids may be explained by the positive association of yield and some of the yield components. For example, maize genotypes with lower ASI had higher grain yield than with higher ASI. Thus, entries 76, 81, 84, and 93 with lower ASI values had 3.1, 4.5, 4.1, and 3.8 t/ha, respectively above the average yield of 2.3 t/ha. Positive association between ASI and plant biomass were found to reduce yield index and vice versa (Bolanos and Edmeades, 1996). Bolanos and Edmeades (1996) reported that ASI is an indicator of assimilate partitioning to the growing ear at flowering rather than variability in plant water or nutrient status. Therefore, a high ASI indicates maize hybrids that are susceptible to drought and low nitrogen in the soil. Furthermore, shorter ASI indicates plants that are tolerant to drought and low nitrogen. The current study identified single-cross hybrids that are well adapted under drought, low N and across the environments.

4.4.2 Grain yield under the optimum environment

The mean grain yields of the single-cross hybrids in both heterotic groups A (6.75 t/ha) and B (6.22 t/ha) were higher under optimum environment compared to the other environments. High yields in this environment may be attributed to favourable environmental conditions that support most of the physiological functions required by the plants. Previous studies have reported that, optimal conditions are important at silk emergence and pollination, and that genotypes do not show much variability under these conditions (Bolanos and Edmeades, 1996; and Bänziger and Lafitte, 1997). Furthermore, favourable conditions result in good synchronization between pollen shed and silk emergency in maize breeding (Bänziger and Lafitte, 1997).

4.4.3 Grain yield under the random drought

Results from random drought environment varied significantly ($p<0.01$) among single-cross hybrids on grain yield (t/ha) in both heterotic groups A (3.43 t/ha) and B (4.77 t/ha). The yields were slightly lower than the yields observed under optimum environments showing the existence of stress tolerant genotypes among the tested hybrids. The yields were also slightly above yield reported in random drought environments in earlier studies by Dai et al. (1990) and Bergamaschi et al. (2004). In addition, there was an increase in days to 50% anthesis and silking as compared to the days observed under optimum environments. This could be due to water deficiency on photosynthesis as reported by Nelson et al. (2007) and Silva et al. (2007). In the current studies, presence of drought tolerant hybrids was further confirmed by good synchronization of the male and female flowers with ASI in the recommended range of 2 days (Byrne et al., 1995; Weber et al., 2012).

4.5 Conclusions

The combined evaluation of the single-cross maize hybrids under stress and unstressed environments showed significant variation among genotypes and the genotype by environment interaction for yields and some of the yielding components were not significant differences for the heterotic group B. In heterotic group A, yield variations were non-significant, but few traits showed significant variations. Promising single-cross hybrids for heterotic group A selected for further breeding were entries 1, 23, 127, 15,122 8 ,134, 109, 34 and 31. Promising maize single-cross hybrids selected in heterotic group B were 69, 81, 65, 97, 92, 40, 117, 58, 101, and 44. These crosses showed good performance in yield and yield components across the environments. They were tolerant to water and low nitrogen stresses. They may therefore, be advanced for further breeding.

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CHAPTER FIVE

DETERMINATION OF THE CORRELATIONS BETWEEN GRAIN YIELD AND SECONDARY TRAITS AND ESTIMATION OF GENETIC PARAMETERS OF SINGLE-CROSS MAIZE HYBRIDS

Abstract

The main objective of the study was to investigate correlations and to determine the phenotypic and genetic coefficients of variation (PCV and GCV), heritability and genetic advances of yield and its related components across the low nitrogen, random drought and optimum environments. The sites were Agricultural Research Council (ARC) farm, Potchefstroom and Cedara research station. The maize single- cross hybrids were from heterotic groups A and B, each with 160 entries and laid out using an alpha lattice design, replicated twice. Data were analysed in Genstat 17th edition. Secondary traits with positive correlations with grain yield were plant height, ear height, anthesis-silking interval, days to 50% silking, days to 50% anthesis, ear length and diameter, number of kernels, number of rows per ear, field weight, and grain weight. However, some traits showed negative correlations with grain yield in some environments; for example, days to 50% anthesis, and anthesis-silking interval for both heterotic groups A and B under optimum and random environments, and ear diameter (heterotic group A) under optimum environment. In low nitrogen environment, only days to 50% anthesis had a negative correlation with grain yield. These relationships are useful in indirect selection of grain yield for the testers based on the secondary traits. For heterotic group A across environment high genetic and phenotypic coefficient of variation (GCV and PCV) values were observed for grain yield, and anthesis silking interval (ASI), ear height (EH), plant height (PH), number of ears (NE) while low PCV (%) and GCV (%) were observed for shelling percentage (SP). In heterotic group B, high GCV and PCV were observed for ASI (354.78%) across environments. Genetic advance was high for plant height, ear height, and number of ears. Heritability ranged from low, moderate and high for most of the traits for instance heritability for days to 50% anthesis was 31%, days 50% silking was 34%, plant height was 91%, ear height was 85% and yield (t/ha) was 42%. High heritability observed was good for effective phenotypic selection. A high additive gene action observed indicated the possibility of improving maize grain yield and some of the yield components through selection in the early generations.

5.1 Introduction

Most maize breeding programmes primarily aim at improving grain yield and yield components. However, stresses like drought and low nitrogen have been reported to reduce maize yields significantly (Nardino et al., 2016). Development of maize genotypes tolerant to drought and low nitrogen requires screening of diverse maize genotypes in drought and low nitrogen environmental conditions (Monneveux et al., 2008; Nardino et al., 2016). Genetic correlations among yield and yield components was reported to increase when maize genotypes were tested under stress environments (Nardino et al., 2016). Improvement of maize yield requires an understanding of the associations among yield and yield components with respect to the environmental conditions (Edmeades et al., 1995; Ribaut et al., 1996).

Improvement of a particular yield component may directly or indirectly affect maize yield in a particular environmental condition. Evaluation of maize genotypes in stressed and unstressed environmental conditions may help to discover the associations among the traits (Bruce et al., 2002). Little information is available on the association among yield and yield components among single-cross maize hybrids.

Morphological and genetic variation in agronomic traits in plant breeding is very important in identifying the performance of the hybrids. The best yield performer can be identified and improvement can be done. The extent of diversity must be recognized to facilitate selection. In plant breeding, genetic variability creation and selection are very important activities that can be used to improve some agronomic traits and yield. However, Hika et al. (2015) suggested that in order to carry out effective selection, the information on genetic variation among maize single-cross hybrids, the nature of component traits on which selection would be effective and the influence of environmental factors on each trait need to be known. Dudly and Moll (1969) indicated that it is essential to understand the nature and extent of variability and heritability in a population for successful selection of genotypes with desirable characteristics in a breeding programme. Therefore, it is important for breeders to know the heritability of the important agronomical characters to improve the yield of the crop.

Heritability can be defined as the proportion of the phenotypic variation that is caused by the differences in genetic constitution (Sesardic, 2005). Selection is assumed effective when the heritability is high and results in high genetic gain (Larik et al., 2000). The high heritability in plant breeding is the result of a diverse genetic background of the germplasm. Heritability is higher also when there is low environmental variation. However, for traits with low heritability, differences will be attributed to environmental factors (Rao and Gu, 2008). The significance of heritability is high as it is used to calculate genetic advancement, which indicates the degree of gain in a trait observed under a particular selection pressure. Thus, genetic advance is yet another important selection parameter that aids breeders in a selection programme.

The aim of this study was to investigate the association among maize yield and yield components in stressed and unstressed environmental conditions and to assess the variability, heritability and genetic advance of grain yield and some of its related components.

5.2 Materials and Methods

Materials and methods are described in Chapter 3.

5.2.1 Statistical analysis

Collected data on maize yield and yield components were organized and recorded in Microsoft Excel 2013. Pearson's correlation coefficients were calculated for the tested traits using GenStat version 17 software. The traits were variables while the replications, blocks, environments, entries, name of genotypes were converted to factor (Li et al., 2015). The analysis was performed using the following linear model:

$Y_{ijkl}=\mu+E_i+R(E)_{j(i)}\ IB(RE)_{bkj}+G_k+GE_{ik}+e_{ijkl}$; ……. equation 5.1.

where μ is the overall mean, E_j is the effect of the j_{th} location, $R(E)_{kj}$ is the effect of the k^{th} replicate within the i^{th} location, $IB(RE)$ is the effect of the incomplete blocks within the k^{th} replicate in the j^{th} environment, G_i is the effect of the i^{th} genotype, GE_{ik} is the interaction effect of the i^{th} genotype with the j^{th} location and $\boldsymbol{e}_{ijkl}$ is an experimental error.

5.2.2 Genetic data estimated

The phenotypic and genetic variance were calculated using the formula by Chaudhary and Prasad (1968) as shown below:

$\delta^2_g = (MS_g – MSgxe)/r$ …………………….equation 5.2

$\delta^2p = (\sigma^2g + \sigma^2gxe + \sigma^2e)$……….. equation 5.3

Where MSg =mean sum square of genotype; MS_{gxE} = mean sum square of genotype by environment interaction and σ^2_e mean sum square of residual. σ^2p = phenotypic variance, E=number of environments, r= number of replications, σ^2_e = residual variance, σ^2_{gxe}= Genotypes x environment interactions variance.

Phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), and environmental coefficient of variation (ECV) were calculated as suggested by Araus et al. (2008)

I. Phenotypic coefficient of variation (PCV) = $(\sqrt{\delta^2{}_p}/X)*100$ ……equation 5.4

II. Genetic coefficient of variation (GCV) = $(\sqrt{\delta^2{}_g}/X)*100$ ……..equation 5.5

III. Environmental coefficient of variation (ECV) = $(\sqrt{\delta^2{}_e}/X)*100$…….equation 5.6

Where, σ^2p = phenotypic standard deviation, σ^2g = genotypic standard deviation, $\delta^2{}_e$ = environmental standard deviation, and x = Grand mean for the characteristic.

Broad sense heritability of the traits was estimated as proposed by Johnson et al. (1955) as follows:

$H=\sigma^2g/(\sigma^2g + \sigma^2gxe/E + \sigma^2e/rE)*100$ …………….equation 5.7

Where, H = Broad sense heritability; σ^2g = Genetic variance and σ^2p = phenotypic variance, E=number of environment, r= number of replications, σ^2e = residual, σ^2gxe= mean square.

The genetic advance (GA) was calculated as suggested by Robinson et al. (1949) and indicated below:

$GA=k*H*\delta p$ ………………………..equation 5.8

Where, GA = Genetic advance; k= selection intensity H = broad sense heritability; σp = phenotypic standard deviation;

Genetic advance as percentage of the means was calculated using the following formula;

GAM (as % of the mean) = (GA/X)*100 (Johnson et al., 1955).

Where, GA = genetic advance; X = grand mean

Phenotypic correlation coefficients

Phenotypic correlation was estimated among the agronomic traits. The estimation of correlation coefficients was done using GenStat 17th edition. The phenotypic correlation was calculated as:

$r_{xy} = \sqrt{(Cov\ (x,y)/(S\ X^2)(S\ y^2))}$…………………………..equation 5.9

Where r_{xy}= the phenotypic correlation between x and y

$Cov_{(x,y)}$ = the covariance between x and y; $S^2{}_x$ = the variance of x; and $S^2{}_y$ = the variance of y

5.3 Results

5.3.1 Correlation coefficients between grain yield and its components for heterotic group A across environments

The phenotypic correlations between yield and yield components were presented in Table 5.1. Significant positive correlations at ($P<0.05$) were detected for grain yield and ear height, ear per plant, cob length, field eight, grain weight, number of ear per plant, and number of kernel per cob. A Significant negative correlation at ($P<0.05$) between grain yield and days to 50% anthesis (AD) , anthesis-silking interval (ASI), days to 50% silking and cob diameter were recorded. Days to 50% anthesis showed positive correlation at ($P<0.05$) with cob diameter, ear height, and days to 50% silking, field and grain weight, shelling percentage, and yield in t/ha (Table 5.1). Days to 50% silking was strongly positively correlated to days to 50% anthesis ($r = 0.89$). It was however, negatively correlated to cob length, and grain weight. Cob length had a positive and strong correlation to grain weight and grain yield in t/ha. Ear height was strongly correlated to number of ear position and grain weight. The number of ear per plant and ear per plot were strongly correlated. Grain yield was strongly ($p<0.05$) and positively correlated to field weight and grain weight (Table 5.1).

Table 5.1: Correlation coefficients of traits from HTGA across sites

	AD	ASI	CBD	CBL	EH	EP	EPP	FW	GW	KN/CB	NE	NP	SD	SP	GY
AD	-														
ASI	-0.008ns	-													
CBD	0.10ns	0.09ns	-												
CBL	-0.47**	-0.18***	-0.04ns	-											
EH	-0.2835**	-0.10ns	-0.09ns	0.3653**	-										
EP	0.1421**	0.09ns	0.08ns	-0.17**	0.53**	-									
EPP	-0.0239ns	0.03ns	0.124**	0.03ns	0.03ns	0.018ns	-								
FW	-0.58**	-0.12**	-0.097ns	0.65**	0 .49**	-0.0024ns	0.082ns	-							
GW	-0.5755**	-0.12**	-0.112**	0.629**	0.50**	0.02ns	0.091ns	0.98**	-						
KN/CB	-0.1251**	-0.120**	-0.05ns	0.38**	-0.002ns	-0.205**	0.014ns	0.27**	0.25**	-					
NE	-0.0184ns	0.045**	0.07ns	0.08ns	0.024ns	0.003ns	0.83**	0.12*	0.13**	0.08ns	-				
NP	0.0156ns	0.00ns	-0.105ns	0.06ns	-0.03ns	-0.026ns	-0.54**	0.036ns	0.04ns	0.08ns	0.03ns	-			
SD	0.8926**	0.43***	0.132**	-0.50**	-0.29**	0.176**	-0.007ns	-0.58**	-0.57**	-0.17**	0.001ns	0.02ns	-		
SP	-0.1186**	-0.05ns	-0.11**	0.0683ns	0.1145**	0.052ns	0.08ns	0.16**	0.35**	0.005ns	0.106ns	0.03ns	-0.125*	-	
Yield t/ha	-0.5611**	-0.119**	-0.13**	0.5617**	0.47**	0.019ns	0.115**	0.92**	0.98**	0.22**	0.162**	0.039ns	-0.55**	0.52**	-

AD = days to 50 % anthesis, SD =days to 50 % silking, ASI =SD-AD, CBD= ear dimeter, CBL= ear length, EH= ear height, EP = ear position, EPP= ear per plant, FW= field weight, GW= grain weight, KN/CB= kernels per ear, NE =number of ears per plot, SP= shelling percentage, Yield= t/ha is yield in tonnes per hectare. * = Significant at 5% level of probability; ** = Significant at 1% level of probability.

Correlation coefficients between yield and yield components among single-cross maize hybrids grown across environments presented in Table 5.2. Days to 50% anthesis and days to 50% silking were negatively correlated to GW and yield (t/ha) (r = 0.97). Other positive correlations were observed among EH and PH (r = 0.91), AD and SD (r = 0.87). AD was also negatively correlated to FW (r = - 0.49). On the other hand, ear height, plant height, grain weight and field weight were positively correlated to grain yield t/ha.

Table 5.2: Correlation coefficient for the traits from heterotic group B across the three environments

	AD	ASI	EH	EP	EPP	FW	GW	NE	NP	PH	SD	SP	GY
AD	-												
ASI	-0.18**	-											
EH	-0.26**	-0.07ns	-										
EP	-0.21**	-0.05ns	0.73**	-									
EPP	-0.14**	-0.03ns	0.09ns	0.11ns	-								
FW	-0.49**	-0.07ns	0.49**	0.31**	0.29**	-							
GW	-0.50***	-0.09nsns	0.48**	0.31**	0.28**	0.94**	-						
NE	-0.127*	-0.06ns	0.09ns	0.02ns	0.33**	0.35**	0.37**	-					
NP	-0.28**	-0.03ns	0.07ns	-0.06ns	-0.04ns	0.33**	0.36**	0.53**	-				
PH	-0.24***	-0.08ns	0.91**	0.44**	0.06ns	0.48**	0.48**	0.13*	0.14**	-			
SD	0.87**	0.33**	-0.28**	-0.22**	-0.15**	-0.51**	-0.53**	-0.15**	-0.28**	-0.27**	-		
SP	-0.13*	-0.09ns	0.09ns	0.06ns	0.06ns	0.03ns	0.36**	0.11*	0.15**	0.07ns	-0.17**	-	
Yield/t/ha	-0.48**	-0.10ns	0.46**	0.29**	0.27**	0.85**	0.97**	0.35**	0.35**	0.44**	-0.51**	0.55**	-

AD = days to 50% anthesis; SD = the days to 50 % silking; ASI = SD-AD; EH = ear height; EP = ear position; EPP = ear per plant; FW = field weight; GW = grain weight; NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha); * = Significant at 5% level of probability; ** = Significant at 1% level of probability

5.3.2 Genetic parameters for maize single-cross hybrid heterotic group A evaluated under random drought environment

5.3.2.1 Mean and range

Significant variation was observed among single-cross maize hybrids for several traits evaluated in random drought environment (Table 5.3). Despite a significant variation in plant height observed among evaluated maize genotypes, all genotypes had a height ranged from 146.2 to 233.70 cm. Days to 50% anthesis and silking ranged from 67 to 87 days and 68 to 90 respectively. Grain yield ranging from 4.57 to 9.45t/ha with a mean of 6.75 t /ha was recorded in this environment.

Table 5.3: Ranges, means, and mean square of genotype (MSg) and mean square error (Mse) for HTG A traits under random drought environment

Traits	**AD**	**SD**	**ASI**	**PH**	**EH**	**NP**	**EP**	**NE**	**FW**	**GW**	**SP**	**GY**
Max	87.5	89.5	8.00	233.7	138.8	17	0.73	17	0.99	3.62	0.83	9.45
Min	67.00	69.00	-3	146.2	61.9	12	0.41	10.5	4.77	1.67	0.68	4.57
Grand mean	75.77	76.7	0.91	182.99	102.1	16.95	0.56	16.02	3.51	2.7	0.77	6.75
MSg	17.34	22.09	3.71	494.3	255.2	12.5	0.00	0.53	0.43	0.29	0.01	2.01
Mse	10.91	15.09	2.88	471.1	159.1	0.28	0.00	0.45	0.25	0.16	0.00	1.09

AD = days to 50% anthesis, SD = days to 50% silking ; ASI = SD-AD; EH = ear height; EP = ear position; FW = field weight; GW = grain weight; NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), msg = mean square of genotypes, mse = mean square error, Max = maximum and min= minimum.

5.3.2.2 Estimate of variance components

Among several evaluated parameters, grain yield (t/ha), days to 50% anthesis (AD), days to 50% silking (SD), plant height (PH) and ear height (EH) showed high genetic and phenotypic variances (Table 5.4). High PCVs were exhibited in ASI (111.73%), EP (87.18%), NE (51.32%), and yield (t/ha) (34.48%). High GCVs were in ASI (13.55%), EP (84.26%), and yield (t/ha) (12.70%). PCVs (6.10) and GCV (1.66) values were minimal for AD, and PCV (6.70) and GCV (1.64) for SD. The differences between the GCV and PCV values were significant for ASI, NE, and PH. The high GCV, high heritability and high PCV makes it easier to select based on the phenotype. The trends fluctuated among the traits as shown in Table 5.4.

Table 5.4: Estimates of genetic parameters and genetic advance of traits from 160 maize single-crosses from HTG A under RD

Trait	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
δ^2p	26.50	33.41	4.65	695.20	248.00	7.95	0.76	13.08	0.33	0.21	0.01	1.40
δ^2g	1.96	2.01	0.07	58.10	19.10	0.19	0.71	0.35	0.06	0.04	0.00	0.19
PCV (%)	6.10	6.70	111.73	17.35	18.31	18.80	87.18	51.32	29.26	31.30	14.42	34.48
GCV (%)	1.66	1.64	13.55	5.01	5.08	2.88	84.26	8.40	12.40	13.04	5.15	12.70
H (%)	7.38	6.02	1.47	8.36	7.70	2.35	93.42	2.68	17.98	17.36	12.78	13.56
GA	0.78	0.72	0.07	4.54	2.50	0.14	1.68	0.20	0.21	0.16	0.03	0.33
GAM %	0.93	0.83	3.39	2.99	2.91	0.91	167.77	2.83	10.83	11.19	3.8	9.63

AD = days to 50 %, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, Yields t/ha is yield in tonnes per hectare, H= Broad sense heritability, δ^2g genotypic variances, δ^2p = phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation. GA= genetic advances, GAM = genetic advance as percent of the mean.

5.3.2.3 Estimate of heritability

Variations in heritability were observed among evaluated attributes (Table 5.4). Some variables had greater ranges of heritability than others. The highest and lowest heritability estimates were observed for EP and ASI, respectively. Grain yield, FW, and GW had low heritability estimates. The estimate of genetic advance for grain yield was 0.33 t/ha. Maximum genetic advance as percentage of mean (GAM) at 5% proportion selected was recorded for EP (167.77%), GW (11.19%), FW (10.83%) and yield (9.63%). For the traits with high heritability, it implies that phenotypic selection would be easier than for traits with low heritability traits. Trends also fluctuated as shown in Table 5.5.

5.3.3 Estimates of the genetic parameters for heterotic group A in an optimum environment

5.3.3.1 Mean and range

Mean and ranges of the evaluated maize genotypes variables are presented in Table 5.5. Summarized results showed a significant variation among variables, some had wide ranges while other had narrow range. Ear height (EH) ranged from 61.9 to 138.8 cm, days to 50% anthesis ranged from 67 days to 87 days, and plant height ranged from 146.20 cm to 233.7 cm. Grain yield ranged from 4.54 t/ha to 9.45 t/ha and days to 50% silking ranged from 69 days to 89.

Table 5.5: Mean, ranges, and mean square of the maize traits from heterotic group A, under optimum conditions

Traits	**AD**	**SD**	**ASI**	**PH**	**EH**	**NP**	**EP**	**NE**	**FW**	**GW**	**SP**	**GY**
Max	87.50	89.50	8.00	233.70	138.80	17.00	0.73	17.00	0.99	3.62	0.83	9.45
Min	67.00	69.00	-3.00	146.20	61.90	12.00	0.41	10.50	4.77	1.67	0.68	4.57
Grand mean	75.77	76.70	0.91	182.99	102.10	16.95	0.56	16.02	3.51	2.70	0.77	6.75
MSg	17.34	22.09	3.71	494.30	255.20	12.50	0.00	0.53	0.43	0.29	0.01	2.01
Mse	10.91	15.09	2.88	471.10	159.10	0.28	0.00	0.45	0.25	0.16	0.00	1.09

AD = Days to 50 % anthesis; SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), msg = mean square of genotypes, mse = mean square error, Max = maximum and min= minimum.

5.3.3.2 Estimate of variance components

Significant genetic and phenotypic variations among maize single-cross hybrids were exhibited on plant height, ear height, days to 50% anthesis, days to 50% silking, and grain yield (t/ha). ASI (200.37), yield (t/ha) (18.44), GW (17.54), and FW (16.63) showed high phenotypic coefficient of variation while ASI (2.37), NP (14.58), and yield (t/ha) (10.04) exhibited high genetic coefficients of variation. Broad sense heritability was high in NP, and SP, and moderately in GY and AD. EH and PH had greater genetic advance as compared to other measured variables.

Table 5.6: Estimates of genetic parameters and genetic advance of traits from 160 maize single HTG A crosses grown under optimum conditions

Trait	**AD**	**SD**	**ASI**	**PH**	**EH**	**NP**	**EP**	**NE**	**FW**	**GW**	**SP**	**GY**
δ^2p	14.13	18.59	3.30	482.70	207.15	6.39	0.00	0.49	0.34	0.22	0.01	1.55
δ^2g	3.22	3.50	0.41	11.60	48.05	6.11	0.00	0.04	0.09	0.06	0.01	0.46
PCV (%)	4.96	5.62	200.37	12.01	14.10	14.91	10.35	4.37	16.63	17.54	11.09	18.44
GCV (%)	2.37	2.44	70.98	1.86	6.79	14.58	7.13	1.23	8.64	9.35	9.47	10.04
H^2 %	22.76	18.83	12.55	2.40	23.20	95.62	47.44	7.91	26.98	28.43	72.92	29.65
GA	6.62	7.21	0.85	23.90	98.98	12.59	0.00	0.08	0.19	0.13	0.01	0.95
GAM	8.74	9.40	94.02	13.06	96.95	74.26	0.59	0.50	5.39	4.87	1.42	14.02

AD = days to 50 % anthesis, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), H= broad sense heritability, δ^2g=genotypic variances, δ^2p=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean.

5.3.3.3 Estimates of heritability

The heritability for different traits of maize single-cross hybrids ranged from 1% to 98%. Number of plants exhibited a high heritability estimate while ASI showed lowest heritability. Moderate heritability estimates for yield, FW, GW, and EP were also observed (Table 5.6). The estimate of genetic advance (GA) for grain yield was 3.02 t/ha. Maximum genetic advance as percentage of mean at 5% (selection intensity = 2.061) was recorded for EH (354.40%), PH (291.29%), NP (150.22%) and yield t/ha (44%).

5.3.3.4 Estimates of combined analysis for the genetic parameters for heterotic group A across environments

5.3.3.4.1 Means and ranges

Results from Table 5.7 shows significant variations among the single-cross maize hybrids. A wide range was observed between the minimum and maximum values. Ear height ranged from 64.83 cm to 112.08 cm, plant height ranged from 130.3 cm to 198.7 cm. Days to 50 % anthesis ranged from 75 days to 87 days. Yield ranged from 0.2 t/ha to 4.04 t/ha with a trial mean of 4.32 t/ha.

Table 5.7: Ranges, means of HTGA maize single-cross across environment

Traits	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	GY
Cross mean	80.08	1.41	94	0.8	1.32	1.03	11.4	14	167	81.51	0.8	2.56
CV (%)	5.4	2.7	14.8	27.5	44.9	46.4	29.4	19.5	14.1	6.1	11.2	52.4
LSD (0.05)	6.07	2.7	19.4	0.32	0.82	0.66	4.68	3.8	32.8	6.87	0.12	1.86
Maximum	87	5	112.08	1.38	2.26	1.71	16	17.5	198.7	88.5	0.84	4.32
Minimum	75.25	-1	64.83	0.5	0.348	0.26	5.5	6.5	130.3	76.25	0.64	0.20

AD = Days to 50 % anthesis; SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, Yields t/ha is yield in tonnes per hectare, msg = mean square of genotypes, mse = mean square error, Max = maximum and min= minimum.

5.3.4.2 Estimate of variance components

Results from maize single-cross hybrids showed high genetic and phenotypic coefficients of variation (Table 5.8). Plant height (348.68), ASI (275.05), ear height (241.22) yield t/ha (81.88), NE (117.91), GW (20.5), FW (32.34), NP (71.29) showed high phenotypic coefficient of variation. High genetic coefficient of variation was exhibited by ear height (19.57), FW (6.54), NE (11.64) and grain yield (15.82) showed high genetic coefficient of variation.

5.3.4.3 Estimate of broad sense heritability

Significant variation on heritability for maize single-cross hybrids was observed and ranged from (0%) to (39%). Grain weight, field weight and grain yield showed moderate to low heritability estimates while days to 50% anthesis, days to 50% silking, ear height and shelling percentage exhibited the lowest heritability of 0%. Heritability estimates for yield t/ha (20.45%), FW (30.05%), and GW (39%) were above 20 % heritability. However, AD, PH, EH, SD and SP were below 10% heritability there were termed to be low heritable traits (Table 5.8).

Table 5.8: Combined estimates of genetic parameters and genetic advance of traits from 160 HTGA maize single-cross hybrids across environments

SOV	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	GY
$\delta^{2}g$	0.00	0.07	0.00	0.00	0.02	0.01	0.53	0.00	0.00	0.00	0.00	0.07
$\delta^{2}g*e$	3.27	0.12	35.75	0.00	0.01	-0.02	0.90	2.25	75.35	4.09	0.00	-0.02
δ^{2}Residual	9.20	3.56	87.46	0.04	0.18	0.12	7.41	6.06	202.20	11.73	0.01	1.16
H	0.00	6.39	0.00	27.17	30.05	39.12	18.59	0.00	0.00	0.00	0.00	20.45
$\delta^{2}p$	12.10	3.75	122.22	0.04	0.22	0.11	8.84	7.93	259.43	15.11	0.01	1.22
mean	80.08	1.41	94.00	0.80	1.32	1.03	11.40	14.00	167.00	81.51	0.80	2.56
PCV	4.34	137.35	11.76	24.81	35.39	32.37	26.08	20.12	9.64	4.77	10.66	43.09
GCV	0.00	18.09	0.00	6.98	11.31	10.66	6.36	0.00	0.00	0.00	0.00	10.52

AD = days to50 % anthesis, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), H= Broad sense heritability, $\delta^{2}g$ genotypic variances, $\delta^{2}p$=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean.

5.3.4 Genetic parameters for traits from heterotic group B evaluated under low N environments

5.3.4.1 Means and ranges

Results from Tables 5.9 and 5.10 show significant variations among the single-cross maize hybrids. A wide range was observed between the minimum and maximum values. Ear height ranged from 45.25 cm to 123.75 cm, plant height ranged from 107.3 cm to 196.5 cm. Days to 50 % anthesis ranged from 111 days to 122 days. Yield ranged from 1.2 t/ha to 4.04 t/ha with a trial mean of 2.3 t/ha.

Table 5. 9*:* Ranges, means and mean squares of the traits of maize single-cross HTG B grown under low N conditions

Traits	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
Max	122.5	125	4	196.5	123.75	17	0.58	16.9	2.15	1.61	0.83	4.04
Min	111.5	113	-3	107.3	45.25	6	0.29	2.4	0.79	0.53	0.49	1.20
Grand mean	116.9	118.74	1.42	152	77.37	14	0.49	12.79	1.30	0.9351	0.719	2.30
MSg	11.91	13.38	3.75	643.94	388.28	4.20	0.0037	7.40	0.15	0.08	0.003	0.64
Mse	6.197	6.49	1.43	28.31	31.3	3.171	0.0026	4.718	0.05	0.03	0.003	0.26

AD = days to 50 % anthesis, SD = days to 50 % silking; ASI = SD-AD; EH = ear height; EP = ear position; EPP = ear per plant; FW = field weight; GW = grain weight; NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), msg = mean square of genotypes, mse = mean square error, Max = maximum and min= minimum.

5.3.4.2 Estimate of variance components

Results from maize single-cross hybrids showed high genetic and phenotypic coefficients of variation (Table 5.13). ASI (113.15), yield t/ha (29.15), NE (19.24), GW (25.99), FW, NP showed high phenotypic coefficient of variation. High genetic coefficient of variation was exhibited by ASI (75.76) FW, and EH (17.26) showed high genetic coefficient of variation.

5.3.4.3 Estimate of heritability

Significant variation on heritability for maize single-cross hybrids was observed and ranged from (10%) to (91%). PH (91) showed highest heritability estimates while shelling (10) percentage exhibited lowest heritability. Heritability estimates for yields t/ha (42%), FW (50%), GW (50%), and EP (17%) were moderate (above 30%). However, NP, EP and NE were low (below 30%) (Table 5.10). The estimate of genetic advance for grain yield was 0.59 t/ha. Maximum genetic advance as percentage of mean (GAM) at 5% selection intensity was recorded for ASI (227.19 %), EH (25.38 %), FW (25.17 %), GW (27.17%) and yield t/ha (25.71 %).

Table 5.10*:* Estimates of genetic parameters and genetic advance of traits from 160 HTGB maize single-crosses under low nitrogen conditions

Trait	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
Ϭ2p	9.05	9.93	2.59	336.12	209.79	3.68	0.00	6.06	0.09	0.06	0.00	0.45
Ϭ2g	2.85	3.45	1.16	307.81	178.49	0.55	0.00	1.34	0.05	0.03	0.00	0.19
PCV (%)	2.57	2.65	113.15	12.06	18.71	13.71	11.45	19.24	24.13	25.99	7.60	29.15
H	0.31	0.34	0.44	0.91	0.85	0.14	0.17	0.22	0.50	0.50	0.01	0.42
GCV (%)	1.44	1.56	75.76	11.54	17.26	5.13	4.82	9.06	17.15	18.51	0.78	19.07
GA	1.96	2.21	3.23	34.58	25.38	0.55	0.02	1.12	0.33	0.25	0.00	0.59
GAM	1.67	1.89	227.19	22.75	32.80	3.95	4.18	8.79	25.17	27.17	0.17	25.71

AD = days to 50 % anthesis, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), H = Broad sense heritability, δ^2 g=genotypic variances,

δ^2p=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean.

5.3.5 Genetic parameters for traits from heterotic group B evaluated under optimum environment

5.3.5.1 Mean and ranges

The results from Tables 5.11 to 5.12 show significant variation between hybrids, moreover maximum and minimum values of traits had a wide range enough to show diversity. For example, plant height ranged from 108.3 to 221.2 cm, and ear height from 61.33 to 137.5cm. Days to 50% anthesis from 69 - 90, days to 50% silking from 69 to 90, and yield ranged from 3.96 t/ha to 8.65 t/ha.

Table 5.11: Ranges, mean and mean square of single-cross maize hybrid heterotic group B when evaluated under optimum conditions

Traits	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
Max	90	90	5	221.2	137.5	17	0.79	17	4.72	3.4	0.93	8.65
Min	69	69	-2	108.3	61.33	5.5	0.48	5.5	2.29	1.69	0.65	3.95
Grand mean	78	77	0.24	167.36	99.19	14.06	0.59	12.68	3.22	2.47	0.76	6.22
MSg	77	117	2.57	749.9	380	9.42	0.01	14.99	0.39	0.24	0.03	2.87
MSe	31	82	1.93	474.3	167.7	8.59	0	13.51	0.26	0.16	0.01	0.95

AD = days to 50 % anthesis, SD = days to 50 % silking; ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight; GW = grain weight; NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), MS_g = mean square of genotypes, MS_e = mean square error, Max = maximum and min= minimum.

5.3.5.2 Estimates of variance components

Plant height, ear height, days to 50% anthesis, days to 50 % silking, grain yield t/ha and anthesis–silking interval exhibited high genetic and phenotypic variations. Greater differences between PCV and GCV were observed for ASI, PH, NP, GY AD and SD (Table 5.12).

5.3.5.3 Estimates of heritability

Heritability for the traits ranged from (5%) to (54%). The highest heritable trait was SP and lowest heritable traits were NE and NP. Heritability for yield, FW, GW, EH, ASI, AD were moderate with more than 30% except for SD, and PH that were low (below 30%). The estimated genetic advance for grain yield was 1.43 (t/ha) with yield increase of 1.43 t/ha to the progeny when crossed to the other third line. Maximum genetic advance as percentage of mean (GAM) at 5% selection intensity recorded for ASI (2685.41%), and yield t/ha (23.71%) (Table 5.12)

Table 5. 12: Estimates of genetic parameters and genetic advance (GA) for traits from of 160 maize single-crosses HTG B optimum conditions

Trait	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
Ϭ^{2}p	54.82	99.98	54.82	612.10	273.85	9.00	0.00	14.25	0.32	0.20	0.02	1.91
Ϭ^{2}g	23.04	17.15	23.04	137.80	106.15	0.42	0.00	0.74	0.07	0.04	0.01	0.96
PCV (%)	9.47	12.83	3101.70	14.78	16.68	21.33	11.07	29.76	17.68	18.01	17.30	22.22
GCV (%)	6.14	5.31	2010.81	7.01	10.39	4.59	4.45	6.78	8.11	8.28	12.75	15.75
H	0.42	0.17	0.42	0.23	0.39	0.05	0.16	0.05	0.21	0.21	0.54	0.50
GA	6.41	3.53	6.41	11.47	13.21	0.29	0.02	0.40	0.25	0.19	0.15	1.43
GAM	8.19	4.53	2685.41	6.86	13.32	2.04	3.69	3.18	7.66	7.84	19.35	23.01

AD = days to 50 %, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, Yields t/ha is yield in tonnes per hectare,H^{2}= Broad sense heritability, δ^{2}g genotypic variances,δ^{2}p=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean.

5.3.6 Genetic parameters for traits from heterotic group B in a random drought environment

5.3.6.1 Estimates of variance components

Plant height, ear height, days to 50% anthesis days, days to 50% silking, grain yield (t/ha), and anthesis-silking interval exhibited high genetic and phenotypic variations. High PCV was exhibited by ASI (181.78), yields (t/ha) (23.32), and NE (31.42). High genetic coefficient of variation (GCV) were observed to be higher on the following traits ASI (43.48), grain yield (t/ha) (16.08), and SP (5.91) (Table 5.13).

5.3.6.2 Estimates of heritability

Heritability for the traits ranged from (1%) to (50%), the highest heritable trait being SP and the lowest heritable trait being PH. Moderate heritability was observed for yield, and GW, with means that were more than 30%. Estimated genetic advance for grain yield was 1.09 t/ha. Estimated maximum genetic advance in percentage of mean (GAM) at 5% selection intensity for yield (t/ha) and days to ASI were (22.84%) and (21.42%), respectively (Table 5.13).

Table 5.13*:* Estimates of genetic parameters and genetic advance for traits of 160 maize single-crosses from HTG B grown in random drought

Trait	**AD**	**SD**	**ASI**	**PH**	**EH**	**NP**	**EP**	**NE**	**FW**	**GW**	**SP**	**GY**
σ^2p	20.55	31.15	5.99	496.05	210.55	6.21	0.00	12.18	0.25	0.16	0.01	1.24
σ^2g	2.51	3.35	0.34	6.05	14.25	0.33	0.00	0.17	0.05	0.05	0.00	0.59
PCV (%)	5.28	6.41	181.78	16.10	17.49	17.14	10.22	31.42	24.76	23.09	8.39	23.32
GCV (%)	1.84	2.10	43.48	1.78	4.55	3.93	2.53	3.66	10.51	13.13	5.91	16.08
H	0.12	0.11	0.06	0.01	0.07	0.05	0.06	0.01	0.18	0.32	0.50	0.48
GA	1.14	1.23	0.29	0.56	2.02	0.27	0.01	0.10	0.19	0.27	0.07	1.09
GAM	1.33	1.42	21.42	0.40	2.44	1.86	1.29	0.88	9.18	15.38	8.59	22.84

AD = days to 50 % anthesis, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, GY=grain yields (t/ha), H=Broad sense heritability,δ^2g genotypic variances, δ^2p=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean.

Genetic parameters for traits from heterotic group B in combined environments

5.3.6.1 Means and ranges

Study results showed that plant height and ear height ranged from 115 to 231 cm and from 61.28 to 107.78 cm, respectively. Days to 50% anthesis and days to 50% silking ranged from 89 to 100 days, and 90 to 101 days respectively. Mean yields ranged from 2.27 t/ha to 5.53 t/ha (Table 5.14).

5.3.6.2 Estimates of variance components

Plant height, ear height, grain yield (t/ha), number of ear and anthesis-silking interval exhibited high genetic and phenotypic variations. High PCV was exhibited by PH (2130.47%), NE (343.61), EH (1202.69) and grain yields (t/ha) (25.62). High genetic coefficient of variation (GCV) were observed to be higher on the following traits plant height (695.97), ear height (443.36), and grain yield (10.37) (Table 5.15).

5.3.6.3 Estimates of heritability

Heritability for the traits ranged from (22%) to (60.00%), the highest heritable trait being field weight and the lowest heritable trait being ASI. Moderate heritability was observed for field weight, grain yield (GY), and GW. Estimated genetic advance for grain yield was 1.10 t/ha. Estimated maximum genetic advance in percentage of mean (GA %) at 5% selection intensity for plant height (1981.12), ear height (1117.12) and number of ear (Table 5.15).

Table 5.14: Combined Ranges, means and mean squares of maize single-cross hybrids grown from HTG B acorss environments

Traits	AD	SD	ASI	PH	EH	NP	EP	NE	FW	GW	SP	GY
Max	100.20	101.17	4.66	231.00	107.00	16.00	1.80	15.50	2.02	1.44	1.36	5.57
Min	89.33	90.83	-1.16	115.00	61.00	10.00	0.53	5.83	0.69	0.51	0.66	2.27
Grand mean	93.83	94.94	1.13	150.00	85.00	14.00	0.90	11.11	1.20	0.91	0.80	3.89
MSg	24.05	30.52	4.38	1109.70	407.70	9.54	0.09	16.68	0.38	0.23	0.02	2.27
Mse	13.27	17.79	3.94	686.10	189.40	5.87	0.07	10.32	0.18	0.11	0.02	0.77

AD = days to 50 % anthesis, SD = days to 50 % silking; ASI = SD-AD; EH = ear height; EP = ear position; FW = field weight; GW = grain weight; NE = number of ears per plot; SP = shelling percentage, GY=grain yield (t/ha), msg = mean square of genotypes, mse = mean square error, Max = maximum and min= minimum.

Table 5.15: Estimates of genetic parameters and genetic advance for traits of 160 maize single-crosses from HTG B at combined environments

SOV	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	GY
$\delta^2 g$	1.22	0.19	25.10	0.01	0.04	0.02	0.97	0.43	69.75	1.54	0.00	0.16
$\delta^2 p$	13.88	4.30	184.70	0.08	0.19	0.12	9.56	6.94	653.60	19.55	0.03	0.99
H	0.36	0.22	0.45	0.33	0.60	0.56	0.39	0.28	0.45	0.34	0.23	0.53
GA	2.77	0.94	12.62	0.20	0.54	0.40	2.51	1.53	23.77	3.13	0.08	1.10
G.M	93.83	94.94	1.13	150.00	85.00	14.00	0.90	11.11	1.20	0.91	0.80	3.89
PCV	3.97	2.19	1202.69	0.19	0.52	2.46	343.61	23.72	2130.47	485.85	20.08	25.62
GCV	1.18	0.46	443.36	0.05	0.23	1.07	109.21	5.93	695.97	136.26	4.01	10.38
GAM (%)	2.95	0.99	1117.12	0.13	0.63	2.84	279.41	13.76	1981.12	344.06	9.57	28.17

AD = days to 50 % anthesis, SD = days to 50 % silking, ASI = SD-AD; EH = ear height; EP = ear position, FW = field weight, GW = grain weight, NE = number of ears per plot; SP = shelling percentage, Yields t/ha is yield in tonnes per hectare, H= Broad sense heritability,$\delta^2 g$

genotypic variances, δ^2p=phenotypic variances, GCV=genotypic coefficient of variation, PCV =phenotypic coefficient of variation.GA= genetic advances, GAM = genetic advance as percent of the mean, GM=Grand mean

5.4 Discussion

5.4.1 Correlation coefficient analysis of maize single-cross across environments

The results showed that days to 50% anthesis (AD) had a significant negative correlation with grain yield. This indicated that any increase in days to 50% anthesis will decrease maize yield under combined environments. Similar observations were reported by Malik et al. (2005) and Azad et al. (2012). Cob length and field weight increased grain yield per cob, as the factors were positively correlated to yield. Selection of maize hybrids with long cobs, and high field weight will improve yield. Similar associations were reported by Nemati et al. (2009), Kashiani et al. (2010), Azad et al. (2012) and Ojo et al. (2006).The positive correlation coefficient between grain yield and number of ears per plant indicated the possibility of improving maize yield through selection of prolific single-cross maize hybrids (Martin and Russell, 1984). Increase in grain weight may cause significant increase in cob length as the traits were observed to be correlated positively (Nemati et al., 2009).

The positive correlation coefficient between shelling percentage and grain weight (GW) indicated the significance of improving maize yield through improving shelling percentage. Similar findings have been reported in groundnut by Kwaga (2014). Selection of maize single-cross hybrids with high shelling percentage may improve grain yield. Grain yield may also be improved through selection of single-cross maize hybrids with heavy grain weight, as the traits were observed to be correlated positively. Similar findings were also reported in early studies by Martin and Russell (1984).

A negative correlation coefficient between ASI and grain yields was observed. An increase in the ASI will significantly reduce grain yield (Zaidi et al., 2007). A positive correlation coefficient between plant height and ear height indicated the ability of improving ear height through selection of tall single-cross maize hybrids. Zarei et al.(2012) reported a positive correlation coefficient between plant height and ear length. In contrast Rahmani et al. (2014) reported that ear height was positively correlated to grain weight. Similar to the current findings, positive association between ear height and the yield was report by Kumar et al. (2015) and Zarei et al. (2012).

The negative correlation coefficient between ASI and grain yield (tonnes per hectare) across environments indicates the ability of improving maize yield through selection of single-cross maize hybrids with a shorter ASI. This means selection of single-cross maize hybrids with shorter ASI may improve yield. Similar findings were reported in early studies by Zaidi et al. (2007).The strong and positive correlation coefficient observed between plant height and grain yield indicated the possibility of improving maize yield through selection of taller single-cross maize hybrids.

An anthesis-silking interval was not correlated to the grain yield under the low nitrogen environment. This is contrary to Bolanos and Edmeades.(1996) who reported negative correlation coefficient between ASI and yield. A Positive correlation coefficient between number of ears per plant and grain yield indicated the ability of improving maize yield through selection of prolific single-cross maize hybrids. Similar observations were also reported by Bolanos and Edmeades (1996).

5.4.2 Genetic parameters

Significant variation among yield and yield components were observed. The diversity observed indicated maximum possibility for selection of maize hybrids based on yield and their yield components. Variation in yield and yield components were also reported by Wolie et al. (2013). The findings were in contrary to Ogunniyan and Olakojo (2014) who reported that there were narrow diversity among traits. High GCV values among yield and yield components indicated the possibility of improving the crops yield through selection. Great differences between the GCV and PCV values among ASI and NE, and PH showed the influence of the environments on plant performance. High heritability estimates observed in some traits showed the possibility of improving the traits phenotypic selection (Singh, 2001).

Variation in yield and yielding components observed among single-cross maize hybrids across conditions showed maximum diversity of traits evaluated. This was also due to maximum expression of the traits. This was confirmed by wide yield gap that allow selection of genotypes based on a particular trait. The possibility of effective selection was further witnessed by the wide differences among phenotypic and genotypic coefficients of variation. Moderate heritability estimates observed for yields, FW, GW and EP indicated easier selection of the traits among maize hybrids under optimum environment. Therefore, evaluating genotypes in this environment will provide the true performance of the hybrids in the absence of stress.

Differences in ranges of yield and yielding components among single-cross maize hybrids grown under low nitrogen conditions was observed. This indicated variation in adaptability of maize hybrids under low nitrogen environment, random drought and optimum conditions. Reduction in days to 50% silking, ASI, PH, EH and yield observed are among the impacts of limited nitrogen in soil and plants at large. Reduction in rate of photosynthesis due to limited nitrogen was also reported by Blum (1988). Evaluation of single-cross maize hybrids under low nitrogen and random drought environments may therefore, allow selection of genotypes that can perform better in environments with low nitrogen. High heritability estimates observed for PH, grain yields, FW, GW and EP indicated the easy with which selection of single-cross maize hybrids based on that traits under low N conditions can be performed (Bänziger et al., 2006).

Variation in grain yield and yield components among single-cross maize hybrids evaluated under random drought environment was also observed. This indicated the differences in adaptability among single-cross maize hybrids under drought conditions. Improvement of yield and yielding components can therefore be done through selection of maize hybrids with better performances. Existence of variation was justified by great differences between the PCV and GCV observed. High heritability of some traits among maize hybrids indicated the ease with which the traits can be improved resulting in maximum genetic advance when the genotypes are advanced for further breeding (Aminu and Izge, 2012).

5.5 Conclusion

Positive and negative associations of yield and yield components were observed among single-cross maize hybrids grown in both stressed and unstressed environments. Improvement of grain yield may be achieved through selection for single-cross maize hybrids with traits that are positively correlated with grain yield in a particular environmental condition. Selection of maize hybrids with reduced days to ASI may also improve maize yield across the environments.

High genetic and phenotypic variances and heritability observed among evaluated variables indicated the possibility of improving maize performances through selections. Selection based on the performance of hybrids across the environments is the best option for improving maize yield in future.

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CHAPTER SIX

GENERAL OVERVIEW OF THE RESEARCH FINDINGS

6.1 Introduction and objectives of the study

New testers in any breeding programme are very important for the success of the breeding programme. Therefore, evaluation of maize hybrids from heterotic group A and B is one of the milestones for the new testers to be identified. Breeders in southern and eastern Africa are now focused on developing new single-crosses testers with good tolerance to drought, high yielding capacity as well having stable performance across the environments such testers can replace the old testers currently used which were developed from old lines. The identified single-cross hybrids for the development of the testers will provide good discriminating testers under stress conditions and improved selection for the development of good three-way hybrids. The objectives of the study, summary of the research findings, breeding implications of the findings and its challenges, future direction of the development of new single-cross testers in maize breeding, and closing remarks are highlighted in this chapter.

6.2 The specific objectives of the study were:

I. To identify elite single-cross hybrids suitable for further evaluation as potential testers for the development of three-way cross hybrids.
II. To determine the correlations between grain yield and secondary traits among single-cross maize hybrids.
III. To estimate phenotypic and genetic variance components, heritability and genetic advances for the yields and its related components among single-crosses of maize hybrids.

6.3 Summary of the major findings

The results of grain yield revealed that there are single-cross hybrids which can be used for further evaluation on the development of the new single hybrid testers for maize breeding programme considering the performances across environments that were used**.** In heterotic group A; entries 1, 23, 127, 15,122 8, 134, 109, 34 and 31 performed well across the environments. In heterotic group B, entries 69, 81, 65, 97, 92, 40, 117, 58, 101, and 44 were the best performers across the environments**.** The positive relationship between the secondary traits and yields but also secondary traits by themselves showed that selection of one trait can be done indirectly based on the secondary traits as well as directly for some of the traits. For example, yield improvement can be done by selecting good cob length. Additional results indicated that yield can be improved by selecting for large cob diameter with many rows per cob. The results indicated that the hybrids were diverse genetically and phenotypically which indicated that the hybrids can be successfully improved through selection. Therefore, the best single-crosses can be advanced for further evaluation and be able to get the best single-cross testers. Genetic gain was exhibited which indicated better performance of the three-way hybrids. High heritability was shown by the following traits across environments for heterotic group B were days to 50 % anthesis (36%), plant height 45(%), grain yield (53%), grain weight (56%), and field weight (60%). And for heterotic group A, high heritability was shown by the following traits field weight (30%), grain weight (39%), and grain yield (21%).

6.4 Implications of the research in plant breeding

The following can be explained in plant breeding perspectives:

- Since hybrids showed genetic and phenotypic diversity, this means that selection of the best hybrids can be done effectively. Also, it will result in high heterosis/hybrid vigour for the three-way hybrid varieties.
- The positive correlation between yields and secondary traits shows that yield can be improved through selection of the secondary traits such as cob length, short ASI, and prolificacy.

6.5 Challenges of tester development

- The first challenge is from other breeders regarding the adoption of the new testers. Most breeders are comfortable using the old testers. However, the concept of “breed forward comes in” meaning new lines to be tested with new testers.

6.6 Recommendations

- The promising single-crosses must be taken for further evaluation in many other locations for genotype by environment interactions.

- DNA finger printing can be used to check their purity with respect to the heterotic groups.
- The information for the single-crosses obtained in this study can be used to decide on new pedigree breeding and in predicting performance of new three-way and double cross hybrids.

6.7 Conclusion

The major objective of the study was to develop new testers from new inbred lines. The specific objective were to identify elite single-cross hybrids suitable for further evaluation as potential testers in three-way cross hybrids, to determine the correlations between grain yield and secondary traits in single-cross maize hybrids and estimate the phenotypic and genetic variance components, heritability and genetic advances for yield and its related components in single-crosses of maize hybrids. The study identified ten promising single-cross hybrids from each of the two heterotic groups which can be further evaluated for their combing ability to be used in tester development. From heterotic group A, the following entries 1, 23, 127, 15,122 8, 134, 109, 34 and 31; from heterotic group B the following entries 69, 81, 65, 97, 92, 40, 117, 58, 101, and 44 were the best performers.

Appendix 3. 1: List of materials for heterotic group A

SN	Stock ID	Name	Source	SN	Stock ID	Name	Source
1	T399-130	TH15342	CIMMYT ZIMBABWE	81	T399-124	TH15279	CIMMYT ZIMBABWE
2	T399-201	TH15349	CIMMYT ZIMBABWE	82	T399-175	TH15357	CIMMYT ZIMBABWE
3	T399-172	TH15344	CIMMYT ZIMBABWE	83	T399-94	TH15321	CIMMYT ZIMBABWE
4	T399-112	TH15332	CIMMYT ZIMBABWE	84	T399-136	TH15269	CIMMYT ZIMBABWE
5	T399-198	TH15328	CIMMYT ZIMBABWE	85	T399-93	TH15320	CIMMYT ZIMBABWE
6	T399-132	TH15344	CIMMYT ZIMBABWE	86	T399-133	TH142616	CIMMYT ZIMBABWE
7	T399-33	TH15278	CIMMYT ZIMBABWE	87	T344-22	TH125324	CIMMYT ZIMBABWE
8	T399-23	TH15270	CIMMYT ZIMBABWE	88	T399-53	TH15295	CIMMYT ZIMBABWE
9	T399-134	TH15345	CIMMYT ZIMBABWE	89	T399-170	TH15326	CIMMYT ZIMBABWE
10	T399-109	TH15329	CIMMYT ZIMBABWE	90	T399-129	TH15323	CIMMYT ZIMBABWE
11	T399-179	TH15283	CIMMYT ZIMBABWE	91	T399-43	TH15285	CIMMYT ZIMBABWE
12	T399-62	TH15300	CIMMYT ZIMBABWE	92	T399-89	TH15317	CIMMYT ZIMBABWE
13	T399-51	TH15293	CIMMYT ZIMBABWE	93	T399-113	TH15333	CIMMYT ZIMBABWE
14	T399-31	TH15276	CIMMYT ZIMBABWE	94	T399-163	TH15258	CIMMYT ZIMBABWE
15	T399-52	TH15294	CIMMYT ZIMBABWE	95	T399-165	TH15282	CIMMYT ZIMBABWE
16	T399-194	TH15295	CIMMYT ZIMBABWE	96	T399-414, T399-421, T399-462		CIMMYT ZIMBABWE
17	T399-48	TH15290	CIMMYT ZIMBABWE	97	T399-185	TH15340	CIMMYT ZIMBABWE
18	T399-46	TH15288	CIMMYT ZIMBABWE	98	T399-144	TH15343	CIMMYT ZIMBABWE
19	T399-126	TH15300	CIMMYT ZIMBABWE	99	T399-24	TH15271	CIMMYT ZIMBABWE
20	T399-18	TH15265	CIMMYT ZIMBABWE	100	T399-171	TH15339	CIMMYT ZIMBABWE
21	T399-90	TH141453	CIMMYT ZIMBABWE	101	T399-96	TH15266	CIMMYT ZIMBABWE
22	T399-92	TH15319	CIMMYT ZIMBABWE	102	T399-178	TH15271	CIMMYT ZIMBABWE
23	T399-60	TH15298	CIMMYT ZIMBABWE	103	T399-83	TH15265	CIMMYT ZIMBABWE
24	T399-102	TH15322	CIMMYT ZIMBABWE	104	T399-203	TH15358	CIMMYT ZIMBABWE
25	T399-41	TH15262	CIMMYT ZIMBABWE	105	T399-22	TH15269	CIMMYT ZIMBABWE
26	T399-99	TH15298	CIMMYT ZIMBABWE	106	T399-103	TH15323	CIMMYT ZIMBABWE
27	T399-56	TH15274	CIMMYT ZIMBABWE	107	T399-120	TH15340	CIMMYT ZIMBABWE
28	T399-189	TH15357	CIMMYT ZIMBABWE	108	T399-107	TH15327	CIMMYT ZIMBABWE
29	T399-164	TH15270	CIMMYT ZIMBABWE	109	T399-39	TH15284	CIMMYT ZIMBABWE
30	T399-169	TH15319	CIMMYT ZIMBABWE	110	T399-131	TH15343	CIMMYT ZIMBABWE
31	T399-88	TH15316	CIMMYT ZIMBABWE	111	T399-45	TH15287	CIMMYT ZIMBABWE
32	T341-50	TH14399	CIMMYT ZIMBABWE	112	T399-104	TH15324	CIMMYT ZIMBABWE
33	T399-28	TH15273	CIMMYT ZIMBABWE	113	T399-91	TH15318	CIMMYT ZIMBABWE
34	T399-117	TH15337	CIMMYT ZIMBABWE	114	T399-122	TH15256	CIMMYT ZIMBABWE
35	T399-101	TH15316	CIMMYT ZIMBABWE	115	T399-147	TH15348	CIMMYT ZIMBABWE
36	T399-95	TH15254	CIMMYT ZIMBABWE	116	T399-143	TH15337	CIMMYT ZIMBABWE
37	T399-82	TH15253	CIMMYT ZIMBABWE	117	T399-9	TH15257	CIMMYT ZIMBABWE
38	T399-59	TH15297	CIMMYT ZIMBABWE	118	T399-32	TH15277	CIMMYT ZIMBABWE
39	T399-139	TH15301	CIMMYT ZIMBABWE	119	T399-3	TH15251	CIMMYT ZIMBABWE
40	T399-128	TH141453	CIMMYT ZIMBABWE	120	T399-184	TH15327	CIMMYT ZIMBABWE
41	T399-85	TH15287	CIMMYT ZIMBABWE	121	T399-47	TH15289	CIMMYT ZIMBABWE
42	T399-111	TH15331	CIMMYT ZIMBABWE	122	T399-13	TH15249	CIMMYT ZIMBABWE
43	T399-108	TH15328	CIMMYT ZIMBABWE	123	T399-8	TH15256	CIMMYT ZIMBABWE
44	T399-15	TH15262	CIMMYT ZIMBABWE	124	T399-20	TH15267	CIMMYT ZIMBABWE
45	T399-19	TH15266	CIMMYT ZIMBABWE	125	T399-146	TH15347	CIMMYT ZIMBABWE

46	T399-137	TH15280	CIMMYT ZIMBABWE	126	T388-9		CIMMYT ZIMBABWE
47	T399-135	TH15257	CIMMYT ZIMBABWE	127	T399-110	TH15330	CIMMYT ZIMBABWE
48	T399-119	TH15339	CIMMYT ZIMBABWE	128	T399-192	TH15272	CIMMYT ZIMBABWE
49	T399-57	TH15285	CIMMYT ZIMBABWE	129	T399-125	TH15290	CIMMYT ZIMBABWE
50	T399-177	TH15259	CIMMYT ZIMBABWE	130	T399-35	TH15280	CIMMYT ZIMBABWE
51	T399-25	TH15272	CIMMYT ZIMBABWE	131	T399-27	TH15261	CIMMYT ZIMBABWE
52	T399-34	TH15279	CIMMYT ZIMBABWE	132	T399-65	TH15303	CIMMYT ZIMBABWE
53	T399-5	TH15253	CIMMYT ZIMBABWE	133	T399-2	TH15250	CIMMYT ZIMBABWE
54	T399-10	TH15258	CIMMYT ZIMBABWE	134	T399-84	TH15276	CIMMYT ZIMBABWE
55	T399-141	TH15318	CIMMYT ZIMBABWE	135	T399-190	TH15359	CIMMYT ZIMBABWE
56	T399-49	TH15291	CIMMYT ZIMBABWE	136	T399-98	TH15288	CIMMYT ZIMBABWE
57	T399-37	TH15282	CIMMYT ZIMBABWE	137	T399-187	TH15348	CIMMYT ZIMBABWE
58	T399-1	TH15249	CIMMYT ZIMBABWE	138	T399-123	TH15268	CIMMYT ZIMBABWE
59	T399-42	TH15273	CIMMYT ZIMBABWE	139	T399-55	TH15263	CIMMYT ZIMBABWE
60	T399-7	TH15255	CIMMYT ZIMBABWE	140	T399-204	TH15359	CIMMYT ZIMBABWE
61	T399-166	TH15293	CIMMYT ZIMBABWE	141	T399-6	TH15254	CIMMYT ZIMBABWE
62	T399-148	TH15349	CIMMYT ZIMBABWE	142	T399-14	TH15261	CIMMYT ZIMBABWE
63	T399-29	TH15274	CIMMYT ZIMBABWE	143	T399-183	TH15320	CIMMYT ZIMBABWE
64	T399-195	TH15305	CIMMYT ZIMBABWE	144	T399-67	TH15305	CIMMYT ZIMBABWE
65	T399-142	TH15324	CIMMYT ZIMBABWE	145	T399-186	TH142616	CIMMYT ZIMBABWE
66	T399-61	TH15299	CIMMYT ZIMBABWE	146	T399-12	TH15260	CIMMYT ZIMBABWE
67	T399-199	TH15341	CIMMYT ZIMBABWE	147	T399-97	TH15277	CIMMYT ZIMBABWE
68	T399-106	TH15326	CIMMYT ZIMBABWE	148	T399-4	TH15252	CIMMYT ZIMBABWE
69	T399-38	TH15283	CIMMYT ZIMBABWE	149	T341-123	VH051340	CIMMYT ZIMBABWE
70	T399-176	TH15358	CIMMYT ZIMBABWE	150	T399-21	TH15268	CIMMYT ZIMBABWE
71	T399-66	TH15304	CIMMYT ZIMBABWE	151	T399-180	TH15294	CIMMYT ZIMBABWE
72	T399-167	TH15303	CIMMYT ZIMBABWE	152	T399-121	TH15341	CIMMYT ZIMBABWE
73	T399-11	TH15259	CIMMYT ZIMBABWE	153	T399-181	TH15304	CIMMYT ZIMBABWE
74	T399-197	TH15321	CIMMYT ZIMBABWE	154	T399-138	TH15291	CIMMYT ZIMBABWE
75	T399-54	TH15252	CIMMYT ZIMBABWE	155	T399-63	TH15301	CIMMYT ZIMBABWE
76	T399-191	TH15260	CIMMYT ZIMBABWE	156	T399-16	TH15263	CIMMYT ZIMBABWE
77	T399-115	TH15335	CIMMYT ZIMBABWE	157	T399-26	TH15250	CIMMYT ZIMBABWE
78	T399-40	TH15251	CIMMYT ZIMBABWE	158	T399-116	TH15336	CIMMYT ZIMBABWE
79	T399-173	TH15347	CIMMYT ZIMBABWE	159	T399-86	TH15297	CIMMYT ZIMBABWE
80	T399-193	TH15284	CIMMYT ZIMBABWE	160	T399-200	TH15345	CIMMYT ZIMBABWE

Appendix 3. 2: List of materials for heterotic group B

S/N	Stock ID	Name	Source	SN	Stock ID	Name	Source
1	T399-281	TH15421	CIMMYT ZIMBABWE	81	T399-363	TH15424	CIMMYT ZIMBABWE
2	T399-259	TH15408	CIMMYT ZIMBABWE	82	T399-324	TH15441	CIMMYT ZIMBABWE
3	T399-343	TH15451	CIMMYT ZIMBABWE	83	T399-305	TH15401	CIMMYT ZIMBABWE
4	T399-223	TH15377	CIMMYT ZIMBABWE	84	T399-242	TH15394	CIMMYT ZIMBABWE
5	T399-408	TH15446	CIMMYT ZIMBABWE	85	T399-332	TH15392	CIMMYT ZIMBABWE
6	T399-381	TH15449	CIMMYT ZIMBABWE	86	T399-224	TH15378	CIMMYT ZIMBABWE
7	T399-371	TH15459	CIMMYT ZIMBABWE	87	T399-373	TH15383	CIMMYT ZIMBABWE
8	T399-326	TH15443	CIMMYT ZIMBABWE	88	T336-68	VH051355	CIMMYT ZIMBABWE
9	T399-369	TH15457	CIMMYT ZIMBABWE	89	T399-367	TH15448	CIMMYT ZIMBABWE
10	T399-319	TH15402	CIMMYT ZIMBABWE	90	T399-254	TH15403	CIMMYT ZIMBABWE
11	T399-407	TH15440	CIMMYT ZIMBABWE	91	T399-296	TH15430	CIMMYT ZIMBABWE
12	T399-231	TH15385	CIMMYT ZIMBABWE	92	T399-399	TH15462	CIMMYT ZIMBABWE
13	T399-244	TH15396	CIMMYT ZIMBABWE	93	T399-379	TH142182	CIMMYT ZIMBABWE
14	T399-384	TH15460	CIMMYT ZIMBABWE	94	T399-233	TH15373	CIMMYT ZIMBABWE
15	T399-255	TH15404	CIMMYT ZIMBABWE	95	T399-248	TH15386	CIMMYT ZIMBABWE
16	T399-368	TH15453	CIMMYT ZIMBABWE	96	T399-391	TH15426	CIMMYT ZIMBABWE
17	T399-366	TH15443	CIMMYT ZIMBABWE	97	T399-251	TH15400	CIMMYT ZIMBABWE
18	T399-411	TH15459	CIMMYT ZIMBABWE	98	T399-311	TH15438	CIMMYT ZIMBABWE
19	T399-397	TH15458	CIMMYT ZIMBABWE	99	T399-314	TH15439	CIMMYT ZIMBABWE
20	T399-357	TH15456	CIMMYT ZIMBABWE	100	T399-374	TH15395	CIMMYT ZIMBABWE
21	T399-382	TH15454	CIMMYT ZIMBABWE	101	T399-318	TH15391	CIMMYT ZIMBABWE
22	T399-323	TH15436	CIMMYT ZIMBABWE	102	T399-226	TH15380	CIMMYT ZIMBABWE
23	T399-315	TH15440	CIMMYT ZIMBABWE	103	T399-239	TH15391	CIMMYT ZIMBABWE
24	T399-317	TH15379	CIMMYT ZIMBABWE	104	T344-49	TH14544	CIMMYT ZIMBABWE
25	T399-398	TH15460	CIMMYT ZIMBABWE	105	T399-256	TH15405	CIMMYT ZIMBABWE
26	T399-370	TH15458	CIMMYT ZIMBABWE	106	T399-247	TH15374	CIMMYT ZIMBABWE
27	T399-309	TH15436	CIMMYT ZIMBABWE	107	T399-297	TH15431	CIMMYT ZIMBABWE
28	T399-303	TH15378	CIMMYT ZIMBABWE	108	T399-360	TH15394	CIMMYT ZIMBABWE
29	T399-283	TH15423	CIMMYT ZIMBABWE	109	T399-250	TH15399	CIMMYT ZIMBABWE
30	T399-229	TH15383	CIMMYT ZIMBABWE	110	T399-392	TH15434	CIMMYT ZIMBABWE
31	T399-289	TH15377	CIMMYT ZIMBABWE	111	T399-394	TH15445	CIMMYT ZIMBABWE
32	T399-377	TH15425	CIMMYT ZIMBABWE	112	T399-361	TH15405	CIMMYT ZIMBABWE
33	T399-410	TH15456	CIMMYT ZIMBABWE	113	T399-409	TH15451	CIMMYT ZIMBABWE
34	T399-396	TH15455	CIMMYT ZIMBABWE	114	T399-387	TH15384	CIMMYT ZIMBABWE
35	T399-359	TH15382	CIMMYT ZIMBABWE	115	T399-312	TH142180	CIMMYT ZIMBABWE
36	T399-222	TH15376	CIMMYT ZIMBABWE	116	T399-328	TH15445	CIMMYT ZIMBABWE
37	T399-279	TH15419	CIMMYT ZIMBABWE	117	T399-412	TH15461	CIMMYT ZIMBABWE
38	T399-308	TH15428	CIMMYT ZIMBABWE	118	T399-225	TH15379	CIMMYT ZIMBABWE
39	T399-336	TH15430	CIMMYT ZIMBABWE	119	T399-340	TH15448	CIMMYT ZIMBABWE
40	T399-389	TH15407	CIMMYT ZIMBABWE	120	T399-275	TH15376	CIMMYT ZIMBABWE
41	T399-257	TH15406	CIMMYT ZIMBABWE	121	T399-325	TH15442	CIMMYT ZIMBABWE
42	T399-346	TH15393	CIMMYT ZIMBABWE	122	T399-227	TH15381	CIMMYT ZIMBABWE
43	T399-393	TH15439	CIMMYT ZIMBABWE	123	T399-240	TH15392	CIMMYT ZIMBABWE
44	T399-219	TH15373	CIMMYT ZIMBABWE	124	T399-284	TH15424	CIMMYT ZIMBABWE
45	T399-402	TH15397	CIMMYT ZIMBABWE	125	T399-280	TH15420	CIMMYT ZIMBABWE

46	T399-298	TH15432	CIMMYT ZIMBABWE
47	T399-378	TH15433	CIMMYT ZIMBABWE
48	T399-282	TH15422	CIMMYT ZIMBABWE
49	T399-243	TH15395	CIMMYT ZIMBABWE
50	T399-327	TH15444	CIMMYT ZIMBABWE
51	T399-364	TH15432	CIMMYT ZIMBABWE
52	T399-277	TH15399	CIMMYT ZIMBABWE
53	T399-310	TH15437	CIMMYT ZIMBABWE
54	T399-253	TH15402	CIMMYT ZIMBABWE
55	T399-295	TH15429	CIMMYT ZIMBABWE
56	T399-321	TH15421	CIMMYT ZIMBABWE
57	T399-293	TH15419	CIMMYT ZIMBABWE
58	T399-304	TH15390	CIMMYT ZIMBABWE
59	T399-331	TH15380	CIMMYT ZIMBABWE
60	T399-347	TH15404	CIMMYT ZIMBABWE
61	T344-211	VH053980	CIMMYT ZIMBABWE
62	T399-286	TH15426	CIMMYT ZIMBABWE
63	T399-322	TH15429	CIMMYT ZIMBABWE
64	T399-287	TH15427	CIMMYT ZIMBABWE
65	T399-241	TH15393	CIMMYT ZIMBABWE
66	T399-234	TH15386	CIMMYT ZIMBABWE
67	T399-338	TH15441	CIMMYT ZIMBABWE
68	T399-299	TH15433	CIMMYT ZIMBABWE
69	T399-403	TH15408	CIMMYT ZIMBABWE
70	T399-301	TH15435	CIMMYT ZIMBABWE
71	T399-351	TH15438	CIMMYT ZIMBABWE
72	T399-385	TH15461	CIMMYT ZIMBABWE
73	T399-337	TH15437	CIMMYT ZIMBABWE
74	T399-354	TH15453	CIMMYT ZIMBABWE
75	T399-252	TH15401	CIMMYT ZIMBABWE
76	T399-341	TH15449	CIMMYT ZIMBABWE
77	T399-300	TH15434	CIMMYT ZIMBABWE
78	T399-349	TH15423	CIMMYT ZIMBABWE
79	T399-237	TH15389	CIMMYT ZIMBABWE
80	T399-291	TH15400	CIMMYT ZIMBABWE
126	T399-335	TH15422	CIMMYT ZIMBABWE
127	T399-276	TH15388	CIMMYT ZIMBABWE
128	T399-356	TH15455	CIMMYT ZIMBABWE
129	T399-413	TH15462	CIMMYT ZIMBABWE
130	T399-333	TH15403	CIMMYT ZIMBABWE
131	T399-313	TH142182	CIMMYT ZIMBABWE
132	T344-208	TH1497	CIMMYT ZIMBABWE
133	T399-329	TH15446	CIMMYT ZIMBABWE
134	T399-294	TH15428	CIMMYT ZIMBABWE
135	T399-383	TH15457	CIMMYT ZIMBABWE
136	T399-258	TH15407	CIMMYT ZIMBABWE
137	T399-285	TH15425	CIMMYT ZIMBABWE
138	T399-228	TH15382	CIMMYT ZIMBABWE
139	T399-395	TH15450	CIMMYT ZIMBABWE
140	T399-406	TH15435	CIMMYT ZIMBABWE
141	T399-238	TH15390	CIMMYT ZIMBABWE
142	T399-220	TH15374	CIMMYT ZIMBABWE
143	T399-342	TH15450	CIMMYT ZIMBABWE
144	T399-307	TH15420	CIMMYT ZIMBABWE
145	T399-339	TH15447	CIMMYT ZIMBABWE
146	T399-290	TH15389	CIMMYT ZIMBABWE
147	T399-388	TH15396	CIMMYT ZIMBABWE
148	T399-236	TH15388	CIMMYT ZIMBABWE
149	T399-353	TH15447	CIMMYT ZIMBABWE
150	T399-365	TH142180	CIMMYT ZIMBABWE
151	T399-245	TH15397	CIMMYT ZIMBABWE
152	T399-405	TH15427	CIMMYT ZIMBABWE
153	T399-401	TH15385	CIMMYT ZIMBABWE
154	T399-355	TH15454	CIMMYT ZIMBABWE
155	T399-380	TH15444	CIMMYT ZIMBABWE
156	T399-230	TH15384	CIMMYT ZIMBABWE
157	T399-375	TH15406	CIMMYT ZIMBABWE
158	T399-352	TH15442	CIMMYT ZIMBABWE
159	T399-345	TH15381	CIMMYT ZIMBABWE
160	T399-350	TH15431	CIMMYT ZIMBABWE

Appendix 4.1: Mean yield and other agronomic traits for single-cross hybrids from heterotic group B under Low N, Random drought and Optimum environments

	Yield				AD			SD			ASI			PH			EH			EP		
1	2.6	2.7	5.7	1.8	119	92	79	120	93	78	1	1	0	175	111	146	97	59	86	0.5	0.5	0.6
2	2.3	2.4	4.5	1.2	119	84	85	122	85	88	2	0	2	115	142	118	60	86	66	0.5	0.6	0.6
3	2.7	2.2	5.5	1.8	113	94	80	115	96	79	2	2	-1	169	91	132	88	51	74	0.5	0.6	0.6
4	3.1	5.2	8.2	2.6	112	85	73	114	86	74	2	0	0	137	140	179	68	84	104	0.4	0.6	0.6
5	2.2	3.4	5.9	1.9	120	82	81	123	82	80	2	0	1	141	130	146	62	78	88	0.4	0.6	0.6
6	2.9	2.9	5.6	1.6	116	85	76	119	86	76	3	1	0	140	139	165	64	81	111	0.4	0.6	0.7
7	3.0	4.2	5.5	1.3	114	82	77	116	81	78	2	-1	0	130	173	169	62	106	94	0.4	0.6	0.6
8	2.7	2.1	6.4	2.3	116	94	78	118	97	79	3	3	-1	132	136	190	65	83	99	0.5	0.6	0.5
9	3.3	5.0	6.1	1.4	117	84	77	119	84	76	1	0	0	158	173	193	87	102	117	0.5	0.6	0.6
10	3.3	4.5	7.5	2.2	115	82	78	117	82	78	4	0	0	167	136	209	95	75	119	0.5	0.6	0.6
11	2.3	4.4	5.4	1.6	116	85	80	118	85	80	2	0	2	150	133	145	72	74	79	0.5	0.5	0.5
12	3.3	3.3	6.0	1.6	120	89	82	120	91	84	-1	2	1	151	154	163	75	90	100	0.5	0.6	0.6
13	2.3	4.2	6.5	2.1	120	85	78	121	85	78	1	0	0	117	170	153	62	99	91	0.5	0.6	0.6
14	2.4	4.0	4.9	1.3	121	86	77	122	86	77	3	0	1	160	140	108	86	79	61	0.5	0.6	0.6
15	2.2	2.9	4.5	1.2	118	87	82	120	95	85	3	8	1	159	144	148	84	86	79	0.5	0.6	0.5
16	2.4	2.8	4.9	1.3	116	84	79	118	83	79	2	-1	1	131	161	137	68	90	82	0.5	0.6	0.6
17	2.3	4.3	5.0	1.4	121	88	83	122	88	83	2	-1	2	142	124	163	79	91	95	0.5	0.8	0.6
18	2.5	3.0	5.1	1.3	119	83	79	121	86	77	2	3	1	136	138	146	62	87	88	0.4	0.6	0.6
19	2.4	3.5	5.9	1.8	119	92	81	121	93	81	1	1	2	153	139	144	65	82	80	0.4	0.6	0.6
20	3.0	3.8	8.7	3.0	117	86	79	119	88	80	2	1	0	154	167	171	84	94	102	0.5	0.6	0.6
21	3.6	3.3	5.1	1.0	120	87	84	121	91	85	-1	4	2	197	133	145	108	80	92	0.5	0.6	0.6
22	3.7	2.0	6.6	2.3	117	93	77	118	98	77	1	5	1	183	124	202	107	70	129	0.6	0.5	0.6
23	2.8	3.4	6.3	1.8	117	86	79	118	89	80	0	2	1	139	146	176	73	87	108	0.5	0.6	0.6
24	3.1	5.3	6.2	1.6	122	89	82	123	92	83	1	3	2	147	120	157	77	74	96	0.5	0.6	0.6
25	2.2	3.6	5.8	1.8	117	88	78	119	90	78	2	1	-1	161	130	160	86	67	90	0.5	0.5	0.6
26	2.2	4.2	4.8	1.4	123	83	85	124	82	87	1	-1	4	121	117	125	47	67	76	0.4	0.6	0.6
27	2.7	4.4	5.4	1.4	120	87	78	122	92	78	3	4	0	137	125	155	68	77	87	0.5	0.6	0.6
28	3.1	2.9	7.8	2.7	114	84	77	116	84	76	2	0	0	159	155	170	84	93	103	0.5	0.6	0.6
29	2.3	4.1	6.1	1.9	121	99	81	124	100	80	2	3	3	152	113	159	71	71	82	0.5	0.6	0.5
30	3.3	4.6	4.8	0.8	115	85	90	117	85	45	2	0	-1	162	146	127	78	92	66	0.5	0.6	0.5
31	2.7	6.4	7.3	2.5	117	88	75	120	88	75	3	0	1	160	152	170	83	84	104	0.5	0.6	0.6
32	2.6	5.3	6.8	2.1	119	87	77	121	89	77	3	2	1	153	126	177	83	75	105	0.5	0.6	0.6
33	3.5	6.0	7.1	1.9	117	83	79	118	83	78	1	0	1	178	149	184	88	93	117	0.4	0.6	0.6
34	4.4	5.2	5.8	0.7	115	90	80	119	91	81	2	0	2	188	115	154	110	77	98	0.6	0.7	0.6
35	2.6	5.1	6.9	2.2	121	85	76	124	84	76	1	-1	1	167	155	189	84	85	118	0.5	0.5	0.6
36	3.0	5.2	6.9	1.9	116	83	76	118	83	77	0	0	1	133	134	168	68	70	107	0.5	0.5	0.6
37	2.3	5.1	6.0	2.0	116	92	79	119	97	78	2	5	-1	130	142	142	64	88	75	0.5	0.6	0.5
38	2.2	4.9	5.6	1.8	122	85	80	125	88	81	2	3	1	111	117	158	51	87	85	0.5	0.7	0.5
39	2.2	5.3	5.5	1.9	117	88	80	120	88	80	3	0	1	147	146	141	76	89	83	0.5	0.6	0.6
40	3.7	5.4	8.5	2.5	116	84	79	115	86	81	-3	2	0	183	172	181	88	100	87	0.5	0.6	0.5
41	2.2	5.2	6.4	2.2	120	86	80	124	88	80	0	2	-1	123	139	172	64	79	98	0.5	0.6	0.6
42	2.5	4.2	6.3	1.9	115	90	76	117	92	76	1	2	-1	165	119	155	63	69	91	0.4	0.6	0.6
43	2.4	5.3	5.8	1.9	115	82	79	119	83	79	1	1	1	188	148	160	105	92	83	0.5	0.6	0.5

	Yield				AD			SD			ASI			PH			EH			EP		
44	2.5	6.2	6.4	2.2	120	83	78	123	82	79	2	-1	1	146	158	176	66	110	96	0.4	0.7	0.5
45	3.4	3.8	8.0	2.6	117	87	76	118	91	76	1	3	0	181	134	211	87	76	126	0.5	0.6	0.6
46	3.0	5.0	7.1	2.1	117	85	79	118	90	79	1	5	-1	169	155	183	81	90	104	0.5	0.6	0.6
47	2.6	4.8	7.5	2.5	117	84	77	119	85	76	1	1	2	141	155	188	74	97	105	0.5	0.6	0.6
48	3.2	4.1	7.2	2.1	121	86	79	122	89	79	1	2	1	151	124	176	70	81	101	0.5	0.7	0.6
49	3.0	4.4	7.2	2.1	113	91	73	115	91	74	2	0	0	138	141	170	63	83	93	0.4	0.6	0.5
50	2.8	4.7	7.1	2.1	116	89	78	119	91	78	2	2	1	152	133	152	60	82	94	0.4	0.6	0.6
51	3.2	4.8	7.5	2.2	115	90	72	117	93	72	2	3	1	147	132	159	78	74	100	0.5	0.6	0.6
52	3.3	5.0	5.6	1.2	117	86	81	115	86	85	-2	-1	-1	137	146	138	68	86	71	0.5	0.6	0.5
53	2.7	5.9	6.5	2.0	119	89	77	120	88	78	2	-1	2	153	134	171	78	70	105	0.5	0.5	0.6
54	3.9	5.5	6.5	1.3	112	87	76	114	90	75	-1	3	1	151	128	154	87	72	86	0.6	0.6	0.6
55	3.5	5.1	7.4	2.0	114	83	72	117	85	72	3	2	0	148	140	182	69	83	107	0.5	0.6	0.6
56	3.1	4.0	7.3	2.2	115	85	79	116	85	79	1	0	1	159	127	156	79	80	84	0.5	0.6	0.5
57	3.4	5.1	5.9	1.3	115	90	78	116	91	78	0	1	0	174	142	161	86	79	92	0.5	0.6	0.6
58	4.0	5.8	7.4	1.7	115	81	74	118	81	74	2	0	1	165	169	174	93	95	104	0.5	0.6	0.6
59	3.3	4.0	6.0	1.4	112	92	78	114	94	79	2	2	3	161	131	158	89	82	94	0.5	0.6	0.6
60	4.1	5.8	5.5	0.9	116	85	80	118	86	81	1	1	1	160	152	123	87	88	88	0.5	0.6	0.8
61	2.4	5.4	5.2	1.7	118	90	88	120	92	40	2	2	-1	125	126	126	56	79	65	0.4	0.6	0.5
62	2.2	3.8	6.3	2.1	118	87	84	123	86	83	3	-1	1	159	116	136	79	66	100	0.4	0.6	0.8
63	2.3	5.7	5.2	1.8	121	83	80	118	83	80	-2	0	1	161	130	140	85	84	81	0.5	0.7	0.6
64	2.0	3.7	6.3	2.2	120	85	0	118	86	0	2	0	-1	133	111	**	66	57	***	0.5	0.5	**
65	3.3	6.3	7.2	2.0	118	82	78	120	83	78	1	1	1	182	155	172	100	95	102	0.6	0.6	0.6
66	2.5	5.0	4.6	1.4	121	88	82	121	92	82	-1	3	1	141	144	153	75	88	90	0.5	0.6	0.6
67	3.0	5.3	6.0	1.6	119	88	83	120	89	83	2	1	0	156	154	150	83	84	87	0.5	0.5	0.6
68	2.3	5.6	7.3	2.5	119	91	79	124	93	80	2	2	3	142	140	185	73	92	104	0.5	0.7	0.6
69	3.9	6.1	8.0	2.0	119	86	82	120	86	83	1	0	0	189	158	189	99	86	117	0.5	0.5	0.6
70	2.8	5.5	6.0	1.7	119	91	76	122	91	76	2	0	1	157	108	221	79	58	138	0.5	0.5	0.6
71	2.4	5.1	6.5	2.1	123	85	78	125	87	78	-1	2	8	133	139	169	68	80	103	0.5	0.6	0.6
72	3.0	3.3	5.5	1.4	119	86	82	120	89	82	1	2	2	172	133	189	97	91	110	0.5	0.7	0.6
73	2.9	5.5	5.7	1.6	114	85	80	115	85	79	2	0	-1	137	154	140	71	95	82	0.5	0.6	0.6
74	2.3	4.5	6.5	2.1	116	91	79	118	91	78	2	0	0	148	110	160	65	60	93	0.4	0.5	0.6
75	3.1	4.9	5.7	1.3	117	83	81	119	83	81	2	0	1	152	129	160	86	69	94	0.5	0.5	0.6
76	3.1	4.6	5.5	1.2	119	90	77	120	88	76	-3	-2	2	136	134	156	60	82	98	0.4	0.6	0.6
77	3.5	4.8	5.6	1.1	115	87	78	116	89	77	1	2	-1	135	154	164	66	96	94	0.5	0.6	0.6
78	2.2	4.8	5.0	1.6	120	81	83	122	83	83	3	1	1	157	122	148	84	73	92	0.5	0.6	0.6
79	2.7	4.7	6.1	1.7	115	86	78	117	89	78	2	3	1	167	153	158	86	90	89	0.5	0.6	0.6
80	3.1	5.5	7.1	2.0	115	82	78	117	81	78	2	-1	1	154	143	178	77	91	100	0.5	0.6	0.6
81	4.5	5.6	6.2	0.8	114	85	77	115	85	75	-3	-2	-1	167	154	190	81	98	118	0.5	0.6	0.6
82	4.2	4.7	7.3	1.7	113	83	77	114	86	76	2	2	1	167	127	181	86	78	114	0.6	0.6	0.6
83	3.2	4.8	6.6	1.7	115	88	74	117	88	73	2	0	0	150	128	175	80	81	112	0.5	0.6	0.6
84	4.1	5.1	6.1	1.0	116	81	80	116	81	80	-3	0	2	148	159	132	80	94	92	0.5	0.6	0.7
85	2.9	4.0	5.6	1.4	116	92	76	118	94	76	2	2	-1	141	111	138	70	67	87	0.5	0.6	0.6
86	2.5	4.6	6.6	2.1	118	88	82	120	85	80	1	-3	2	132	103	156	57	56	87	0.5	0.5	0.6
87	2.4	5.7	6.8	2.3	121	85	80	121	84	80	1	-1	1	128	140	141	66	88	82	0.5	0.6	0.6
88	2.7	5.2	5.9	1.7	117	88	77	119	88	76	3	-1	0	137	133	181	72	90	94	0.5	0.7	0.5
89	4.5	4.5	7.1	1.5	112	84	75	113	86	75	2	1	0	143	144	160	81	87	100	0.5	0.6	0.6
90	2.4	5.9	7.5	2.6	119	83	79	119	84	79	0	1	2	136	154	183	50	88	109	0.4	0.6	0.6

	Yield				AD			SD			ASI			PH			EH			EP		
91	3.0	4.7	7.2	2.1	114	89	78	116	89	77	3	0	0	140	119	162	80	74	87	0.6	0.6	0.5
92	2.8	7.5	7.8	2.8	116	84	79	122	81	80	2	-3	-1	142	160	180	71	91	95	0.5	0.6	0.5
93	3.8	4.9	6.7	1.5	116	84	77	115	84	75	-3	-1	0	148	131	184	70	80	102	0.5	0.6	0.5
94	2.1	4.6	5.8	1.9	115	85	73	117	84	73	2	-1	0	177	139	200	95	93	130	0.6	0.7	0.7
95	3.1	5.6	5.8	1.5	115	80	80	117	81	78	3	1	2	134	160	162	61	95	91	0.5	0.6	0.6
96	3.5	5.2	6.3	1.4	117	87	76	119	89	77	2	2	-1	149	134	167	77	81	102	0.5	0.6	0.6
97	2.4	6.8	7.7	2.8	118	84	78	120	84	82	1	-1	1	138	184	170	61	110	87	0.5	0.6	0.5
98	3.2	4.9	5.9	1.4	117	85	80	119	87	80	3	2	3	195	151	160	124	95	95	0.6	0.6	0.6
99	2.8	5.9	6.7	2.1	121	90	79	122	94	79	2	3	-1	153	158	181	70	96	105	0.3	0.6	0.6
100	2.6	5.7	6.8	2.1	116	86	80	119	87	80	3	1	1	164	133	162	89	69	78	0.6	0.5	0.5
101	3.5	5.6	6.2	1.4	114	88	76	116	88	76	1	-1	3	142	145	176	77	74	103	0.5	0.5	0.6
102	2.2	6.3	7.9	3.0	120	85	86	121	85	86	2	0	1	132	155	192	67	99	102	0.5	0.6	0.8
103	2.8	5.5	6.0	1.7	115	85	77	120	86	76	3	1	1	127	120	174	50	82	99	0.4	0.7	0.6
104	2.9	6.1	6.8	2.1	120	90	80	121	86	80	1	3	2	128	149	166	48	81	99	0.4	0.5	0.6
105	3.9	3.5	6.6	1.7	117	80	81	119	81	85	2	1	1	166	147	166	85	94	99	0.5	0.6	0.6
106	3.5	4.2	6.4	1.5	117	85	77	119	87	77	1	2	1	122	137	201	50	85	122	0.4	0.6	0.6
107	2.8	5.5	6.1	1.7	122	82	78	123	82	79	2	0	2	135	136	169	67	74	94	0.5	0.5	0.6
108	3.1	4.6	7.1	2.0	118	85	78	120	87	80	-1	2	0	154	133	184	98	79	118	0.6	0.6	0.6
109	4.8	4.7	6.0	0.7	112	85	82	113	89	81	1	3	2	184	145	162	96	91	91	0.5	0.6	0.6
110	3.2	5.2	6.8	1.8	123	89	80	124	78	80	2	0	3	139	108	175	70	66	103	0.5	0.6	0.6
111	3.3	6.0	7.2	2.0	117	89	78	118	89	78	1	0	1	158	138	186	79	82	114	0.5	0.6	0.6
112	3.0	6.1	6.4	1.9	116	78	80	117	78	79	2	0	3	175	168	150	84	95	107	0.5	0.6	0.8
113	3.7	5.0	5.6	0.9	113	84	76	115	86	76	2	2	4	146	152	165	74	96	98	0.4	0.6	0.6
114	2.9	3.6	5.6	1.4	119	87	83	120	91	85	0	4	4	148	124	159	67	84	93	0.4	0.7	0.6
115	4.2	5.2	8.3	2.1	116	89	78	120	85	78	3	-4	4	156	140	192	71	89	105	0.5	0.6	0.6
116	3.2	4.3	6.0	1.4	119	83	79	121	86	78	2	2	3	159	137	182	69	85	108	0.5	0.6	0.6
117	4.1	5.4	7.7	1.8	117	82	84	119	82	88	1	-1	3	166	148	180	80	86	110	0.5	0.6	0.6
118	3.0	4.8	5.7	1.4	117	89	84	119	90	86	2	1	2	160	127	163	76	69	105	0.5	0.5	0.6
119	3.6	3.7	7.1	2.0	119	91	80	120	98	80	1	6	2	164	111	179	88	72	95	0.6	0.6	0.5
120	4.0	4.8	7.3	1.7	120	94	80	120	91	82	-1	1	-1	176	153	189	91	102	123	0.5	0.7	0.6
121	3.0	4.6	6.0	1.5	115	85	80	117	86	81	2	1	2	165	133	181	79	83	106	0.5	0.6	0.6
122	3.1	5.3	6.6	1.7	116	81	77	117	83	77	2	2	1	170	148	164	88	93	121	0.5	0.6	0.7
123	3.1	4.8	6.2	1.5	116	87	80	119	90	80	3	2	0	152	140	191	76	87	114	0.5	0.6	0.6
124	3.6	5.4	6.0	1.3	118	87	78	119	89	79	1	2	-1	184	133	189	106	76	116	0.5	0.6	0.6
125	3.7	5.0	6.6	1.4	113	84	77	114	86	77	1	2	0	143	159	158	79	90	93	0.5	0.6	0.6
126	3.0	6.0	6.6	1.9	119	80	81	121	81	82	2	0	1	187	141	178	95	82	106	0.5	0.6	0.6
127	3.6	5.9	7.9	2.2	115	80	83	117	80	84	2	0	-1	145	154	157	87	91	92	0.5	0.6	0.6
128	3.7	4.9	6.3	1.3	114	86	75	117	86	74	3	0	1	172	137	211	86	79	135	0.5	0.6	0.6
129	3.9	5.5	5.2	0.9	116	86	80	119	89	87	-1	3	3	166	139	169	90	81	108	0.5	0.6	0.6
130	2.7	3.9	6.0	1.7	119	90	85	119	93	91	3	3	-1	140	133	159	68	77	107	0.5	0.6	0.7
131	3.1	5.3	5.6	1.3	116	88	82	119	86	83	3	-2	1	169	139	183	78	77	109	0.5	0.6	0.6
132	3.7	6.2	6.3	1.5	116	83	80	118	84	81	3	0	2	167	151	175	100	92	116	0.5	0.6	0.7
133	2.9	4.7	6.6	1.9	118	87	74	124	87	73	-2	0	1	136	124	181	59	81	102	0.5	0.7	0.6
134	2.4	4.7	5.8	1.7	120	85	79	122	86	78	2	1	3	107	131	171	45	79	102	0.4	0.6	0.6
135	3.4	4.1	5.4	1.0	116	92	84	117	96	85	1	4	3	156	139	153	99	92	91	0.6	0.7	0.6
136	3.2	6.0	7.7	2.3	113	85	78	115	87	80	2	1	-3	150	148	173	72	97	98	0.5	0.7	0.6
137	2.9	4.7	5.2	1.2	115	85	74	117	87	74	2	2	0	159	134	168	69	77	103	0.5	0.6	0.6

	Yield				AD			SD			ASI			PH			EH			EP		
138	3.3	2.9	6.9	2.2	118	87	39	120	92	39	2	5	1	156	112	160	84	65	88	0.5	0.6	0.6
139	2.9	6.5	7.0	2.2	117	81	74	119	81	74	3	0	5	137	147	169	68	88	103	0.5	0.6	0.6
140	3.1	4.5	5.5	1.2	119	89	77	119	90	77	-1	0	1	122	147	153	59	80	104	0.5	0.5	0.7
141	3.5	4.2	6.5	1.6	119	85	86	120	91	89	1	6	1	146	110	150	81	68	92	0.5	0.6	0.6
142	2.8	5.0	5.1	1.3	120	91	78	122	94	78	1	3	2	169	120	185	76	73	106	0.5	0.6	0.6
143	3.0	4.8	5.6	1.3	116	86	77	118	91	77	2	4	2	183	145	183	112	86	106	0.5	0.6	0.6
144	2.7	5.7	8.3	2.8	119	82	81	120	83	81	1	1	2	147	131	168	84	78	100	0.5	0.6	0.6
145	3.2	3.9	7.4	2.2	117	84	76	119	83	78	3	-1	-1	124	127	182	54	74	112	0.5	0.6	0.6
146	3.9	5.3	6.8	1.4	118	79	80	120	79	82	2	0	1	143	145	178	78	92	114	0.5	0.6	0.6
147	3.2	4.6	6.6	1.7	118	86	79	119	86	81	1	-1	1	166	135	157	89	88	98	0.5	0.6	0.6
148	2.8	4.7	7.3	2.3	118	83	81	120	85	83	2	1	-3	152	155	184	80	96	103	0.5	0.6	0.6
149	3.2	4.8	6.6	1.7	114	86	73	115	88	74	0	2	1	143	160	171	80	93	109	0.5	0.6	0.6
150	3.3	5.7	5.4	1.3	118	84	81	119	84	83	2	0	3	151	138	186	73	78	117	0.5	0.6	0.6
151	3.0	4.2	6.6	1.8	116	87	78	119	89	78	2	2	4	151	129	157	86	75	99	0.6	0.6	0.6
152	3.8	4.6	7.2	1.8	115	85	78	117	86	78	3	0	3	156	150	166	84	93	101	0.5	0.6	0.6
153	4.0	4.8	5.4	0.7	117	84	77	120	84	78	1	0	1	190	129	197	102	78	122	0.5	0.6	0.6
154	3.2	5.1	5.5	1.2	117	84	80	119	85	81	2	0	2	172	133	187	86	77	113	0.5	0.6	0.6
155	3.8	5.4	4.6	0.8	119	86	83	121	90	85	2	3	2	166	150	167	88	85	109	0.5	0.6	0.7
156	2.7	4.1	5.8	1.5	120	86	84	122	86	88	2	0	5	132	112	149	61	64	88	0.5	0.6	0.6
157	3.2	4.6	6.1	1.4	115	89	75	117	91	76	2	2	1	152	109	181	74	69	114	0.5	0.6	0.6
158	3.5	3.9	7.5	2.2	113	91	78	115	95	77	1	4	0	125	128	172	58	79	81	0.5	0.6	0.5
159	2.7	5.8	5.6	1.7	118	83	74	120	84	72	-3	1	3	154	154	192	75	88	124	0.5	0.6	0.6
160	3.0	4.8	6.2	1.6	118	87	73	119	90	72	2	3	0	154	134	201	75	81	117	0.5	0.6	0.6
#sites	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1.0	1.0	1.0
cv	24.9	16.9	17.0		2.1	5.3	7.2	2.1	6.1	11.7	15.4	176.5	7.2	3.5	16.0	13.0	7.2	16.9	13.1	10.4	9.9	10.1
lsd	1.0	1.6	2.1		4.9	9.1	11.2	5.0	10.6	18.1	0.4	4.8	11.2	10.6	44.1	43.1	11.1	27.9	25.7	0.1	0.1	0.1
Max	4.0	7.5	8.7		122.5	99.0	90.0	125.0	100.4	90.5	4.0	8.0	5.00	196.5	184.0	221.2	123.8	110.3	137.5	0.6	0.8	0.8
Min	1.2	2.0	4.0		111.5	78.0	39.0	113.0	77.6	39.0	-3.0	-3.5	-2.0	107.3	90.8	108.3	45.3	50.8	61.3	0.3	0.5	0.5
Grand mean	2.3	4.8	6.2		116.9	85.9	78.2	118.7	87.1	78.0	1.4	1.3	0.2	152.0	138.3	167.4	77.4	83.0	99.2	0.5	0.6	0.6
MSg	0.6	1.7	1.8		11.9	23.1	77.9	13.4	34.5	117.1	3.8	6.3	2.567	643.9	502.1	749.9	388.3	224.8	380.0	0.0	0.0	0.0
Mse	0.3	1.1	0.65		6.2	21.0	31.8	6.5	27.8	82.8	1.4	5.6	1.928	28.3	490.0	474.3	31.3	196.3	167.7	0.0	0.0	0.0
H (%)	47	48	50		32	12.19	42	34	10.74	17	44.8	5.72	42	91	1.22	23	85	6.77	39	17	6.14	16

Appendix 4.2: Continuation of Appendix 4.1 for traits NP, NE, FW, GW and SP

	Yield				NP			NE			FW			GW			SP		
1	2.6	2.7	5.7	1.8	14	14	17	13	8	16	1.0	1.4	3.0	0.7	1.1	2.3	0.7	0.8	0.8
2	2.3	2.4	4.5	1.2	15	14	13	14	11	12	1.0	1.8	2.4	0.7	1.2	1.8	0.7	0.7	0.8
3	2.7	2.2	5.5	1.8	13	16	14	11	8	15	1.1	1.2	3.0	0.8	0.9	2.2	0.7	0.8	0.7
4	3.1	5.2	8.2	2.6	16	16	17	13	16	17	1.4	2.9	4.1	1.0	2.2	3.2	0.7	0.7	0.8
5	2.2	3.4	5.9	1.9	13	14	10	8	12	9	0.8	1.8	3.1	0.6	1.4	2.4	0.7	0.8	0.8
6	2.9	2.9	5.6	1.6	15	16	15	11	13	15	1.1	1.6	3.0	0.8	1.2	2.3	0.8	0.8	0.8
7	3.0	4.2	5.5	1.3	16	17	17	14	16	15	1.1	2.2	3.2	0.9	1.7	2.3	0.8	0.8	0.7
8	2.7	2.1	6.4	2.3	16	16	14	11	4	14	1.2	1.3	3.3	0.8	0.9	2.6	0.7	0.7	0.8
9	3.3	5.0	6.1	1.4	15	17	16	16	14	16	1.5	2.7	4.4	1.0	2.0	2.8	0.7	0.8	0.6
10	3.3	4.5	7.5	2.2	11	14	17	12	11	15	1.3	2.3	3.8	1.0	1.8	3.0	0.7	0.8	0.8
11	2.3	4.4	5.4	1.6	13	11	14	10	12	10	1.0	2.1	2.8	0.7	1.7	2.1	0.7	0.8	0.8
12	3.3	3.3	6.0	1.6	16	16	14	14	12	11	1.2	1.7	2.9	1.0	1.3	2.3	0.8	0.8	0.8
13	2.3	4.2	6.5	2.1	13	13	15	9	12	14	0.9	2.5	3.3	0.6	1.8	2.6	0.8	0.7	0.8
14	2.4	4.0	4.9	1.3	12	15	13	10	13	7	0.9	2.3	2.5	0.7	1.7	1.9	0.7	0.7	0.8
15	2.2	2.9	4.5	1.2	15	16	10	12	9	6	0.8	1.6	2.4	0.6	1.2	1.8	0.7	0.7	0.7
16	2.4	2.8	4.9	1.3	12	16	10	5	10	6	0.9	2.0	2.4	0.7	1.3	1.8	0.7	0.7	0.8
17	2.3	4.3	5.0	1.4	15	16	12	12	15	12	1.0	2.2	3.0	0.7	1.7	2.1	0.7	0.8	0.7
18	2.5	3.0	5.1	1.3	16	14	12	11	10	13	1.1	2.1	2.6	0.8	1.4	2.0	0.7	0.7	0.8
19	2.4	3.5	5.9	1.8	16	16	9	11	10	10	1.0	1.9	3.0	0.7	1.5	2.3	0.7	0.7	0.8
20	3.0	3.8	8.7	3.0	16	13	14	15	11	14	1.3	2.1	3.1	1.0	1.6	2.8	0.7	0.7	0.9
21	3.6	3.3	5.1	1.0	15	15	14	15	13	8	1.5	1.8	2.7	1.1	1.4	2.0	0.8	0.7	0.8
22	3.7	2.0	6.6	2.3	16	16	16	11	10	13	1.4	1.3	3.3	1.1	0.9	2.6	0.7	0.7	0.8
23	2.8	3.4	6.3	1.8	16	15	13	14	9	13	1.2	1.8	3.1	0.8	1.3	2.4	0.7	0.7	0.8
24	3.1	5.3	6.2	1.6	14	15	15	14	14	13	1.3	2.7	3.2	1.0	2.1	2.5	0.7	0.8	0.8
25	2.2	3.6	5.8	1.8	14	16	15	13	13	15	0.9	1.8	3.1	0.6	1.4	2.3	0.7	0.8	0.8
26	2.2	4.2	4.8	1.4	13	13	14	15	11	11	0.9	2.2	2.4	0.6	1.7	1.8	0.7	0.8	0.8
27	2.7	4.4	5.4	1.4	13	16	14	9	11	13	1.0	2.4	2.8	0.7	1.8	2.1	0.7	0.8	0.8
28	3.1	2.9	7.8	2.7	13	17	17	10	11	17	1.1	1.6	4.0	0.9	1.2	3.1	0.8	0.7	0.8
29	2.3	4.1	6.1	1.9	6	13	15	2	6	15	1.5	1.5	3.0	0.8	1.4	2.4	0.6	0.9	0.8
30	3.3	4.6	4.8	0.8	16	17	14	13	12	8	1.4	1.9	2.4	1.0	1.7	1.9	0.7	0.9	0.7
31	2.7	6.4	7.3	2.5	13	15	13	11	15	13	1.2	2.8	3.2	0.8	2.4	2.5	0.7	0.9	0.8
32	2.6	5.3	6.8	2.1	14	16	17	11	13	17	1.0	2.0	3.5	0.7	1.8	2.7	0.7	0.9	0.8
33	3.5	6.0	7.1	1.9	15	13	16	14	12	15	1.5	2.3	3.4	1.1	2.1	2.7	0.7	0.9	0.8
34	4.4	5.2	5.8	0.7	15	15	13	14	8	11	1.7	2.0	3.0	1.3	1.8	2.3	0.8	0.9	0.8
35	2.6	5.1	6.9	2.2	14	15	16	14	12	15	1.1	1.8	3.8	0.8	1.7	2.8	0.7	0.9	0.7
36	3.0	5.2	6.9	1.9	15	15	16	14	13	15	1.3	2.1	3.4	0.9	1.8	2.6	0.7	0.9	0.8
37	2.3	5.1	6.0	2.0	16	16	14	11	9	14	1.0	2.3	3.0	0.7	1.9	2.4	0.7	0.8	0.8
38	2.2	4.9	5.6	1.8	10	16	15	14	10	15	0.8	1.9	2.8	0.6	1.7	2.2	0.7	0.9	0.8
39	2.2	5.3	5.5	1.9	15	17	16	11	11	16	1.5	2.0	2.8	0.7	1.8	2.2	0.8	0.9	0.8
40	3.7	5.4	8.5	2.5	13	13	14	13	13	14	1.8	2.3	3.6	1.2	2.0	3.0	0.7	0.9	0.8
41	2.2	5.2	6.4	2.2	15	15	17	12	13	16	0.9	2.1	3.9	0.6	1.8	2.7	0.7	0.9	0.7
42	2.5	4.2	6.3	1.9	16	13	14	12	8	12	1.0	1.7	3.2	0.7	1.5	2.5	0.7	0.9	0.8
43	2.4	5.3	5.8	1.9	11	17	16	10	15	15	1.0	2.1	3.0	0.7	1.9	2.3	0.8	0.9	0.8
44	2.5	6.2	6.4	2.2	13	13	16	14	12	14	1.1	2.8	2.9	0.7	2.4	2.4	0.7	0.9	0.8
45	3.4	3.8	8.0	2.6	14	15	17	11	9	17	1.5	1.4	4.7	1.1	1.3	3.4	0.7	0.9	0.7

		Yield				NP			NE			FW			GW			SP	
46	3.0	5.0	7.1	2.1	16	16	12	15	12	12	1.3	1.9	3.3	0.9	1.7	2.6	0.7	0.9	0.8
47	2.6	4.8	7.5	2.5	14	15	16	13	13	14	1.1	1.9	3.7	0.8	1.7	2.9	0.7	0.9	0.8
48	3.2	4.1	7.2	2.1	16	13	14	14	11	14	1.4	1.6	3.6	1.0	1.4	2.8	0.7	0.9	0.8
49	3.0	4.4	7.2	2.1	14	17	14	13	11	14	1.3	1.7	3.8	0.9	1.5	2.9	0.7	0.9	0.8
50	2.8	4.7	7.1	2.1	15	14	15	13	12	15	1.3	2.0	3.5	0.9	1.7	2.7	0.7	0.8	0.8
51	3.2	4.8	7.5	2.2	15	15	16	15	11	16	1.4	1.9	3.9	1.0	1.7	3.0	0.7	0.9	0.8
52	3.3	5.0	5.6	1.2	15	14	14	15	12	10	1.4	2.2	2.7	1.0	1.9	2.1	0.7	0.8	0.8
53	2.7	5.9	6.5	2.0	12	15	13	10	14	10	1.1	2.5	3.4	0.8	2.1	2.5	0.7	0.9	0.8
54	3.9	5.5	6.5	1.3	13	15	15	12	14	13	1.8	2.3	3.2	1.3	2.0	2.5	0.7	0.9	0.8
55	3.5	5.1	7.4	2.0	16	14	16	13	12	16	1.3	2.1	3.8	1.0	1.8	2.9	0.8	0.9	0.8
56	3.1	4.0	7.3	2.2	15	12	15	14	10	13	1.3	1.9	3.7	0.9	1.5	2.9	0.7	0.8	0.8
57	3.4	5.1	5.9	1.3	14	17	15	10	12	14	1.3	1.8	3.2	1.0	1.7	2.4	0.8	0.9	0.7
58	4.0	5.8	7.4	1.7	16	15	12	15	16	17	1.5	2.4	3.6	1.2	2.1	2.9	0.8	0.9	0.8
59	3.3	4.0	6.0	1.4	14	15	16	14	10	15	1.2	1.6	3.1	1.0	1.4	2.4	0.8	0.9	0.8
60	4.1	5.8	5.5	0.9	15	17	17	15	14	16	1.7	2.3	2.8	1.3	2.0	2.2	0.8	0.9	0.8
61	2.4	5.4	5.2	1.7	14	14	13	13	9	7	1.0	2.1	2.6	0.7	1.9	2.0	0.7	0.9	0.7
62	2.2	3.8	6.3	2.1	13	15	16	14	10	15	0.8	1.8	3.2	0.6	1.5	2.5	0.7	0.8	0.8
63	2.3	5.7	5.2	1.8	13	16	10	15	14	8	0.9	2.4	2.6	0.6	2.1	2.0	0.7	0.9	0.8
64	2.0	3.7	6.3	2.2	14	12	**	13	10	**	0.8	1.5	**	0.5	1.3	**	0.7	0.9	**
65	3.3	6.3	7.2	2.0	16	16	16	17	14	14	1.5	3.2	3.5	1.1	2.6	2.7	0.7	0.8	0.7
66	2.5	5.0	4.6	1.4	15	10	12	12	9	10	1.1	1.8	2.6	0.7	1.7	2.0	0.7	0.9	0.8
67	3.0	5.3	6.0	1.6	14	14	11	13	11	8	1.3	2.4	2.4	0.9	2.0	1.8	0.7	0.9	0.7
68	2.3	5.6	7.3	2.5	15	17	14	10	10	12	1.0	2.0	3.0	0.7	1.9	2.3	0.7	0.9	0.8
69	3.9	6.1	8.0	2.0	15	15	13	14	13	12	1.9	2.7	3.8	1.3	2.3	3.0	0.7	0.8	0.8
70	2.8	5.5	6.0	1.7	16	14	17	13	9	17	1.3	2.1	4.2	0.9	1.9	3.2	0.6	0.9	0.8
71	2.4	5.1	6.5	2.1	15	16	15	11	12	15	1.0	2.0	3.2	0.7	1.7	2.4	0.7	0.9	0.7
72	3.0	3.3	5.5	1.4	15	11	17	16	7	13	1.4	1.7	3.3	1.0	1.3	2.6	0.7	0.8	0.8
73	2.9	5.5	5.7	1.6	14	17	15	15	15	13	1.3	2.4	2.8	0.9	2.0	2.2	0.7	0.9	0.8
74	2.3	4.5	6.5	2.1	14	15	15	13	10	13	1.1	1.9	3.1	0.7	1.6	2.3	0.6	0.9	0.8
75	3.1	4.9	5.7	1.3	16	12	13	12	8	13	1.1	1.9	3.2	0.9	1.7	2.5	0.7	0.9	0.8
76	3.1	4.6	5.5	1.2	15	15	14	15	10	13	1.1	2.0	3.1	0.8	1.7	2.3	0.7	0.8	0.8
77	3.5	4.8	5.6	1.1	15	17	13	13	12	9	1.3	1.8	2.8	1.0	1.6	2.2	0.8	0.9	0.8
78	2.2	4.8	5.0	1.6	13	13	12	12	9	12	0.9	1.7	2.8	0.6	1.6	2.2	0.7	0.9	0.8
79	2.7	4.7	6.1	1.7	14	17	14	13	10	13	1.2	1.8	2.9	0.8	1.6	2.0	0.7	0.9	0.7
80	3.1	5.5	7.1	2.0	16	17	14	17	13	14	1.4	2.2	3.2	1.0	2.0	2.4	0.7	0.9	0.8
81	4.5	5.6	6.2	0.8	15	17	15	15	14	15	2.0	2.3	3.6	1.5	2.0	2.8	0.7	0.9	0.8
82	4.2	4.7	7.3	1.7	16	16	13	15	11	13	1.8	1.7	3.0	1.4	1.6	2.3	0.7	0.9	0.8
83	3.2	4.8	6.6	1.7	15	16	16	15	13	16	1.5	2.0	3.6	1.1	1.7	2.8	0.7	0.9	0.8
84	4.1	5.1	6.1	1.0	14	17	16	13	13	16	1.5	2.2	3.4	1.2	1.8	2.6	0.8	0.8	0.8
85	2.9	4.0	5.6	1.4	15	15	11	15	7	10	1.2	1.5	2.8	0.9	1.3	2.1	0.7	0.9	0.7
86	2.5	4.6	6.6	2.1	14	11	15	11	9	15	1.0	1.7	2.8	0.7	1.5	2.2	0.7	0.9	0.8
87	2.4	5.7	6.8	2.3	14	15	14	11	13	15	0.9	2.3	3.2	0.7	2.0	2.5	0.7	0.9	0.8
88	2.7	5.2	5.9	1.7	15	17	17	10	14	14	1.1	2.1	3.5	0.8	1.9	2.7	0.7	0.9	0.8
89	4.5	4.5	7.1	1.5	15	15	16	13	12	10	2.0	1.8	3.1	1.5	1.6	2.3	0.7	0.9	0.8
90	2.4	5.9	7.5	2.6	14	16	8	15	15	14	1.0	3.2	3.7	0.7	2.4	2.8	0.7	0.8	0.8
91	3.0	4.7	7.2	2.1	16	13	11	15	13	11	1.3	2.0	2.4	0.9	1.7	1.8	0.7	0.9	0.8
92	2.8	7.5	7.8	2.8	15	14	14	14	13	14	1.3	3.2	3.6	0.9	2.7	2.8	0.7	0.9	0.8

	Yield				NP			NE			FW			GW			SP		
93	3.8	4.9	6.7	1.5	15	10	15	14	10	14	1.7	2.0	3.9	1.2	1.7	3.1	0.7	0.9	0.8
94	2.1	4.6	5.8	1.9	11	15	15	10	12	13	1.6	1.7	3.5	0.7	1.6	2.7	0.5	0.9	0.8
95	3.1	5.6	5.8	1.5	14	13	13	13	12	13	1.2	2.2	3.1	0.9	1.9	2.3	0.8	0.9	0.8
96	3.5	5.2	6.3	1.4	15	13	14	14	10	14	1.6	2.1	3.2	1.1	1.8	2.4	0.7	0.9	0.7
97	2.4	6.8	7.7	2.8	10	15	16	9	14	12	1.0	2.6	3.3	0.7	2.2	2.5	0.7	0.9	0.8
98	3.2	4.9	5.9	1.4	15	12	15	13	10	14	1.4	1.9	2.9	1.0	1.7	2.2	0.7	0.9	0.8
99	2.8	5.9	6.7	2.1	16	14	14	14	9	13	1.0	2.3	3.0	0.8	2.1	2.3	0.8	0.9	0.8
100	2.6	5.7	6.8	2.1	10	14	15	7	11	15	1.1	2.4	3.5	0.8	2.0	2.7	0.7	0.9	0.8
101	3.5	5.6	6.2	1.4	14	16	14	14	12	13	1.5	2.9	3.4	1.1	2.5	2.6	0.7	0.9	0.8
102	2.2	6.3	7.9	3.0	14	13	14	12	12	12	0.9	2.6	3.1	0.6	2.2	2.4	0.7	0.9	0.8
103	2.8	5.5	6.0	1.7	16	14	12	14	12	12	1.2	2.2	2.9	0.9	1.9	2.2	0.7	0.9	0.8
104	2.9	6.1	6.8	2.1	15	14	14	14	12	13	1.3	2.3	3.1	0.9	2.1	2.4	0.7	0.9	0.8
105	3.9	3.5	6.6	1.7	16	13	13	15	13	9	1.7	2.2	3.4	1.3	1.5	2.7	0.7	0.7	0.8
106	3.5	4.2	6.4	1.5	11	15	14	11	9	14	1.6	1.6	3.3	1.1	1.5	2.6	0.7	0.9	0.8
107	2.8	5.5	6.1	1.7	15	15	16	11	13	13	1.1	2.1	3.3	0.8	1.9	2.5	0.7	0.9	0.8
108	3.1	4.6	7.1	2.0	15	15	14	13	12	12	1.4	1.7	3.1	1.0	1.6	2.4	0.7	0.9	0.8
109	4.8	4.7	6.0	0.7	14	16	14	14	12	13	2.2	1.9	3.6	1.6	1.7	2.8	0.7	0.9	0.8
110	3.2	5.2	6.8	1.8	16	15	14	14	13	12	1.4	2.1	3.5	1.0	1.8	2.5	0.7	0.9	0.7
111	3.3	6.0	7.2	2.0	15	15	16	12	11	15	1.5	2.3	3.4	1.1	2.0	2.7	0.7	0.9	0.8
112	3.0	6.1	6.4	1.9	14	15	15	11	12	14	1.4	2.6	3.5	0.9	2.2	2.8	0.7	0.9	0.8
113	3.7	5.0	5.6	0.9	16	14	13	12	11	12	1.7	1.8	3.4	1.2	1.6	2.6	0.7	0.9	0.8
114	2.9	3.6	5.6	1.4	15	17	16	14	6	10	1.3	1.3	2.8	0.9	1.2	2.1	0.7	0.9	0.8
115	4.2	5.2	8.3	2.1	16	16	15	15	14	15	1.8	2.0	3.6	1.3	1.8	2.5	0.8	0.9	0.7
116	3.2	4.3	6.0	1.4	15	14	15	12	10	15	1.4	1.6	4.0	1.0	1.5	3.2	0.7	0.9	0.8
117	4.1	5.4	7.7	1.8	16	13	15	14	13	13	1.8	2.1	3.4	1.3	1.9	2.5	0.7	0.9	0.7
118	3.0	4.8	5.7	1.4	15	13	13	13	9	11	1.2	1.7	2.3	0.9	1.6	1.7	0.7	0.9	0.7
119	3.6	3.7	7.1	2.0	13	17	12	12	7	11	1.6	1.3	3.0	1.2	1.2	2.3	0.7	0.9	0.8
120	4.0	4.8	7.3	1.7	14	16	16	12	14	16	1.8	2.0	3.8	1.3	1.7	2.9	0.7	0.9	0.8
121	3.0	4.6	6.0	1.5	15	14	15	14	12	15	1.3	1.7	3.6	0.9	1.5	2.8	0.7	0.9	0.8
122	3.1	5.3	6.6	1.7	15	16	17	12	11	13	1.4	2.0	3.2	1.0	1.8	2.4	0.7	0.9	0.7
123	3.1	4.8	6.2	1.5	15	16	15	14	12	15	1.5	2.1	3.3	1.0	1.7	2.6	0.7	0.8	0.8
124	3.6	5.4	6.0	1.3	15	14	13	13	13	13	1.5	2.1	3.0	1.1	1.9	2.4	0.7	0.9	0.8
125	3.7	5.0	6.6	1.4	12	15	15	12	12	15	1.4	2.7	3.2	1.1	2.0	2.4	0.8	0.8	0.8
126	3.0	6.0	6.6	1.9	14	13	16	11	12	14	1.3	2.3	3.4	0.9	2.1	2.6	0.7	0.9	0.8
127	3.6	5.9	7.9	2.2	14	18	16	14	13	14	1.6	2.3	3.4	1.2	2.0	2.6	0.7	0.9	0.8
128	3.7	4.9	6.3	1.3	16	16	13	14	15	13	1.7	2.0	4.1	1.2	1.7	3.2	0.7	0.9	0.8
129	3.9	5.5	5.2	0.9	15	18	16	15	12	11	1.6	2.1	3.2	1.2	1.9	2.5	0.7	0.9	0.8
130	2.7	3.9	6.0	1.7	15	15	14	13	9	8	1.2	1.4	2.5	0.8	1.3	2.0	0.7	0.9	0.8
131	3.1	5.3	5.6	1.3	16	13	17	15	12	14	1.3	2.0	3.0	1.0	1.8	2.4	0.7	0.9	0.8
132	3.7	6.2	6.3	1.5	16	16	14	15	14	10	1.7	2.5	2.9	1.2	2.2	2.2	0.7	0.9	0.8
133	2.9	4.7	6.6	1.9	15	17	16	14	14	9	1.2	1.8	3.1	0.9	1.6	2.4	0.7	0.9	0.8
134	2.4	4.7	5.8	1.7	14	14	17	12	12	17	1.0	1.8	3.5	0.7	1.6	2.7	0.7	0.9	0.8
135	3.4	4.1	5.4	1.0	15	12	12	12	6	9	1.5	1.7	3.0	1.1	1.5	2.3	0.7	0.9	0.8
136	3.2	6.0	7.7	2.3	15	17	14	10	15	12	1.4	2.5	2.8	1.0	2.2	2.1	0.7	0.9	0.8
137	2.9	4.7	5.2	1.2	12	17	16	12	12	15	1.1	1.9	4.1	0.8	1.7	3.1	0.8	0.9	0.8
138	3.3	2.9	6.9	2.2	15	12	16	12	4	7	1.3	1.4	2.7	1.0	1.1	2.0	0.8	0.8	0.7
139	2.9	6.5	7.0	2.2	16	12	17	14	12	14	1.3	2.6	3.5	0.9	2.3	2.7	0.7	0.9	0.8

	Yield				NP			NE			FW			GW			SP		
140	3.1	4.5	5.5	1.2	15	15	15	13	11	16	1.3	1.8	3.7	0.9	1.6	2.8	0.7	0.9	0.8
141	3.5	4.2	6.5	1.6	15	13	14	13	8	12	1.5	1.6	3.0	1.1	1.4	2.3	0.7	0.9	0.7
142	2.8	5.0	5.1	1.3	13	16	13	12	12	11	1.1	1.8	3.3	0.8	1.6	2.5	0.8	0.9	0.8
143	3.0	4.8	5.6	1.3	13	16	6	13	14	6	1.3	1.9	2.7	0.9	1.7	2.0	0.7	0.9	0.7
144	2.7	5.7	8.3	2.8	13	15	16	12	11	13	1.2	2.4	3.1	0.8	2.0	2.3	0.7	0.9	0.7
145	3.2	3.9	7.4	2.2	16	9	17	12	7	17	1.5	1.4	4.1	1.0	1.3	3.2	0.7	0.9	0.8
146	3.9	5.3	6.8	1.4	15	12	14	12	10	14	1.5	2.1	3.6	1.2	1.9	2.8	0.8	0.9	0.8
147	3.2	4.6	6.6	1.7	15	16	17	15	12	16	1.4	1.7	3.3	1.0	1.6	2.6	0.7	0.9	0.8
148	2.8	4.7	7.3	2.3	15	13	15	15	12	12	1.3	2.0	3.3	0.9	1.7	2.6	0.7	0.9	0.8
149	3.2	4.8	6.6	1.7	16	17	17	15	11	17	1.5	1.8	3.7	1.0	1.6	2.9	0.7	0.9	0.8
150	3.3	5.7	5.4	1.3	16	16	16	14	11	15	1.5	2.2	3.4	1.0	2.0	2.6	0.7	0.9	0.8
151	3.0	4.2	6.6	1.8	14	13	10	13	10	9	1.5	1.7	2.7	1.0	1.5	2.1	0.6	0.9	0.8
152	3.8	4.6	7.2	1.8	16	16	15	14	12	14	1.8	1.8	3.5	1.3	1.6	2.7	0.7	0.9	0.8
153	4.0	4.8	5.4	0.7	13	15	14	10	12	13	1.7	1.8	3.6	1.3	1.7	2.8	0.7	0.9	0.8
154	3.2	5.1	5.5	1.2	15	16	15	13	12	14	1.4	2.0	3.1	1.0	1.8	2.3	0.7	0.9	0.7
155	3.8	5.4	4.6	0.8	14	15	12	13	10	8	1.8	2.0	2.8	1.3	1.8	2.1	0.7	0.9	0.8
156	2.7	4.1	5.8	1.5	15	10	11	14	8	6	1.2	1.6	2.4	0.8	1.4	1.8	0.7	0.9	0.8
157	3.2	4.6	6.1	1.4	13	16	11	12	11	12	1.4	1.8	3.1	1.0	1.6	2.3	0.7	0.9	0.8
158	3.5	3.9	7.5	2.2	14	16	14	12	7	14	1.5	1.4	3.2	1.1	1.3	2.4	0.7	0.9	0.8
159	2.7	5.8	5.6	1.7	15	15	14	11	13	14	1.2	2.4	4.0	0.8	2.1	3.0	0.7	0.9	0.8
160	3.0	4.8	6.2	1.6	17	16	6	13	12	7	1.3	2.6	2.9	0.9	2.0	2.2	0.7	0.8	0.8
# sites	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
cv	24.9	16.9	17.0		12.5	16.7	21.8	17.0	31.2	30.5	17.0	22.4	15.7	18.2	19.0	16.0	7.6	6.0	3.9
lsd	1.0	1.6	2.1		3.5	4.8	6.1	4.3	6.9	7.7	0.4	0.9	1.0	0.3	0.7	0.8	0.1	0.1	0.1
Max	4.0	7.5	8.7		17.0	17.5	17.0	16.9	16.0	17.0	2.2	3.2	4.7	1.6	2.7	3.4	0.8	0.9	0.9
Min	1.2	2.0	4.0		6.0	8.5	5.5	2.4	3.5	5.5	0.8	1.2	2.3	0.5	0.9	1.7	0.5	0.7	0.6
Grand mean	2.3	4.8	6.2		14.0	14.5	14.1	12.8	11.1	12.7	1.3	2.0	3.2	0.9	1.7	2.5	0.7	0.9	0.8
MSg	0.6	1.7	1.8		4.2	5.8	8.6	7.4	10.3	13.5	0.1	0.3	0.4	0.1	0.2	0.2	0.0	0.0	0.0
Mse	0.3	1.1	0.65		3.2	5.9	9.4	4.7	12.0	15.0	0.0	0.2	0.3	0.0	0.1	0.2	0.0	0.0	0.0
H (%)	42	47	50		14	5.26	5	22	1.36	5	50	18.0	21	50	32.33	21	1	49.7	5

Appendix 4. 3: Mean yield and other agronomic traits for maize hybrids from heterotic group A under Random drought and Optimum

	Yields			AD		SD		ASI		PH		EH		EP	
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
1	4.5	8.2	2.6	81	76	81	76	1	0	177	205	96	116	0.5	0.6
2	2.2	7.7	3.9	87	79	89	81	2	2	122	173	72	104	0.6	0.6
3	5.9	5.1	0.5	83	79	85	78	2	-1	186	161	103	102	0.6	0.6
4	3.6	7.3	2.7	79	74	81	74	2	0	167	177	85	105	0.5	0.6
5	3.0	6.7	2.6	81	74	83	75	2	1	129	180	66	108	0.5	0.6
6	5.3	7.5	1.5	85	75	87	75	2	0	169	199	101	119	0.6	0.6
7	3.7	6.5	2.0	82	77	85	77	3	0	177	190	98	101	0.6	0.5
8	4.6	9.4	3.4	79	72	82	72	3	-1	163	178	97	105	0.6	0.6
9	3.2	5.2	1.4	82	79	84	79	2	0	155	147	92	88	0.6	0.6
10	3.9	7.6	2.6	81	74	82	74	1	0	169	185	91	101	0.5	0.5
11	2.6	5.9	2.3	90	82	90	87	1	2	144	167	67	109	0.5	0.6
12	1.6	7.0	3.8	93	72	95	73	3	1	100	181	63	103	0.6	0.6
13	4.4	7.1	1.9	80	78	83	78	3	0	173	178	94	106	0.5	0.6
14	3.3	5.8	1.8	81	78	81	78	1	1	172	183	95	104	0.6	0.6
15	4.4	8.9	3.1	79	73	81	74	2	1	177	206	105	114	0.6	0.6
16	4.6	8.3	2.6	84	73	85	74	1	1	160	204	89	121	0.6	0.6
17	2.4	7.0	3.2	92	77	93	79	2	2	107	206	68	107	0.6	0.5
18	2.9	7.1	3.0	85	77	86	77	1	1	136	181	75	99	0.5	0.6
19	4.2	7.9	2.7	80	77	81	79	1	2	167	179	98	96	0.6	0.5
20	2.7	7.2	3.2	80	76	83	76	4	0	154	181	93	102	0.6	0.6
21	2.4	9.3	4.9	86	76	91	77	6	2	170	197	108	116	0.6	0.6
22	2.9	6.7	2.7	87	77	87	78	1	1	129	161	72	88	0.6	0.5
23	3.2	8.0	3.4	85	77	86	78	1	1	175	202	82	127	0.5	0.6
24	2.6	6.7	2.9	88	75	92	77	4	2	126	188	77	106	0.6	0.6
25	3.4	6.7	2.3	83	78	83	78	1	-1	157	194	88	112	0.6	0.6
26	2.5	5.3	2.0	85	81	86	86	1	4	164	146	83	89	0.5	0.6
27	3.0	9.3	4.4	84	74	85	74	1	0	161	201	95	115	0.6	0.6
28	3.0	6.0	2.1	84	76	89	76	6	0	172	194	94	106	0.5	0.5
29	4.8	6.4	1.1	84	76	90	79	6	3	125	203	74	113	0.6	0.6
30	4.6	7.1	1.7	82	77	84	77	2	-1	172	184	108	102	0.6	0.6
31	4.8	8.6	2.7	84	74	88	74	4	1	141	208	75	103	0.5	0.5
32	3.2	6.9	2.7	82	77	82	78	0	1	132	174	73	84	0.6	0.5
33	3.2	8.0	3.4	81	76	83	77	2	1	162	205	87	114	0.5	0.6
34	3.6	8.4	3.4	81	73	82	75	2	2	174	196	91	112	0.5	0.6
35	3.7	7.6	2.7	86	77	90	78	4	1	149	187	84	114	0.6	0.6
36	4.3	6.6	1.6	85	77	87	78	2	1	170	163	84	89	0.5	0.6
37	3.7	7.3	2.6	80	76	82	75	2	-1	148	213	80	127	0.5	0.6
38	3.9	6.1	1.6	81	79	84	80	3	1	161	175	85	94	0.5	0.5
39	4.4	6.4	1.5	86	73	87	74	1	1	148	185	79	104	0.5	0.6
40	2.4	6.1	2.6	84	77	86	77	2	0	141	174	77	99	0.5	0.6
41	4.4	6.1	1.2	84	76	79	76	1	-1	178	175	93	96	0.5	0.5
42	2.6	7.7	3.6	89	73	93	73	4	-1	131	215	77	117	0.6	0.5
43	3.6	7.8	3.0	84	75	85	75	1	1	159	217	104	119	0.6	0.6
44	3.6	5.7	1.5	84	77	88	77	4	1	115	197	71	102	0.6	0.5

			Yields		AD		SD		ASI		PH		EH		EP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
45	4.3	7.5	2.3	85	77	87	77	2	0	141	187	80	111	0.6	0.6
46	1.6	7.2	4.0	92	75	95	74	3	-1	111	190	74	104	0.7	0.5
47	2.2	6.5	3.0	91	79	94	80	3	2	134	162	70	110	0.5	0.7
48	3.3	6.5	2.3	85	73	86	74	2	1	175	195	94	101	0.5	0.5
49	3.8	7.3	2.4	93	75	95	75	3	0	155	173	83	104	0.5	0.6
50	4.6	6.0	1.0	81	78	81	79	0	1	158	147	97	86	0.6	0.6
51	3.4	6.2	1.9	87	79	90	79	3	1	154	157	90	95	0.6	0.6
52	6.4	4.6	1.3	87	76	91	75	4	-1	158	151	89	69	0.6	0.5
53	2.5	7.0	3.1	88	75	93	77	5	2	137	203	89	102	0.6	0.5
54	3.3	6.2	2.0	88	77	90	78	2	1	138	187	77	99	0.6	0.5
55	3.0	6.7	2.6	86	75	85	75	-1	0	140	201	78	98	0.6	0.5
56	4.7	5.2	0.4	86	76	87	77	1	1	144	148	97	88	0.7	0.6
57	3.8	6.4	1.8	84	70	84	70	1	0	163	209	98	98	0.6	0.5
58	4.1	7.3	2.2	81	75	82	75	1	1	189	167	96	91	0.5	0.5
59	3.5	6.2	1.9	86	77	87	80	1	3	133	166	88	114	0.7	0.7
60	4.5	6.9	1.7	86	72	88	73	2	1	141	181	79	101	0.6	0.6
61	3.7	5.7	1.4	86	81	87	80	1	-1	159	175	94	108	0.6	0.6
62	4.0	7.9	2.8	83	76	84	77	2	1	141	192	79	100	0.6	0.5
63	2.4	6.4	2.9	90	77	92	78	3	1	148	234	86	114	0.6	0.5
64	2.7	8.0	3.8	85	77	89	77	4	-1	150	186	102	97	0.7	0.5
65	3.2	5.9	1.9	84	79	87	80	3	1	162	188	89	100	0.5	0.5
66	2.1	4.9	2.0	79	82	80	83	1	1	168	186	86	86	0.5	0.5
67	3.3	4.6	0.9	90	80	89	80	-1	0	139	172	71	75	0.5	0.4
68	2.4	6.1	2.6	91	78	94	81	3	3	135	177	75	103	0.6	0.6
69	3.6	4.9	1.0	85	81	87	81	2	0	160	177	94	101	0.6	0.6
70	3.1	5.6	1.8	84	79	84	80	1	1	126	171	65	93	0.5	0.5
71	4.0	5.2	0.8	85	82	86	90	1	8	171	165	110	97	0.6	0.6
72	4.8	7.1	1.6	79	72	82	74	3	2	187	200	103	106	0.5	0.5
73	3.9	7.9	2.9	88	77	91	76	4	-1	149	208	77	115	0.5	0.6
74	1.8	7.3	3.9	89	77	92	77	3	0	155	192	85	101	0.6	0.5
75	2.8	7.6	3.4	81	75	82	75	1	1	143	205	82	119	0.6	0.6
76	2.3	6.6	3.0	85	79	89	81	4	2	141	185	86	99	0.6	0.5
77	2.0	7.7	4.0	91	75	93	75	3	-1	125	198	79	109	0.6	0.5
78	4.1	5.5	1.0	85	82	85	83	1	1	171	199	100	107	0.6	0.5
79	4.5	5.5	0.7	78	78	79	79	2	1	148	170	83	94	0.6	0.6
80	5.1	6.4	1.0	78	74	79	75	1	1	192	178	111	97	0.6	0.5
81	2.2	6.0	2.7	96	74	93	76	2	2	144	185	79	108	0.6	0.6
82	2.0	7.5	3.8	83	74	85	75	2	1	150	182	85	96	0.6	0.5
83	3.5	6.9	2.4	81	80	84	80	4	0	164	209	94	116	0.6	0.6
84	2.8	5.8	2.1	86	72	88	74	2	2	151	192	95	100	0.6	0.5
85	1.7	5.7	2.8	89	80	91	80	3	-1	114	182	70	105	0.6	0.6
86	2.5	6.8	3.1	84	76	85	77	1	2	161	198	88	104	0.5	0.5
87	3.1	6.9	2.7	85	77	87	77	2	1	134	208	75	93	0.6	0.4
88	4.1	6.8	1.9	86	72	87	72	1	0	145	192	90	103	0.6	0.5
89	2.2	6.0	2.7	92	77	94	77	3	0	119	186	60	98	0.5	0.5
90	3.7	4.7	0.7	91	81	95	82	4	2	155	156	72	83	0.5	0.5

			Yields		AD		SD		ASI		PH		EH		EP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
91	4.1	4.9	0.6	88	80	92	80	4	0	130	165	69	89	0.5	0.5
92	4.9	5.6	0.5	83	76	83	75	0	-1	167	184	92	93	0.6	0.5
93	4.6	6.7	1.5	80	73	80	73	0	0	175	172	98	94	0.6	0.5
94	3.0	5.9	2.1	83	75	89	75	6	0	158	186	89	114	0.6	0.6
95	2.2	6.7	3.2	82	74	85	75	3	2	154	193	84	85	0.5	0.4
96	3.8	7.2	2.4	83	77	84	76	1	-1	176	164	88	100	0.5	0.6
97	3.0	7.5	3.1	83	74	88	75	5	1	138	185	89	110	0.6	0.6
98	3.5	7.6	3.0	82	72	84	75	2	3	156	194	85	112	0.5	0.6
99	2.9	6.5	2.6	94	75	95	74	1	-1	137	177	80	96	0.6	0.5
100	2.8	4.9	1.5	84	82	89	82	6	1	148	150	80	79	0.5	0.5
101	3.3	6.9	2.6	81	75	83	77	2	3	190	182	108	101	0.6	0.6
102	2.5	6.6	2.9	91	77	94	78	4	1	152	170	92	92	0.6	0.5
103	2.8	6.9	2.9	83	77	88	78	5	1	137	179	81	90	0.6	0.5
104	3.5	6.4	2.0	83	75	85	77	3	2	167	182	96	100	0.6	0.5
105	4.4	6.4	1.5	78	76	79	77	1	1	159	165	93	95	0.6	0.6
106	3.2	7.5	3.0	79	75	79	76	-1	1	140	181	86	126	0.6	0.7
107	3.8	8.0	3.0	82	75	89	77	7	2	147	185	77	95	0.5	0.5
108	2.3	7.4	3.6	86	75	84	75	-2	0	139	166	75	96	0.5	0.6
109	3.6	8.9	3.8	84	72	85	74	1	2	166	202	108	115	0.6	0.6
110	3.6	7.2	2.6	81	75	81	78	0	3	160	201	95	101	0.6	0.5
111	2.8	6.0	2.3	82	72	84	73	2	1	151	201	86	116	0.6	0.6
112	2.6	6.2	2.6	85	76	85	79	1	3	141	171	68	86	0.5	0.5
113	3.1	6.5	2.3	80	78	83	82	3	4	174	190	92	123	0.5	0.6
114	3.1	6.6	2.5	83	74	84	77	1	4	130	190	65	100	0.5	0.5
115	3.0	6.6	2.6	82	73	83	76	1	4	162	163	95	87	0.6	0.5
116	4.6	7.0	1.7	81	75	80	78	-1	3	163	174	94	92	0.6	0.5
117	3.1	6.9	2.7	84	76	86	78	2	3	155	174	87	95	0.6	0.5
118	4.2	7.7	2.5	86	74	87	76	1	2	203	194	104	120	0.5	0.6
119	3.0	6.6	2.5	85	75	88	76	3	2	156	169	85	96	0.5	0.6
120	2.8	7.2	3.1	90	76	95	75	5	-1	139	169	82	105	0.6	0.6
121	3.3	8.4	3.6	80	72	81	73	1	2	197	183	98	92	0.5	0.5
122	4.0	8.9	3.5	83	69	86	70	3	1	152	215	82	119	0.5	0.6
123	3.9	7.4	2.5	84	72	86	72	2	0	153	183	92	102	0.6	0.6
124	2.7	7.1	3.1	88	75	92	75	4	-1	146	183	86	97	0.6	0.5
125	3.6	7.3	2.6	88	76	88	76	0	0	147	201	84	106	0.6	0.5
126	2.7	7.2	3.2	87	75	92	76	5	1	110	196	69	111	0.6	0.6
127	5.0	8.3	2.3	85	72	87	71	2	-1	169	186	100	93	0.6	0.5
128	3.6	7.6	2.8	80	72	84	73	4	1	129	165	76	94	0.6	0.6
129	3.9	6.6	1.9	85	74	86	77	2	3	138	180	71	95	0.5	0.5
130	4.5	6.3	1.2	81	79	81	78	1	-1	171	183	103	91	0.6	0.5
131	3.7	7.5	2.7	86	77	87	78	2	1	164	190	78	139	0.5	0.7
132	3.9	6.4	1.8	81	73	81	75	1	2	168	170	95	85	0.6	0.5
133	3.9	5.8	1.3	87	88	89	89	2	1	140	154	77	101	0.6	0.7
134	5.0	7.8	2.0	79	77	82	80	3	3	135	184	69	114	0.5	0.6
135	2.3	6.1	2.7	83	83	87	87	4	3	123	169	76	106	0.6	0.6
136	2.8	6.0	2.2	82	77	83	75	1	-3	145	196	90	116	0.6	0.6

			Yields		AD		SD		ASI		PH		EH		EP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
137	2.0	5.7	2.6	93	74	93	74	0	0	125	180	65	115	0.5	0.6
138	3.6	5.8	1.6	84	77	86	77	2	1	156	183	102	112	0.7	0.6
139	3.3	5.2	1.4	83	79	83	84	-1	5	182	168	109	106	0.6	0.6
140	4.3	5.9	1.1	81	78	84	79	3	1	145	181	83	123	0.6	0.7
141	3.3	7.9	3.2	88	76	91	77	3	1	170	189	91	117	0.5	0.6
142	2.1	6.1	2.9	87	82	88	83	1	2	131	177	72	108	0.5	0.6
143	3.6	6.1	1.7	86	74	87	76	1	2	156	183	90	116	0.6	0.6
144	2.3	6.5	3.0	86	74	88	76	2	2	146	196	98	118	0.7	0.6
145	2.0	6.2	3.0	92	80	92	79	0	-1	118	169	59	91	0.5	0.5
146	4.3	6.6	1.7	82	76	83	77	2	1	186	172	102	98	0.5	0.6
147	3.4	5.1	1.3	87	78	89	78	2	1	181	169	110	91	0.6	0.5
148	5.0	5.7	0.4	85	76	86	73	1	-3	139	163	72	88	0.5	0.5
149	3.3	6.8	2.5	86	72	86	73	0	1	167	182	94	98	0.6	0.5
150	3.5	6.0	1.8	89	72	90	75	2	3	145	193	82	102	0.6	0.5
151	4.5	6.5	1.4	79	72	80	76	1	4	172	185	92	94	0.5	0.5
152	3.0	6.3	2.3	85	72	89	75	4	3	149	188	86	96	0.6	0.5
153	4.6	7.2	1.9	84	75	86	76	2	1	182	178	95	97	0.5	0.5
154	3.7	5.1	1.0	87	78	87	76	0	2	139	148	75	62	0.5	0.4
155	2.6	9.0	4.5	91	67	96	69	5	2	128	186	72	105	0.6	0.6
156	3.1	5.9	2.0	82	78	85	82	4	5	148	177	80	108	0.5	0.6
157	2.9	5.9	2.1	86	78	89	79	3	1	129	179	80	93	0.6	0.5
158	3.9	7.8	2.7	80	73	81	73	2	0	162	181	97	91	0.6	0.5
159	3.6	7.8	3.0	91	72	92	75	1	3	165	161	88	88	0.5	0.6
160	2.7	6.2	2.4	81	78	82	78	2	0	126	183	86	93	0.7	0.5
sites	1	1		1	1	1	1	1	1	1	1	1	1	1	1
Cv (%)	32	15		6	4	7	5	111	187	17	12	18	12	11	8
Lsd	2	2		10	7	12	8	4	3	50	43	30	25	0	0
Max	6	9		96	88	96	90	7	8	203	234	111	139	1	1
Min	2	5		78	67	79	69	-2	-3	100	146	59	62	0	0
G.M	3	6.8		84	76	86	77	2	1	152	183	86	102	1	1
MSg	1.6	2.0		27.8	17.3	34.3	22.1	4.7	3.7	753.3	494.3	267.1	255.2	0.0	0.0
Mse	1.2	1.1		27.3	10.9	33.9	15.1	4.6	2.9	637.1	471.1	228.9	159.1	0.0	0.0
H (%)	14	30		7	23	6	19	1.4	13	8.4	2.4	7.7	23	93	47

Appendix 4.4: Continuation of Appendix 4.3 for traits NP, NE, FW, GW,SP.

	Yields			NP		NE		FW		GW		SP	
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
1	4.5	8.2	2.6	16	17	13	16	2.5	4.0	1.9	3.3	0.8	0.8
2	2.2	7.7	3.9	16	17	5	16	1.3	3.7	1.0	2.9	0.5	0.8
3	5.9	5.1	0.5	15	17	14	16	2.8	3.0	2.3	2.2	0.8	0.7
4	3.6	7.3	2.7	16	17	12	16	2.1	3.7	1.5	2.9	0.8	0.8
5	3.0	6.7	2.6	16	17	12	16	1.7	3.5	1.3	2.7	0.8	0.8
6	5.3	7.5	1.5	16	17	10	16	2.5	3.7	1.9	2.9	0.8	0.8
7	3.7	6.5	2.0	16	17	13	16	2.1	3.6	1.6	2.7	0.8	0.8
8	4.6	9.4	3.4	16	17	15	16	2.4	4.5	1.9	3.6	0.8	0.8
9	3.2	5.2	1.4	12	17	12	16	1.8	2.8	1.3	2.1	0.8	0.8
10	3.9	7.6	2.6	10	17	9	16	2.2	4.0	1.6	3.1	0.8	0.8
11	2.6	5.9	2.3	16	17	11	16	1.6	2.9	1.2	2.3	0.7	0.8
12	1.6	7.0	3.8	12	17	8	16	1.0	3.6	0.7	2.8	0.8	0.8
13	4.4	7.1	1.9	16	17	12	16	2.5	3.7	1.9	2.9	0.8	0.8
14	3.3	5.8	1.8	16	17	14	16	2.3	3.0	1.5	2.3	0.8	0.8
15	4.4	8.9	3.1	16	17	14	16	2.4	4.5	1.8	3.5	0.8	0.8
16	4.6	8.3	2.6	16	17	10	16	2.4	4.1	1.9	3.2	0.8	0.8
17	2.4	7.0	3.2	11	17	7	16	1.3	3.8	1.0	2.9	0.8	0.8
18	2.9	7.1	3.0	14	17	12	16	1.8	3.7	1.3	2.9	0.7	0.8
19	4.2	7.9	2.7	15	17	12	16	2.2	4.1	1.7	3.2	0.8	0.8
20	2.7	7.2	3.2	17	17	12	16	1.5	3.4	1.1	2.8	0.8	0.8
21	2.4	9.3	4.9	15	17	11	17	1.4	4.4	1.0	3.5	0.8	0.8
22	2.9	6.7	2.7	15	17	10	16	1.7	3.5	1.3	2.7	0.8	0.8
23	3.2	8.0	3.4	14	17	15	16	1.8	4.1	1.3	3.2	0.6	0.8
24	2.6	6.7	2.9	17	17	11	16	1.6	3.4	1.1	2.7	0.8	0.8
25	3.4	6.7	2.3	15	17	14	16	1.9	3.4	1.4	2.7	0.8	0.8
26	2.5	5.3	2.0	13	17	9	16	1.4	2.8	1.1	2.2	0.7	0.8
27	3.0	9.3	4.4	16	17	13	16	1.8	4.2	1.3	3.5	0.8	0.8

			Yields		NP		NE		FW		GW		SP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
28	3.0	6.0	2.1	14	17	9	16	1.7	3.0	1.3	2.4	0.8	0.8
29	4.8	6.4	1.1	17	17	12	16	2.7	3.3	2.0	2.6	0.6	0.8
30	4.6	7.1	1.7	15	17	13	16	2.5	3.5	1.9	2.8	0.8	0.8
31	4.8	8.6	2.7	17	17	17	16	2.6	4.5	2.0	3.5	0.8	0.8
32	3.2	6.9	2.7	17	17	9	16	1.8	3.5	1.4	2.7	0.8	0.8
33	3.2	8.0	3.4	15	17	13	16	2.0	3.9	1.4	3.1	0.7	0.8
34	3.6	8.4	3.4	14	17	10	16	2.0	3.7	1.5	3.0	0.8	0.8
35	3.7	7.6	2.7	13	17	10	16	1.9	3.8	1.5	3.0	0.9	0.8
36	4.3	6.6	1.6	15	17	9	16	2.3	3.3	1.8	2.6	0.8	0.8
37	3.7	7.3	2.6	15	17	14	16	2.0	3.9	1.5	3.0	0.8	0.8
38	3.9	6.1	1.6	13	17	12	16	1.9	3.2	1.5	2.5	0.9	0.8
39	4.4	6.4	1.5	15	17	18	16	2.4	3.3	1.8	2.6	0.8	0.8
40	2.4	6.1	2.6	11	17	8	16	1.4	3.1	1.0	2.4	0.8	0.8
41	4.4	6.1	1.2	13	17	7	16	2.6	3.3	1.9	2.5	0.8	0.8
42	2.6	7.7	3.6	15	17	10	16	1.6	4.1	1.2	3.2	0.8	0.8
43	3.6	7.8	3.0	15	17	11	16	2.0	3.8	1.5	3.0	0.8	0.8
44	3.6	5.7	1.5	18	17	10	16	2.0	3.2	1.5	2.4	0.8	0.7
45	4.3	7.5	2.3	17	17	13	16	2.3	3.8	1.8	3.0	0.8	0.8
46	1.6	7.2	4.0	16	17	9	16	1.2	3.7	0.8	2.9	0.6	0.8
47	2.2	6.5	3.0	18	17	8	17	1.4	3.1	1.0	2.5	0.6	0.8
48	3.3	6.5	2.3	14	17	11	16	1.7	3.4	1.3	2.6	0.8	0.8
49	3.8	7.3	2.4	15	17	9	16	2.3	3.6	1.7	2.9	0.7	0.8
50	4.6	6.0	1.0	19	17	16	16	2.6	3.1	2.0	2.4	0.8	0.8
51	3.4	6.2	1.9	16	17	12	16	2.0	3.2	1.5	2.4	0.8	0.8
52	6.4	4.6	1.3	17	17	9	16	3.4	2.2	2.6	1.7	0.8	0.7
53	2.5	7.0	3.1	15	17	10	16	1.5	3.6	1.1	2.8	0.7	0.8
54	3.3	6.2	2.0	17	17	10	16	1.9	3.3	1.4	2.5	0.8	0.8
55	3.0	6.7	2.6	14	17	11	16	1.6	3.4	1.3	2.7	0.8	0.8
56	4.7	5.2	0.4	20	17	8	16	2.5	2.9	1.9	2.2	0.8	0.8

			Yields		NP		NE		FW		GW		SP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
57	3.8	6.4	1.8	17	17	15	16	2.0	3.4	1.6	2.6	0.8	0.8
58	4.1	7.3	2.2	15	17	12	16	2.1	3.6	1.6	2.9	0.8	0.8
59	3.5	6.2	1.9	17	17	12	16	1.7	3.4	1.4	2.5	0.9	0.7
60	4.5	6.9	1.7	17	17	9	16	2.4	3.8	1.8	2.9	0.8	0.8
61	3.7	5.7	1.4	15	17	14	16	2.3	3.0	1.6	2.3	0.7	0.8
62	4.0	7.9	2.8	14	17	10	16	2.4	4.2	1.7	3.2	0.7	0.8
63	2.4	6.4	2.9	16	17	10	16	1.4	3.9	1.0	2.8	0.8	0.7
64	2.7	8.0	3.8	15	17	9	16	1.6	4.5	1.2	3.3	0.7	0.7
65	3.2	5.9	1.9	17	17	13	16	1.9	3.1	1.4	2.3	0.7	0.8
66	2.1	4.9	2.0	16	17	14	16	1.9	2.7	1.1	2.0	0.5	0.7
67	3.3	4.6	0.9	15	17	11	16	1.8	2.5	1.4	1.9	0.7	0.8
68	2.4	6.1	2.6	16	17	9	16	1.5	3.2	1.1	2.5	0.7	0.8
69	3.6	4.9	1.0	13	17	10	16	2.0	2.8	1.5	2.1	0.8	0.7
70	3.1	5.6	1.8	13	17	12	16	1.7	3.0	1.3	2.3	0.8	0.8
71	4.0	5.2	0.8	15	17	12	16	2.2	2.6	1.7	2.0	0.8	0.8
72	4.8	7.1	1.6	17	17	14	16	2.6	3.8	2.0	2.9	0.8	0.8
73	3.9	7.9	2.9	13	17	11	16	2.0	4.1	1.6	3.2	0.8	0.8
74	1.8	7.3	3.9	16	17	13	16	1.0	3.8	0.8	2.9	0.8	0.8
75	2.8	7.6	3.4	16	17	8	16	1.5	3.8	1.1	3.0	0.8	0.8
76	2.3	6.6	3.0	16	17	8	16	1.3	3.3	1.0	2.6	0.8	0.8
77	2.0	7.7	4.0	16	17	10	16	1.6	3.9	1.0	3.0	0.8	0.8
78	4.1	5.5	1.0	16	17	13	16	2.4	3.0	1.8	2.3	0.7	0.8
79	4.5	5.5	0.7	16	17	13	16	2.4	3.0	1.9	2.3	0.8	0.7
80	5.1	6.4	1.0	13	17	15	16	2.7	3.6	2.1	2.7	0.8	0.7
81	2.2	6.0	2.7	15	17	6	16	1.3	3.1	0.9	2.3	0.6	0.8
82	2.0	7.5	3.8	17	17	12	16	1.6	3.8	1.0	3.0	0.6	0.8
83	3.5	6.9	2.4	11	17	10	16	2.0	3.7	1.5	2.9	0.8	0.8
84	2.8	5.8	2.1	14	17	9	16	1.7	3.9	1.2	2.6	0.7	0.7
85	1.7	5.7	2.8	20	17	10	16	1.4	3.1	0.9	2.3	0.5	0.7

			Yields		NP		NE		FW		GW		SP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
86	2.5	6.8	3.1	14	17	10	16	1.4	3.9	1.1	2.8	0.8	0.7
87	3.1	6.9	2.7	17	17	14	16	2.0	3.5	1.4	2.7	0.7	0.8
88	4.1	6.8	1.9	15	17	12	16	2.1	3.5	1.7	2.7	0.8	0.8
89	2.2	6.0	2.7	11	17	7	16	1.5	3.2	1.0	2.5	0.7	0.8
90	3.7	4.7	0.7	14	17	10	16	1.7	2.6	1.4	1.9	0.9	0.7
91	4.1	4.9	0.6	16	17	7	16	2.4	2.6	1.8	1.9	0.7	0.8
92	4.9	5.6	0.5	14	17	13	16	2.5	3.1	2.0	2.3	0.8	0.8
93	4.6	6.7	1.5	16	17	14	16	2.5	3.6	1.9	2.8	0.8	0.8
94	3.0	5.9	2.1	16	17	12	16	1.9	3.2	1.4	2.4	0.7	0.7
95	2.2	6.7	3.2	12	17	5	16	1.3	3.6	0.9	2.8	0.8	0.8
96	3.8	7.2	2.4	13	17	12	16	2.1	3.6	1.6	2.8	0.8	0.8
97	3.0	7.5	3.1	12	17	9	16	1.5	4.3	1.1	3.2	0.8	0.7
98	3.5	7.6	3.0	16	17	13	16	2.0	4.1	1.5	3.1	0.7	0.8
99	2.9	6.5	2.6	16	17	10	16	1.6	3.5	1.2	2.7	0.8	0.8
100	2.8	4.9	1.5	15	17	12	16	1.5	2.5	1.2	1.9	0.8	0.7
101	3.3	6.9	2.6	15	17	14	16	2.2	3.7	1.5	2.8	0.7	0.8
102	2.5	6.6	2.9	16	17	9	16	1.5	3.4	1.1	2.6	0.8	0.8
103	2.8	6.9	2.9	13	17	9	17	1.7	3.2	1.2	2.5	0.8	0.8
104	3.5	6.4	2.0	14	17	10	16	2.0	3.4	1.5	2.6	0.8	0.8
105	4.4	6.4	1.5	13	17	14	16	2.6	3.5	1.9	2.6	0.7	0.8
106	3.2	7.5	3.0	13	13	10	11	1.7	4.0	1.3	3.1	0.8	0.8
107	3.8	8.0	3.0	19	17	16	17	2.1	4.3	1.6	3.3	0.8	0.8
108	2.3	7.4	3.6	11	17	8	16	1.3	3.8	1.0	3.0	0.8	0.8
109	3.6	8.9	3.8	13	17	10	16	2.1	4.5	1.6	3.5	0.8	0.8
110	3.6	7.2	2.6	15	17	14	16	2.0	3.7	1.5	2.9	0.8	0.8
111	2.8	6.0	2.3	17	17	11	16	1.5	3.0	1.2	2.4	0.8	0.8
112	2.6	6.2	2.6	14	17	11	17	1.5	3.3	1.1	2.5	0.8	0.8
113	3.1	6.5	2.3	13	17	11	16	2.2	3.3	1.5	2.9	0.6	0.8
114	3.1	6.6	2.5	16	17	12	16	1.8	3.5	1.3	2.7	0.7	0.8

			Yields		NP		NE		FW		GW		SP
Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
115	3.0	6.6	2.6	14	17	12	16	2.4	3.4	1.5	2.7	0.7	0.8
116	4.6	7.0	1.7	14	17	14	16	2.6	3.6	1.9	2.8	0.8	0.8
117	3.1	6.9	2.7	17	17	13	16	1.8	3.4	1.3	2.7	0.8	0.8
118	4.2	7.7	2.5	12	17	14	16	2.4	4.0	1.8	3.1	0.8	0.8
119	3.0	6.6	2.5	14	17	11	16	1.7	3.2	1.3	2.6	0.8	0.8
120	2.8	7.2	3.1	14	17	12	16	1.5	3.6	1.1	2.8	0.8	0.8
121	3.3	8.4	3.6	14	17	12	17	1.9	4.1	1.4	3.3	0.7	0.8
122	4.0	8.9	3.5	15	17	13	17	2.1	4.8	1.6	3.6	0.8	0.8
123	3.9	7.4	2.5	16	17	13	16	2.1	3.7	1.6	2.9	0.8	0.8
124	2.7	7.1	3.1	16	17	10	16	2.2	3.6	1.3	2.8	0.5	0.8
125	3.6	7.3	2.6	16	17	14	17	2.1	3.9	1.6	2.9	0.6	0.8
126	2.7	7.2	3.2	11	17	9	16	1.6	3.7	1.2	2.9	0.8	0.8
127	5.0	8.3	2.3	13	17	11	17	2.7	4.1	2.1	3.2	0.8	0.8
128	3.6	7.6	2.8	15	17	12	16	2.0	3.8	1.5	3.0	0.8	0.8
129	3.9	6.6	1.9	16	17	13	16	2.1	3.4	1.6	2.7	0.8	0.8
130	4.5	6.3	1.2	17	17	12	16	2.4	3.3	1.8	2.5	0.8	0.8
131	3.7	7.5	2.7	14	17	13	16	2.2	4.0	1.6	3.1	0.7	0.8
132	3.9	6.4	1.8	14	17	12	16	2.2	3.3	1.6	2.6	0.8	0.8
133	3.9	5.8	1.3	17	17	14	16	2.1	3.0	1.6	2.3	0.8	0.8
134	5.0	7.8	2.0	15	17	14	16	2.9	3.9	2.1	3.1	0.7	0.8
135	2.3	6.1	2.7	20	17	9	16	1.2	3.1	0.9	2.4	0.8	0.8
136	2.8	6.0	2.2	8	17	9	16	1.5	3.1	1.1	2.4	0.8	0.8
137	2.0	5.7	2.6	13	17	6	16	1.1	2.9	0.9	2.2	0.8	0.8
138	3.6	5.8	1.6	16	17	13	16	2.0	3.4	1.5	2.5	0.8	0.7
139	3.3	5.2	1.4	16	17	13	17	2.4	2.9	1.6	2.2	0.7	0.7
140	4.3	5.9	1.1	9	17	8	17	2.4	3.1	1.8	2.4	0.8	0.8
141	3.3	7.9	3.2	16	17	11	16	1.8	4.1	1.4	3.2	0.8	0.8
142	2.1	6.1	2.9	13	17	11	16	1.4	3.3	0.9	2.5	0.6	0.8
143	3.6	6.1	1.7	16	16	13	16	1.7	3.6	1.3	2.6	0.8	0.7

		Yields			NP		NE		FW		GW		SP	
	Entry	RD	OPT Pot	StDev	RD	OPT	RD	OPT	RD	OPT	RD	OPT	RD	OPT
	144	2.3	6.5	3.0	16	17	11	16	1.3	3.6	0.9	2.7	0.7	0.8
	145	2.0	6.2	3.0	16	17	6	16	1.2	3.0	0.9	2.4	0.4	0.8
	146	4.3	6.6	1.7	14	17	14	16	2.4	3.5	1.8	2.7	0.8	0.8
	147	3.4	5.1	1.3	15	17	11	16	1.9	2.7	1.5	2.0	0.8	0.8
	148	5.0	5.7	0.4	12	17	13	16	2.7	3.1	2.1	2.3	0.8	0.7
	149	3.3	6.8	2.5	16	17	13	16	1.8	3.6	1.4	2.8	0.8	0.8
	150	3.5	6.0	1.8	16	17	13	16	1.9	3.3	1.5	2.5	0.8	0.7
	151	4.5	6.5	1.4	14	17	13	16	2.6	3.5	1.9	2.7	0.8	0.8
	152	3.0	6.3	2.3	15	17	10	16	1.6	3.5	1.2	2.6	0.8	0.7
	153	4.6	7.2	1.9	17	17	16	17	2.6	3.9	2.0	3.0	0.8	0.8
	154	3.7	5.1	1.0	15	17	14	16	2.0	2.8	1.6	2.2	0.8	0.8
	155	2.6	9.0	4.5	15	17	10	16	1.5	4.4	1.1	3.5	0.8	0.8
	156	3.1	5.9	2.0	17	17	12	16	1.7	3.1	1.3	2.4	0.8	0.8
	157	2.9	5.9	2.1	15	17	10	16	1.7	3.1	1.3	2.4	0.8	0.8
	158	3.9	7.8	2.7	17	17	14	16	2.2	3.8	1.7	3.0	0.8	0.8
	159	3.6	7.8	3.0	15	17	15	17	2.2	3.8	1.6	3.0	0.7	0.8
	160	2.7	6.2	2.4	14	17	12	16	1.5	3.0	1.1	2.4	0.8	0.8
sites		1	1		1	1	1	1	1	1	1	1	1	1
CV (%)		32	15		19	3	11	4	1	14	28	15	14	3
Lsd		2	2		6	1	7	1	1	1	1	1	0	0
Max		6	9		17	17	18	17	3	1	3	4	1	1
Min		2	5		8	12	5	11	1	5	1	2	0	1
Grand mean		3	6.8		15	17	7	16	2	4	1	3	1	1
MSg		1.6	2.0		7.5	12.5	11.5	0.4	0.4	0.4	0.2	0.3	0.01	0.001
Mse		1.2	1.1		7.8	0.3	12.7	0.5	0.3	0.2	0.2	0.2	0.01	0.001
H (%)		14	30		2.3	95	2.6	8	17	26	17	28	12	73

Appendix 4.5: Mean grain yield and yield components for heterotic group B across three environments

Entry	GY	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP
1	2.87	96.33	0.33	78.89	0.77	0.91	0.70	10.17	13.67	141.80	96.67	0.73
2	2.27	95.83	2.00	68.78	0.81	0.79	0.52	8.50	11.50	123.00	97.83	0.72
3	2.63	95.33	1.17	68.28	0.83	0.86	0.63	9.50	13.00	125.20	96.50	0.75
4	4.71	90.00	1.00	81.11	0.97	1.87	1.44	14.00	14.83	148.30	91.00	0.77
5	3.01	93.83	1.00	74.22	0.87	1.08	0.86	9.00	11.33	134.90	94.83	0.77
6	2.99	92.00	1.17	83.50	0.91	0.97	0.74	12.33	14.67	146.10	93.17	0.77
7	3.43	90.67	0.83	85.39	0.92	1.24	0.95	13.17	15.00	156.00	91.50	0.76
8	2.95	95.83	1.83	80.50	0.71	1.03	0.76	8.83	14.67	150.70	90.83	0.78
9	4.01	92.50	0.33	99.00	0.90	1.93	1.29	13.50	15.00	171.60	97.67	0.69
10	4.30	91.33	0.83	93.72	0.94	1.55	1.23	11.67	12.67	168.70	92.83	0.77
11	3.17	93.50	0.67	73.33	1.09	1.07	0.81	11.67	12.33	139.70	92.17	0.76
12	3.35	96.67	1.33	84.33	0.76	1.03	0.83	11.83	15.17	152.20	94.17	0.75
13	3.53	94.00	0.67	81.94	0.87	1.18	1.12	11.67	13.50	144.80	98.00	0.77
14	2.98	94.33	0.50	71.11	0.68	0.99	0.74	8.67	13.00	129.80	94.67	0.76
15	2.39	95.33	4.67	76.11	0.56	0.72	0.52	5.83	13.50	140.40	94.83	0.72
16	2.51	92.67	0.33	75.50	0.62	0.83	0.57	6.83	12.17	136.60	100.00	0.70
17	3.07	97.00	0.50	83.83	0.93	1.16	0.83	11.17	12.50	140.10	93.00	0.63
18	2.74	93.33	1.17	76.89	0.98	1.05	0.72	9.17	11.67	137.00	97.50	0.71
19	3.10	97.17	1.00	73.61	0.84	1.08	0.80	10.17	13.50	140.90	94.50	0.74
20	4.51	93.83	1.33	90.39	0.97	1.44	1.21	11.17	12.83	161.70	98.17	0.83
21	3.19	96.67	2.33	85.33	0.79	1.09	0.82	11.67	14.67	143.00	95.17	0.74
22	3.31	95.33	2.00	99.83	0.80	1.08	0.84	11.50	15.67	165.60	99.00	0.75
23	3.38	93.83	1.33	87.50	0.80	1.10	0.86	10.33	13.67	149.30	97.33	0.78
24	4.06	97.50	1.50	80.06	0.92	1.49	1.16	12.83	14.50	137.20	95.17	0.75
25	3.07	94.33	1.00	75.44	0.83	1.01	0.78	11.17	13.83	141.10	99.00	0.77
26	2.93	96.67	0.67	61.28	0.81	0.90	0.69	8.67	11.50	116.80	95.33	0.79
27	3.25	94.83	2.33	75.44	0.71	1.08	0.84	9.67	14.17	135.30	97.33	0.78
28	3.81	91.33	0.33	87.11	0.84	1.35	1.05	12.83	15.33	154.30	97.17	0.78
29	3.04	100.17	1.00	72.33	0.77	0.99	0.72	7.67	10.50	145.10	91.67	0.71
30	3.63	96.50	0.67	76.94	0.71	0.90	0.67	11.00	15.33	142.10	101.17	0.74
31	4.77	93.33	0.83	84.17	1.02	1.38	1.04	12.67	13.50	151.20	97.17	0.76
32	4.12	94.17	1.17	83.83	0.90	1.17	0.90	13.17	15.17	147.70	94.17	0.77
33	4.73	92.67	0.17	90.28	0.97	1.40	1.13	13.33	14.33	158.60	95.33	0.80
34	4.30	95.00	1.50	88.78	0.77	1.21	0.96	10.17	13.67	141.70	92.83	0.76
35	4.05	93.50	0.83	93.56	0.88	1.26	0.93	11.50	13.83	165.90	96.50	0.74
36	4.23	91.17	1.17	79.89	0.88	1.25	0.97	12.67	15.17	142.90	94.33	0.77
37	3.69	95.50	2.50	74.89	0.76	1.09	0.81	9.67	14.17	135.40	92.33	0.78
38	3.45	95.50	2.50	72.39	1.03	0.83	0.66	9.83	12.33	122.60	98.00	0.76
39	3.53	95.00	1.00	80.50	0.86	1.08	0.73	11.50	14.67	138.30	98.00	0.76
40	5.00	92.83	1.00	89.89	0.99	1.75	1.35	12.67	13.00	171.00	96.00	0.75
41	3.79	95.00	2.00	81.06	0.83	1.27	0.89	11.50	15.17	146.10	93.83	0.70
42	3.53	93.50	1.17	72.72	0.80	0.97	0.73	10.50	13.83	136.30	97.00	0.76

Entry	GY	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP
43	3.70	92.00	1.50	81.61	0.93	1.04	0.80	12.00	13.50	153.00	94.67	0.76
44	4.81	93.33	1.17	88.78	0.88	1.33	1.03	12.00	13.67	156.10	93.50	0.77
45	4.28	93.33	1.33	94.72	0.83	1.54	1.09	10.33	14.50	171.60	94.50	0.72
46	3.90	93.50	2.00	89.72	0.80	1.18	0.91	11.33	14.50	166.80	94.67	0.77
47	4.18	92.33	1.00	88.56	0.89	1.22	0.95	12.00	15.00	157.10	95.50	0.77
48	4.04	95.17	1.17	82.11	0.92	1.17	0.91	12.33	14.00	144.70	93.33	0.76
49	4.05	92.00	1.00	78.06	0.85	1.27	0.95	12.67	15.00	146.30	96.33	0.74
50	4.08	94.17	1.67	76.56	0.93	1.25	0.94	12.17	13.17	138.10	93.00	0.70
51	4.38	92.17	1.83	81.89	0.93	1.39	1.05	13.83	15.00	143.90	95.83	0.75
52	3.84	94.67	0.33	73.17	0.84	1.11	0.84	11.67	14.33	136.20	94.00	0.77
53	4.22	94.50	0.50	82.56	0.83	1.31	0.99	11.00	13.33	148.20	95.00	0.78
54	4.47	91.50	1.17	79.56	0.92	1.44	1.10	12.17	13.67	142.20	95.00	0.77
55	4.51	89.33	1.83	84.50	0.88	1.37	1.07	12.33	14.67	153.10	92.67	0.78
56	4.02	92.50	0.67	79.17	0.98	1.28	0.95	11.67	12.50	144.90	91.17	0.72
57	4.01	94.00	0.67	81.50	0.83	1.12	0.87	11.83	14.83	147.90	93.17	0.79
58	4.93	89.50	1.33	94.61	1.06	1.51	1.22	15.50	14.00	166.70	94.67	0.80
59	3.64	93.67	1.50	86.72	0.87	0.98	0.75	11.67	14.00	148.10	95.17	0.75
60	4.32	93.67	1.17	85.56	0.88	1.27	0.99	13.50	15.83	142.30	94.83	0.78
61	3.51	98.50	0.33	64.94	0.68	0.90	0.69	7.83	13.50	122.60	98.83	0.64
62	3.30	96.17	1.00	69.89	0.72	0.94	0.67	8.50	13.33	115.00	97.17	0.69
63	3.61	94.33	-0.83	81.50	0.86	0.96	0.73	10.83	12.83	140.60	93.50	0.78
64	2.37	98.00	-1.17	64.89	0.96	0.69	0.52	7.50	10.00	134.70	93.33	0.75
65	5.10	92.67	0.83	95.83	0.91	1.69	1.25	13.50	15.00	163.50	93.50	0.74
66	3.34	96.67	1.17	81.44	0.83	0.83	0.63	9.83	12.00	143.90	97.83	0.77
67	3.60	96.33	0.83	77.17	0.88	1.03	0.76	10.50	12.83	143.10	97.17	0.74
68	3.84	96.17	2.83	84.39	0.73	1.00	0.80	10.67	15.17	149.10	99.00	0.76
69	5.57	95.17	0.83	96.83	0.94	1.76	1.34	12.50	13.67	172.90	96.00	0.76
70	4.62	95.00	1.17	89.67	0.84	1.52	1.16	11.83	14.50	160.00	96.17	0.73
71	3.67	95.00	1.50	81.89	0.87	1.07	0.79	12.00	14.17	144.60	96.50	0.74
72	3.45	95.33	1.33	95.89	0.85	1.13	0.78	11.67	14.17	160.70	96.67	0.66
73	3.85	92.67	0.33	79.28	0.93	1.15	0.87	14.00	15.00	139.80	93.00	0.76
74	3.36	95.17	0.17	70.56	0.82	1.02	0.72	11.33	14.33	137.10	95.33	0.70
75	4.02	93.33	0.83	79.00	0.88	1.09	0.87	10.83	13.50	142.90	94.17	0.79
76	3.66	95.00	-0.33	78.17	0.84	1.04	0.78	10.00	12.83	139.70	94.67	0.74
77	3.77	93.00	0.83	83.33	0.81	0.98	0.77	11.17	14.50	148.50	93.83	0.79
78	3.43	94.33	1.17	78.67	0.73	0.82	0.64	9.00	12.17	138.00	95.50	0.79
79	3.31	92.83	1.50	86.39	0.79	0.97	0.68	10.83	14.17	157.20	94.33	0.68
80	4.10	91.67	0.17	87.39	0.95	1.27	0.96	14.00	15.50	156.10	91.83	0.76
81	5.19	91.50	-0.17	100.72	0.96	1.64	1.28	13.83	14.67	172.10	91.33	0.78
82	3.62	90.83	1.00	94.61	1.16	1.18	0.91	12.00	13.83	157.40	91.83	0.78
83	4.26	92.17	0.00	89.11	0.98	1.37	1.01	14.50	15.00	148.40	92.17	0.73
84	4.17	92.00	-0.17	86.14	0.81	1.21	0.94	12.17	14.67	136.10	91.83	0.80
85	3.14	94.50	1.50	71.11	0.78	0.82	0.59	9.67	13.17	123.60	96.00	0.73
86	3.40	95.83	-0.83	66.28	0.94	0.83	0.64	9.67	11.33	123.70	95.00	0.78
87	3.64	94.83	-0.17	75.94	0.91	0.99	0.75	11.33	12.50	140.50	94.50	0.73
88	4.11	93.67	0.50	83.61	0.87	1.23	0.94	12.00	15.00	152.30	94.17	0.77
89	4.14	90.17	0.83	89.33	0.80	1.32	0.98	11.67	15.00	151.00	91.00	0.75
90	4.75	93.50	0.33	84.33	1.81	2.02	1.44	13.17	12.17	155.00	93.83	0.72

Entry	GY	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP
91	3.32	93.50	0.50	79.94	0.99	0.89	0.65	10.50	10.83	140.30	94.00	0.74
92	5.05	92.83	1.17	85.61	0.98	1.69	1.31	13.50	14.17	162.80	94.00	0.77
93	4.69	92.17	-1.00	85.89	1.03	1.53	1.17	12.17	12.17	156.10	91.17	0.77
94	3.65	90.50	0.50	107.78	0.90	1.26	0.82	11.67	13.33	172.80	91.00	0.68
95	4.01	91.50	0.33	83.94	0.96	1.15	0.90	11.50	12.17	153.70	91.83	0.78
96	4.00	93.00	1.67	83.56	0.93	1.28	0.94	11.17	12.67	148.80	94.67	0.73
97	5.08	93.17	1.67	88.06	0.86	1.29	0.98	11.33	13.50	164.60	94.83	0.76
98	3.82	94.00	1.33	97.72	0.89	1.07	0.82	10.67	12.50	162.20	95.33	0.77
99	4.05	96.50	1.50	88.78	0.83	1.11	0.88	8.50	12.67	231.00	98.00	0.79
100	4.23	93.83	1.17	80.83	0.88	1.32	1.00	10.00	12.00	153.20	95.00	0.76
101	4.84	92.50	0.33	84.28	0.87	1.59	1.23	12.17	14.17	156.40	92.83	0.78
102	3.98	96.67	0.33	91.11	1.06	1.44	1.02	9.00	12.00	161.60	97.00	1.37
103	3.84	92.17	1.67	79.06	0.99	1.09	0.84	10.83	11.83	140.30	93.83	0.74
104	3.60	96.50	-0.83	77.94	1.00	1.24	0.99	12.67	14.17	148.70	95.67	0.77
105	3.96	92.67	2.17	92.11	0.91	1.45	0.99	11.83	13.83	155.40	94.83	0.69
106	3.97	92.50	1.33	83.61	0.77	1.16	0.89	9.00	11.83	146.40	93.83	0.77
107	4.09	93.67	0.67	78.61	0.80	1.19	0.92	12.00	15.00	148.50	94.33	0.78
108	3.80	93.50	1.83	94.06	0.80	1.06	0.81	11.50	14.17	154.70	95.33	0.77
109	4.76	92.83	1.33	90.06	0.92	1.56	1.20	13.00	14.67	158.90	94.17	0.77
110	3.76	97.00	-0.33	78.83	0.78	1.18	0.85	11.17	14.50	142.60	96.67	0.77
111	4.54	94.33	0.67	93.44	0.85	1.41	1.09	11.83	14.67	162.70	95.00	0.78
112	4.66	91.00	0.33	96.44	0.85	1.48	1.16	12.33	14.67	164.40	91.33	0.78
113	4.23	90.83	1.17	86.61	0.97	1.29	0.98	11.67	13.33	154.20	92.00	0.79
114	3.20	96.17	2.17	79.72	0.66	0.80	0.59	10.00	15.67	141.60	98.33	0.73
115	4.19	93.83	0.33	90.22	0.95	1.46	1.03	14.00	15.17	164.30	94.17	0.72
116	4.44	93.50	1.00	89.28	0.87	1.35	1.05	12.33	14.50	159.10	94.50	0.76
117	4.99	94.17	1.67	90.72	0.96	1.77	1.33	13.33	14.50	162.90	95.83	0.76
118	3.25	96.50	1.83	85.17	0.72	0.74	0.56	8.83	12.50	151.80	98.33	0.73
119	3.57	96.50	2.50	84.83	0.73	0.96	0.73	8.50	12.33	147.40	99.00	0.78
120	4.28	98.00	0.67	95.44	0.83	1.43	1.06	12.00	14.00	159.90	98.67	0.75
121	4.20	93.17	1.50	85.94	0.97	1.19	0.93	13.33	14.33	152.20	94.67	0.78
122	3.97	90.83	1.17	96.72	0.79	1.21	0.89	11.83	15.50	155.40	92.00	0.73
123	4.05	94.33	1.83	93.67	0.92	1.28	0.95	13.17	14.83	163.00	96.17	0.74
124	4.30	94.00	1.50	93.67	0.96	1.19	0.97	11.50	12.67	162.60	95.50	0.83
125	4.10	91.00	1.00	85.33	0.95	1.43	1.01	10.67	12.17	152.40	92.00	0.74
126	4.42	93.33	1.00	95.00	0.89	1.35	1.05	11.50	13.17	168.60	94.33	0.78
127	4.53	92.17	1.33	84.22	0.92	1.43	1.10	13.67	15.83	146.10	93.50	0.77
128	4.72	91.33	0.83	98.39	0.97	1.60	1.20	14.00	15.00	168.80	92.17	0.75
129	4.41	93.83	4.17	90.44	0.81	1.31	1.03	12.67	16.00	153.60	98.00	0.79
130	3.12	97.83	3.00	86.00	0.71	0.71	0.53	9.83	14.17	145.70	100.83	0.77
131	4.02	95.17	0.67	87.61	0.89	1.11	0.87	12.67	14.67	159.30	95.83	0.80
132	4.37	93.00	1.00	100.83	0.84	1.36	1.04	12.67	15.17	166.60	94.00	0.77
133	3.85	92.50	2.17	82.78	0.81	1.04	0.80	12.00	16.00	148.40	94.67	0.78
134	3.77	94.50	0.67	77.22	0.85	1.12	0.84	11.17	13.67	138.40	95.17	0.75
135	3.61	97.17	2.17	89.11	0.78	1.05	0.77	9.17	13.00	145.40	99.33	0.74
136	4.04	91.83	1.83	85.22	0.78	1.24	0.94	10.67	13.83	150.90	93.67	0.76
137	4.27	90.83	1.67	82.72	0.94	1.38	1.03	12.83	14.83	143.60	92.50	0.74
138	2.96	91.17	2.50	77.17	0.53	0.82	0.54	7.17	14.17	142.10	93.67	0.67

Entry	GY	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP
139	4.61	90.33	0.67	85.39	0.91	1.48	1.13	13.00	14.67	152.70	91.00	0.77
140	4.05	94.83	0.17	81.06	0.84	1.28	0.96	11.83	14.67	140.80	95.00	0.74
141	3.60	96.33	3.67	80.94	0.83	1.02	0.76	11.00	13.83	137.20	100.00	0.73
142	3.97	95.83	1.83	85.50	0.91	1.05	0.82	11.67	14.00	155.90	97.67	0.77
143	3.46	93.00	2.00	93.89	0.90	0.96	0.70	10.00	11.50	165.60	95.00	0.73
144	3.86	93.50	1.00	85.39	0.84	1.23	0.88	11.83	14.33	148.30	94.50	0.70
145	4.36	92.17	0.83	82.03	0.90	1.33	1.03	11.17	13.17	144.80	93.00	0.77
146	4.71	92.17	1.17	95.22	0.97	1.40	1.13	11.33	12.50	157.40	93.33	0.80
147	4.03	94.00	1.00	87.56	0.79	1.14	0.88	11.67	15.50	150.30	95.00	0.77
148	3.86	93.67	2.00	94.06	0.92	1.20	0.89	11.67	13.17	165.50	95.67	0.73
149	4.28	90.83	1.50	94.28	0.88	1.36	1.03	13.67	16.00	159.90	92.33	0.77
150	4.40	94.17	1.00	89.44	0.87	1.35	1.04	12.50	15.00	156.30	95.17	0.78
151	3.26	93.50	1.50	86.44	0.95	0.95	0.65	10.50	12.00	144.70	95.00	0.72
152	4.19	92.50	0.83	89.89	0.88	1.36	1.01	13.17	15.33	158.80	93.33	0.74
153	4.55	92.33	1.33	96.00	0.87	1.39	1.10	11.67	13.83	165.30	93.67	0.79
154	3.76	93.67	1.00	91.11	0.88	1.16	0.85	11.33	13.50	159.20	94.67	0.73
155	4.08	95.83	2.50	95.94	0.77	1.21	0.92	10.33	13.67	162.90	98.33	0.77
156	3.02	96.33	2.17	72.94	0.81	0.72	0.52	8.33	10.67	132.70	98.50	0.73
157	3.76	92.83	1.50	87.39	0.96	1.08	0.82	9.83	11.33	148.90	94.33	0.77
158	3.34	94.00	1.50	74.61	0.84	1.02	0.78	9.33	12.50	143.70	95.50	0.77
159	4.55	91.33	0.17	97.56	0.95	1.52	1.15	13.00	14.17	168.60	91.50	0.75
160	3.74	92.17	1.33	92.72	0.99	1.29	0.97	9.17	12.50	164.90	93.50	0.75
Cross mean	3.89	93.83	1.13	85	0.9	1.2	0.91	11	14	150	94.94	0.8
CV (%)	22.5	3.90	175.4	16.3	31.1	35.2	35.3	28.4	17.6	17.4	4.4	19.4
LSD (0.05)	0.995	4.13	2.25	15.6	0.31	0.48	0.364	3.6	2.7	29.7	4.785	0.17
F-Test	**	**	ns	***	ns	**	**	**	**	**	**	**
Maximum	5.572	100.2	4.667	107.78	1.807	2.023	1.44	15.5	16	231	101.17	0.6324
Minimum	2.27	89.33	-1.167	61.28	0.527	0.69	0.515	5.83	10	115	90.83	1.368

***= significantly different at 0.001 probability level; AD = days to 50% anthesis; ASI= anthesis-silking days interval, SD=Days to 50% silking, EH= Ear height, EP ear per plant, SP= shelling percentage, GW= grain weight, FW= field weight, NP = number of plants per plot, PH= plant height and NE number of ear per plot and GY=grain yields (t/ha).

Appendix 4.6: Mean grain yield and yield components for heterotic group A across environments

Entry	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	YD
1	78.25	0.75	106.08	0.96	2.17	1.71	15.75	16.25	190.90	79.00	0.78	4.32
2	83.00	2.00	88.17	0.60	0.74	0.58	7.00	13.25	147.60	85.00	0.67	1.46
3	80.75	0.50	102.33	0.97	1.28	0.96	13.25	13.75	173.50	81.25	0.73	-0.20
4	76.00	1.00	94.92	0.83	1.45	1.16	14.00	17.50	171.90	77.00	0.80	2.98
5	77.25	1.25	86.67	0.79	1.12	0.87	12.50	15.75	154.50	78.50	0.77	2.14
6	79.75	1.00	109.50	0.78	1.38	1.10	13.25	17.50	184.00	80.75	0.80	2.79
7	79.25	1.25	99.67	0.82	1.43	1.11	12.75	15.50	183.20	80.50	0.78	2.72
8	75.50	1.00	101.00	1.13	2.00	1.58	16.00	14.25	170.20	76.50	0.79	4.01
9	80.25	1.00	89.92	0.89	0.88	0.70	9.50	11.00	150.70	81.25	0.79	1.76
10	77.00	0.50	96.25	0.94	1.71	1.34	11.50	12.25	177.10	77.50	0.78	3.34
11	85.75	1.25	87.92	0.62	0.88	0.72	9.50	15.50	155.30	88.50	0.81	1.86
12	82.25	1.75	82.83	0.68	0.93	0.74	9.75	14.25	140.20	84.00	0.78	1.93
13	78.75	1.25	99.92	0.81	1.63	1.27	13.00	16.00	175.20	80.00	0.78	3.16
14	79.00	0.50	99.83	0.88	1.15	0.92	10.50	12.25	177.50	79.50	0.80	2.34
15	76.00	1.00	109.42	1.08	2.09	1.65	15.25	14.50	191.50	77.00	0.78	4.17
16	78.25	0.75	104.92	0.79	1.40	1.14	11.50	14.75	182.20	79.00	0.80	3.00
17	84.00	1.75	87.58	0.79	1.21	0.95	9.75	12.75	156.20	85.75	0.80	2.36
18	80.75	0.50	86.83	0.86	1.28	0.95	11.25	13.00	158.10	81.25	0.75	2.25
19	78.00	1.25	96.67	0.83	1.42	1.12	12.00	14.75	172.60	79.50	0.78	2.81
20	77.75	1.75	97.33	0.85	1.50	1.24	13.00	15.75	167.50	79.50	0.82	3.28
21	80.50	3.50	111.83	0.79	1.15	0.93	11.50	14.75	183.40	84.00	0.82	2.38
22	81.50	0.75	80.17	0.76	1.24	0.98	11.25	14.75	144.70	82.25	0.78	2.44
23	80.50	1.00	104.58	0.93	2.26	1.72	12.75	13.25	188.20	81.50	0.72	4.21
24	81.50	2.75	91.83	0.70	1.08	0.89	11.00	15.75	157.10	84.25	0.82	2.35
25	80.25	0.00	99.92	0.89	1.27	1.02	12.75	14.50	175.60	80.25	0.80	2.63
26	83.00	2.00	85.67	0.73	0.75	0.59	9.00	13.00	154.90	85.75	0.77	1.44
27	78.75	0.25	104.83	0.82	1.42	1.13	11.75	14.25	180.80	79.00	0.78	2.87
28	79.50	2.75	99.83	0.80	0.99	0.80	8.25	11.00	183.20	82.25	0.80	2.06
29	79.75	4.25	93.75	0.79	1.05	0.75	12.50	16.00	164.20	84.00	0.71	1.83
30	79.50	0.75	104.83	0.87	1.55	1.24	12.25	14.25	177.70	80.25	0.80	3.14
31	78.75	2.00	88.92	0.96	1.90	1.49	16.00	16.75	174.40	80.75	0.78	3.73
32	79.50	0.25	78.50	0.63	1.25	1.02	9.75	15.75	153.10	79.75	0.84	2.66
33	78.25	1.25	100.50	0.86	1.56	1.24	14.25	16.50	183.10	79.50	0.78	3.19
34	76.75	1.50	101.58	0.80	1.80	1.45	13.50	16.50	184.90	78.25	0.79	3.75
35	81.25	2.50	99.17	0.84	1.47	1.22	11.00	13.25	168.10	83.75	0.84	3.20
36	80.50	1.50	86.25	0.59	1.00	0.80	9.00	15.25	166.60	82.00	0.81	2.04
37	78.00	0.50	103.58	0.94	1.59	1.24	14.75	16.25	180.30	78.50	0.78	3.12
38	79.75	2.00	89.67	0.87	1.20	0.98	11.00	13.00	167.80	81.75	0.82	2.56
39	79.50	1.00	91.42	0.95	1.46	1.16	12.75	13.00	166.70	80.50	0.79	2.96
40	80.50	0.75	88.17	0.70	0.87	0.72	8.75	12.25	157.40	81.25	0.83	1.89
41	79.75	0.00	94.33	0.77	1.32	1.01	10.00	13.25	176.40	79.75	0.81	2.45
42	80.75	1.75	96.83	0.83	1.47	1.15	12.25	15.00	172.50	82.50	0.79	2.80
43	79.25	0.75	111.42	0.85	1.53	1.25	11.75	14.25	187.90	80.00	0.81	3.29
44	80.25	2.25	86.42	0.70	1.02	0.78	10.75	15.75	156.10	82.50	0.78	1.92
45	80.75	0.75	95.33	0.74	1.51	1.18	11.75	16.25	163.70	81.50	0.79	2.96

Entry	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	YD
46	83.50	0.75	89.00	0.71	1.07	0.84	12.00	17.00	150.60	84.25	0.70	2.13
47	84.75	2.25	90.33	0.55	0.90	0.71	7.75	14.25	147.70	87.00	0.75	1.87
48	78.75	1.00	97.33	0.81	1.17	0.95	11.50	14.25	184.50	79.75	0.82	2.48
49	83.50	1.25	93.25	0.78	1.45	1.15	11.25	14.50	164.10	84.75	0.79	2.88
50	79.00	0.50	91.00	0.86	1.51	1.18	13.75	16.00	152.80	79.50	0.79	2.91
51	82.75	1.50	92.67	0.74	1.02	0.76	10.50	14.25	155.10	84.25	0.73	1.82
52	81.50	1.50	78.92	0.83	0.35	0.26	6.00	10.00	154.30	83.00	0.73	0.65
53	81.50	3.25	95.33	0.88	1.21	0.94	10.50	12.50	169.80	84.75	0.78	2.37
54	82.25	1.25	88.17	0.74	1.21	0.95	12.50	16.75	162.40	83.50	0.79	2.34
55	80.00	-0.25	87.67	0.93	1.16	0.95	11.00	12.25	170.30	79.75	0.81	2.46
56	80.75	0.75	92.42	0.64	0.92	0.77	8.75	16.25	146.30	81.50	0.80	2.06
57	76.75	0.25	98.00	0.99	1.34	1.07	12.00	12.75	185.70	77.00	0.80	2.73
58	77.75	0.75	93.50	0.80	1.49	1.21	12.25	15.50	178.00	78.50	0.81	3.14
59	81.50	1.50	100.92	0.75	1.15	0.90	11.00	14.75	149.40	83.00	0.81	2.28
60	78.75	1.50	89.83	0.77	1.20	0.92	10.50	14.75	160.90	80.25	0.77	2.23
61	83.25	0.00	100.92	0.90	1.30	0.96	13.00	14.50	166.60	83.25	0.74	2.29
62	79.00	1.25	89.42	0.82	1.91	1.45	11.50	14.00	166.70	80.25	0.74	3.56
63	83.00	1.75	99.50	0.72	1.25	0.88	10.25	14.50	190.90	84.75	0.73	1.99
64	81.00	1.50	99.33	0.94	1.67	1.25	13.75	14.75	168.20	82.50	0.74	2.98
65	81.25	2.00	94.25	0.66	0.91	0.68	10.25	15.50	174.60	83.25	0.76	1.70
66	80.25	0.75	85.75	0.69	0.91	0.55	10.50	15.50	177.20	81.00	0.64	1.10
67	85.00	-0.50	73.00	0.65	0.54	0.43	8.00	12.25	155.60	84.50	0.78	1.06
68	84.50	3.00	89.17	0.65	1.02	0.76	10.00	15.50	155.90	87.50	0.75	1.86
69	83.00	1.00	97.25	0.68	1.02	0.75	9.25	13.75	168.20	84.00	0.74	1.76
70	81.25	0.75	79.00	0.82	1.01	0.78	11.75	14.25	148.50	82.00	0.77	1.91
71	83.25	4.50	103.25	0.67	1.03	0.82	9.00	13.50	168.20	87.75	0.79	2.06
72	75.25	2.50	104.00	0.81	1.78	1.42	12.00	15.00	193.70	77.75	0.79	3.56
73	82.00	1.25	95.67	1.03	1.69	1.35	13.00	12.50	178.80	83.25	0.80	3.41
74	82.75	1.25	93.17	0.79	1.85	1.45	12.25	15.50	173.40	84.00	0.77	3.62
75	77.75	0.50	100.17	0.65	1.27	1.05	11.00	17.00	173.90	78.25	0.83	2.77
76	81.75	3.00	92.25	0.66	0.96	0.78	9.50	14.25	163.30	84.75	0.80	2.03
77	82.75	1.00	93.83	0.78	1.47	1.21	12.00	15.25	161.70	83.75	0.83	3.18
78	83.25	0.75	103.50	0.82	1.34	1.01	11.50	14.25	184.90	84.00	0.76	2.40
79	77.75	1.00	88.67	0.78	1.34	1.03	11.00	14.25	159.30	78.75	0.76	2.50
80	75.75	0.75	104.33	1.02	1.77	1.36	13.50	13.00	184.70	76.50	0.76	3.30
81	84.75	1.25	93.33	0.63	0.80	0.62	6.00	10.75	164.50	86.00	0.71	1.57
82	78.50	1.25	90.42	0.84	1.42	1.07	13.25	16.00	165.70	79.75	0.71	2.66
83	80.25	1.75	104.67	0.97	1.46	1.14	12.25	13.00	186.20	82.00	0.78	2.83
84	78.50	2.00	97.50	0.81	1.40	0.90	11.50	14.50	171.40	80.50	0.67	2.00
85	84.25	1.00	87.25	0.63	0.89	0.59	10.75	17.50	148.10	85.25	0.65	1.30
86	79.75	1.25	96.08	0.90	1.27	0.93	12.25	13.75	179.70	81.00	0.74	2.19
87	80.75	1.25	83.75	0.86	1.39	1.05	12.50	15.00	171.20	82.00	0.75	2.57
88	78.75	0.50	96.58	1.06	1.63	1.28	11.00	11.25	168.40	79.25	0.78	3.26
89	84.00	1.25	79.17	0.84	0.96	0.71	9.25	11.75	152.30	85.25	0.75	1.71
90	85.75	2.50	77.75	0.62	0.73	0.60	9.25	14.75	155.20	88.25	0.79	1.63
91	83.75	1.75	79.17	0.50	0.63	0.48	7.00	14.00	147.30	85.50	0.73	1.17
92	79.25	-0.25	92.25	1.07	1.42	1.12	10.25	10.25	175.20	79.00	0.77	2.80
93	76.25	0.00	95.83	0.90	1.69	1.32	14.50	16.25	173.70	76.25	0.78	3.27

Entry	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	YD
94	78.75	3.00	101.50	0.83	1.17	0.85	9.75	12.00	172.00	81.75	0.73	2.00
95	77.75	2.00	84.42	0.69	1.06	0.83	8.00	11.75	173.40	79.75	0.79	2.07
96	79.75	0.00	93.92	0.92	1.52	1.20	13.25	14.50	169.70	79.75	0.79	3.05
97	78.25	2.75	99.83	1.06	1.54	1.13	12.00	12.00	161.30	81.00	0.77	2.68
98	76.75	2.50	98.25	0.85	1.68	1.28	12.25	14.50	174.90	79.25	0.76	3.10
99	84.25	-0.25	88.08	0.98	1.18	0.92	10.75	12.50	156.90	84.00	0.79	2.30
100	82.50	3.00	79.50	0.77	0.67	0.50	8.25	11.75	149.00	85.50	0.77	1.21
101	77.75	2.25	104.00	0.93	1.60	1.16	13.25	14.25	185.60	80.00	0.72	2.71
102	83.75	2.25	91.92	0.69	1.05	0.84	11.25	16.00	161.20	86.00	0.80	2.14
103	79.75	2.75	85.50	0.74	1.00	0.81	9.75	13.50	158.10	82.50	0.80	2.25
104	78.75	2.00	97.83	0.80	1.31	1.03	11.25	14.25	174.50	80.75	0.79	2.56
105	77.00	0.75	94.17	0.88	1.66	1.24	14.50	17.25	162.00	77.75	0.74	2.96
106	77.00	0.25	105.58	0.85	1.31	0.82	11.00	13.25	160.20	77.25	0.65	1.97
107	78.50	4.25	85.83	0.91	1.83	1.42	14.50	16.00	165.90	82.75	0.78	3.50
108	80.50	-1.00	85.25	0.82	1.18	0.95	11.00	13.00	152.60	79.50	0.79	2.42
109	77.75	1.25	111.33	0.92	1.92	1.52	12.75	13.75	184.10	79.00	0.78	3.85
110	78.00	1.25	97.67	0.79	1.45	1.16	12.00	15.25	180.40	79.25	0.80	2.97
111	76.75	1.50	101.00	0.63	0.92	0.75	8.75	14.00	176.30	78.25	0.81	2.01
112	80.00	1.75	77.00	0.80	1.01	0.80	11.25	14.00	155.90	81.75	0.79	2.01
113	78.75	3.25	107.83	0.78	1.56	1.11	12.25	15.25	182.20	82.00	0.70	2.67
114	78.25	2.00	82.58	0.79	1.28	0.99	12.00	15.50	159.70	80.25	0.77	2.44
115	77.00	2.25	91.17	0.87	1.55	1.07	12.00	14.00	162.40	79.25	0.74	2.50
116	77.75	1.25	92.58	0.97	1.72	1.36	14.50	15.00	168.60	79.00	0.79	3.45
117	79.50	2.25	90.83	0.81	1.22	1.00	13.25	16.50	164.20	81.75	0.81	2.61
118	80.00	1.50	112.08	1.01	1.80	1.42	13.00	13.25	198.70	81.50	0.80	3.55
119	79.75	2.00	90.83	0.79	1.11	0.91	11.00	14.00	162.50	81.75	0.81	2.37
120	82.75	2.00	93.33	0.92	1.15	0.94	12.50	13.75	154.10	84.75	0.80	2.46
121	75.75	1.25	95.08	0.88	1.63	1.33	12.25	13.75	189.70	77.00	0.80	3.45
122	75.50	2.00	100.50	0.92	2.08	1.61	14.00	15.25	183.20	77.50	0.77	4.01
123	77.75	1.00	96.75	0.99	1.52	1.22	13.25	13.75	167.90	78.75	0.80	3.16
124	81.50	1.50	91.58	0.83	1.54	1.05	11.00	14.00	164.20	83.00	0.66	2.55
125	82.00	0.00	94.92	0.86	1.63	1.22	13.50	15.75	174.00	82.00	0.69	3.03
126	80.75	3.00	90.08	0.85	1.25	0.99	11.50	13.50	153.00	83.75	0.78	2.52
127	78.25	0.50	96.58	0.89	2.00	1.63	12.00	13.25	177.70	78.75	0.80	4.20
128	75.75	2.25	84.92	0.85	1.50	1.22	12.50	14.75	146.60	78.00	0.80	3.18
129	79.25	2.25	82.75	0.77	1.41	1.13	12.00	15.50	159.00	81.50	0.80	2.87
130	79.50	-0.25	96.83	0.92	1.46	1.17	10.50	12.50	176.50	79.25	0.80	2.94
131	81.25	1.25	108.25	0.92	1.73	1.32	13.75	15.00	176.80	82.50	0.76	3.18
132	76.50	1.25	90.17	0.91	1.37	1.09	11.50	12.50	169.00	77.75	0.79	2.75
133	87.00	1.50	89.17	0.82	1.17	0.96	12.00	14.50	147.00	88.50	0.82	2.50
134	78.00	2.75	91.25	0.97	2.02	1.59	13.75	14.25	159.00	80.75	0.79	3.96
135	82.75	3.25	91.08	0.60	0.79	0.66	9.50	17.00	145.90	86.75	0.82	1.76
136	79.25	-0.75	103.25	1.38	0.90	0.75	8.00	6.50	170.20	78.50	0.82	1.97
137	83.00	0.00	90.08	0.75	0.65	0.53	5.50	9.00	152.30	83.00	0.80	1.37
138	80.25	1.25	106.50	0.94	1.36	1.00	11.50	12.50	169.20	81.50	0.74	2.32
139	81.00	2.00	107.33	0.76	1.30	0.86	10.75	14.00	174.90	83.00	0.70	1.88
140	79.25	2.00	102.67	0.83	1.36	1.08	7.50	9.25	163.00	81.25	0.80	2.73
141	82.00	1.75	103.75	0.85	1.57	1.25	10.50	12.75	179.20	83.75	0.81	3.17

Entry	AD	ASI	EH	EP	FW	GW	NE	NP	PH	SD	SP	YD
142	84.00	1.25	90.08	0.77	0.96	0.71	10.75	14.00	153.80	85.25	0.66	1.74
143	79.75	1.25	103.08	0.82	1.30	0.94	12.50	15.25	169.80	81.00	0.75	2.21
144	79.75	1.75	107.75	1.10	1.08	0.79	13.25	13.50	171.20	81.50	0.72	1.86
145	86.75	-1.25	74.67	0.59	0.83	0.64	9.25	15.25	143.70	85.50	0.76	1.94
146	78.75	1.00	99.92	0.93	1.57	1.23	12.25	13.25	179.20	79.75	0.78	3.06
147	82.25	1.00	100.25	0.74	0.92	0.72	9.50	12.75	174.90	83.25	0.81	1.78
148	80.25	-1.00	80.08	1.02	1.56	1.20	11.00	11.25	151.00	79.25	0.77	2.94
149	79.00	0.50	95.83	0.94	1.33	1.06	12.75	14.25	174.20	79.50	0.80	2.67
150	80.25	2.00	92.00	0.77	1.26	0.96	12.75	16.75	168.60	82.25	0.75	2.31
151	75.25	2.25	92.67	0.91	1.66	1.27	12.50	13.75	178.20	77.75	0.77	3.07
152	78.50	3.00	90.67	0.77	1.17	0.89	12.00	15.50	168.20	81.50	0.77	2.16
153	79.50	1.25	95.58	0.90	1.90	1.44	14.25	15.75	180.20	80.75	0.76	3.47
154	82.25	1.00	64.83	0.79	0.86	0.68	9.00	16.00	130.30	83.25	0.77	1.95
155	79.00	3.50	88.42	0.78	1.57	1.28	13.25	17.00	156.90	82.50	0.80	3.36
156	79.50	4.00	94.25	0.71	1.02	0.80	10.50	14.50	162.40	83.50	0.81	2.02
157	82.00	1.75	86.50	0.71	1.05	0.81	10.00	14.25	153.70	83.75	0.77	1.98
158	76.00	0.75	94.00	0.89	1.61	1.30	12.50	14.25	171.20	76.75	0.81	3.40
159	81.25	2.00	88.17	0.98	1.62	1.29	14.00	14.50	163.10	83.25	0.79	3.32
160	79.00	0.75	89.25	0.78	0.90	0.77	10.25	13.00	154.60	79.75	0.84	2.07
Cross mean	80.08	1.408	94	0.8	1.318	1.026	11.4	14	167	81.51	0.8	2.56
CV (%)	5.4	2.7	14.8	27.5	44.9	46.4	29.4	19.5	14.1	6.1	11.2	52.4
LSD (0.05)	6.069	2.685	19.4	0.32	0.823	0.662	4.68	3.8	32.8	6.878	0.12	1.865
F-Test	*	**	***	ns	***	***	**	**	*	**	ns	ns
Maximum	87	4.5	112.08	1.382	2.26	1.715	16	17.5	198.7	88.5	0.84	4.317
Minimum	75.25	-1.25	64.83	0.497	0.348	0.263	5.5	6.5	130.3	76.25	0.636	-0.204

***= significantly different at 0.001 probability level; AD = days to 50% anthesis; HP = plant height, SD =Days to 50%silking, ASI=Anthesis-silking interval, EP =ear position, FW= field weight, GW= grain weight, NE=Number of ear, NP=number of plants SP=shelling percentage of plant, Yt/ha=yield tones/ha.