INHERITANCE OF RESISTANCE TO GREY LEAF SPOT AND NITROGEN UTILISATION EFFICIENCY IN MAIZE (Zea mays L.)

By

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DECLARATION

I, **KABAMBA MWANSA** do hereby declare that this dissertation represents my own work and that it has not previously been submitted for the degree at this or any other University.

Signed..........................

Date.....27/05/2005.....

APPROVAL

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

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ABSTRACT

Maize is an important staple and cash crop in Zambia. Abiotic and biotic stress conditions, particularly low soil fertility (low nitrogen) and grey leaf spot (*Cercospora zeae- maydis*), reduce maize yields. Most varieties developed by the Zambian National Maize Programme have neither resistance to GLS nor tolerance to low nitrogen stress. This is because earlier variety selections were done under optimum soil fertility and before GLS disease was introduced in Zambia. The objectives of the study were to (i) determine important gene action controlling the important traits in maize and how these are affected by the condition of optimum and low soil nitrogen (ii) estimate GCA and SCA of lines and testers (iii) estimate narrow sense heritabilities for yield and secondary traits under optimum and low soil nitrogen conditions, and (iv) identify good hybrids. In this study 10 inbred lines from the Zambian National Maize Programme were crossed to 12 CIMMYT single cross testers using a North Carolina Design II. The 110 progenies realized were evaluated under fertilizer and no fertilizer (low N) conditions at 6 sites that were also endemic to grey leaf spot disease in Zambia and Zimbabwe. Results showed highly significant differences between lines, testers and crosses (entries) $(p<0.01)$ for grain yield, anthesis date, silking date, anthesis silking interval, plant height, leaf senescence, ears per plant, single kernel weight, number of kernels per ear and the leaf diseases grey leaf spot, *Exserohilum turcicum* and rust. The mean squares for General combining ability (GCA for lines and testers) were significant for all traits studied. However, the specific combining ability (SCA for line x tester) were not significant for the all the traits studied. This showed that additive gene action rather than non-additive gene action controlled the traits. Lines L1 and L11 and testers T8 and T9 consistently performed well under low N, high N and across environments. These parents had high and positive GCA effects for grain yield, plant height, and ears per plant. They were also good combiners for single kernel weight, the number of kernels per ear and had reduced leaf senescence and a short anthesis-silking interval (except line 11). Significant and negative GCA effects for GLS was exhibited by lines L10 and L2 and testers T8 and T5 while the susceptible parents were lines L1 and L11 and tester T3 respectively. Genetic correlations between grain yield and most secondary traits were significant except for anthesis (lines and testers at low N), SKW (testers under low N), ASI (testers across environments and lines at high N) and leaf senescence (line and testers). High heritability estimates under nitrogen stress were found for GY (h^2=0.51), AD (h^2=0.51), SD (h^2=0.57), PH (h^2=0.68), SKW (h^2=0.81), and turcicum (h^2=0.89). Low heritabilities under low N were observed for ASI (h^2=0.44), leaf senescence (h^2=0.29), number of kernels per ear (h^2=0.42), and EPP (h^2=0.38). High heritability was also found for GLS (h^2=0.77) as well as rust (h^2=0.89) under high N conditions. Hybrids involving L11 x T9 and L10 x T9 were among hybrids performing well under both low N, high N and across environments and there were also resistant to GLS as well as turcicum and rust. The occurrence of GLS under high N condition was an indication that GLS incidence associated with increased nitrogen and that nitrogen stress environments may not provide suitable environment for selecting and screening maize resistant to GLS. The study provides some essential information needed to develop maize varieties with enhanced tolerance and resistance to both abiotic and biotic stresses so as to sustain maize yields.

DEDICATION

To my dearest wife Erica and my lovely daughter's Bwalya, Mukuka, Mwaka and Chishala for their spiritual support, inspiration and love which kept me going. God bless you.

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CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) is one of the most important food crops worldwide. Among the world's major cereal crops, maize ranks third after wheat (*Triticum aestivum* L.) and rice (*Oryza sativa* L.) in production. In 2000 about 140 million hectares were put to maize globally and of this approximately 96 million hectares were in developing countries (Pingali and Pandey, 2000). Current annual maize production is estimated at 500 million tones and by 2020 the projected demand for maize in developing countries will surpass the demand for both wheat and rice (Pingali and Pandey, 2000).

In Zambia maize is a staple crop followed by cassava, sorghum, and millet. It accounts for more than 70% of dietary carbohydrates for most Zambians. Almost 90% of the maize produced is used directly for human consumption, with livestock and industry (bear making) taking up the rest (Mungoma and Mwambula, 1996; Ministry of Agriculture Food and Fisheries, 1995). Maize is also an important cash crop grown by the majority of smallholder farmers in the country.

Successful maize production would naturally result in improved food security in the country since maize is the main source of food and income for the majority of the people of Zambia. In Zambia cultivation of maize is done throughout the three agro-ecological zones of Zambia namely regions I, II, and III and by all categories of farmers (Bunyolo et al., 1995). The average productivity stands at 1.5 t/ha and this hardly results in food self-sufficiency in the country (Ministry of Agriculture Food and Fisheries, 2000).

Among the constraints affecting maize production and thereby eroding income and food security in Zambia and the southern African region are drought, low soil fertility, soil acidity (low pH), and pest and diseases (Zambezi and Mwambula, 1996; Banziger et al., 2001; Mungoma and Mwambula, 1996; Reddy et al., 1989; Betram et al., 2003).

One of the most serious, but new disease of maize since 1996 has been grey leaf spot (GLS) caused by *Cercospora zeae maydis (*Kaula personal communication, 2003; Verma, 2001; Ngwira and Pixley, 2000; Tembo and Pixley, 1998*)*. Disease severity on susceptible varieties can range between 60-100% plant coverage and leaf damage by the time the crop reaches physiological maturity. This severe blighting results in weakened stems, leading to lodging. According to Ngwira and Pixley (2000), the disease can reduce grain yield of maize under heavy infestation by up to100%.

Since the 1990s Zambia has experienced droughts and the worst one occurred during 1991/92 season resulting in seriously reduced production of maize and the importation of the commodity (Mungoma and Mwambula, 1996; Zambezi and Mwambula, 1996). Since then partial droughts have occurred frequently. In addition infertile soils, especially low nitrogen has exacerbated the effect of insufficient rainfall. Despite intensifying their cropping, farmers still realize poor yields due to continuous use of non-restorative fallows (Banziger et al., 2001), as well as farm soils that are old and depleted of nutrients. A relatively small number of farmers can afford chemical fertilizers, which is now rarely subsidized and few do obtain credit to purchase inputs. With such unreliable rainfall, farmers who do manage to obtain fertilizer cannot be sure when to apply it and when they apply, they usually apply less than the recommended rates. The result of growing maize under low input condition results in wide yield gaps between researchers and smallholder farmers. According to Zambezi and Mwambula (1996) researchers may obtain 10 t/ha compared to smallholder farmers who often reap less than 1 t/ha.

Since 1983 the Zambia National Maize Research Program has developed commercial maize varieties currently on the market. Most varieties have been found to display different levels of susceptibility to grey leaf spot and none can be considered to be resistant. Under favorable conditions for grey leaf spot infection, these varieties will develop significant levels of the disease. This is expected, as the varieties were not selected for resistance to grey leaf spot, as it was not present in Zambia.

In addition these varieties possess little or no tolerance to low soil nitrogen stress. Earlier selections were only done under optimal fertilizer conditions as opposed to screening the germplasm under stress conditions as well. The program according to Mungoma and Mwambula (1996) relied on the theory that good performing selections at optimal fertility levels would perform similarly at sub-optimal levels.

Declining soil fertility, use of marginal areas, high cost of fertilizer, lack of credit facility, and the sub-optimal application of nitrogen fertilizer will continue to affect yields of maize.

In mitigating these problems, the Maize Research Program under the Ministry of Agriculture and Co-operatives embarked on a collaborative programme with the International Maize and Wheat Improvement center (CIMMYT-Zimbabwe) to develop germplasm with enhanced tolerance to both biotic and abiotic stresses. The improved germplasm would be used as parents for improved maize varieties. It is envisaged that the developed germplasm would tackle the problems of grey leaf spot, drought and low soil fertility leading to more stable yields and incomes, and improvement in the food security of the country and the region as a whole.

The value of improved maize germplasm as parents of commercial hybrid varieties in any breeding programme can be determined primarily by their combining ability. Therefore, the objectives of the study were to:

1. Determine important gene action for grey leaf spot (GLS) resistance and low nitrogen tolerance, and the interaction between the two traits.
2. Estimate narrow sense heritabilities of the traits.
3. Determine the general combining ability (GCA) and specific combining ability (SCA) of female (tester) and male (line) parents.
4. Identify hybrids that are suitable under optimal and low soil nitrogen conditions which are also resistant to grey leaf spot.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 GREY LEAF SPOT (GLS)

Grey leaf spot of maize, caused by the fungus *Cercospora zeae-maydis*, is considered a disease of major concern in many parts of the world (Ward et al., 1997). The disease was first identified in the United States of America (USA) in 1925. According to Hurrf et al., (1988) GLS developed to epidemic levels in the USA in the 1970's. In Southern Africa, the first report of the disease was in South Africa in the 1980's. However, significant epidemics caused by GLS in the country happened during the 1991/92 growing season (Gevers et al., 1994; Ward and Nowell, 1997). Therefore, prior to 1994, GLS was of economic importance in South Africa. Nevertheless, GLS has now become one of the prevalent and severe diseases of maize in Eastern and Southern African regions (Ngwira and Pixley, 2000; Tembo and Pixley, 1998). In 1994, GLS was observed in Uganda and *in 1995/96 the disease was seen in Kenya and Zimbabwe (Pixley, 1996).*

In Zambia, GLS was observed in 1996 (Kaula personal communication, 2003; Ngwira and Pixley, 2000; Tembo and Pixley, 1998). The disease is wide spread through out the country and is now considered as the single most important diseases of maize in the Zambia. In the past, maize streak virus (msv), leaf blight (*Exserohilum turcicum*), and common rust (*Puccinia sorghi)* were the major diseases of maize in Zambia (Rao et al., 1987). As such, research in the maize program is now focusing on selecting germplasm material that has enhanced resistance to grey leaf spot.

2.1.1 GLS disease conditions

Grey leaf spot requires a warm or hot and humid rainy weather conditions. Under these conditions, the pathogens or inoculum, would bloom suddenly especially on overcast days (Ngwira and Pixley, 2000), under high relative humidity (Beckman et al., 1983; Donahue et al., 1991) and with the extended leaf wetness (Beckman and Payne 1982; Donahue et al., 1991). Although GLS is highly influenced by the microclimatic conditions, the disease prevalence varies depending on the location and climatic conditions (Donahue et al., 1991). This makes the assessment of the disease for both inheritance studies and resistance breeding very difficult (Saghai maroof et al., 1996). According to Ngwira and Pixley (2000) the disease therefore spreads more rapidly in high rainfall area than in dry areas.

Apart from warm and humid rainy weather, there are also other factors known to cause the rapid spread of the disease. In Southern Africa, the for instance presence of inoculum and extensive cultivation of susceptible host plants are some of the factors (Tembo and Pixley, 1998; Ngwira and Pixley, 2000). Other factors are the widespread use of minimum tillage techniques whose practice leave fields covered with infected stover (Thompson et al., 1987). Payne and Waldron, (1983) stated that these conditions contribute to over wintering of fungus on corn debris thereby serving as a source of disease inoculum in the rainy season. This could lead into early infections to the crop the following season with symptoms appearing about mid season. While increased severity has been associated with no-tillage maize, Perkins et al (1995) however observed that the disease is just as prevalent under conventional tillage practices.

Minimum tillage is commonly practiced now as a conservation method of farming with the objective of restoring soil fertility. In Zambia, Golden Valley Agricultural Research Trust (GART) and some Non Governmental Organization (NGO) are spearheading and promoting this technology. In areas where this technology is introduced more than 50% of the farmers have already adopted the technique (Moono personal communication, 2004).

In addition, continuous and or extensive cropping of maize is also another contributing factor. In Zambia, like in most maize growing areas, the practice has been to grow maize traditionally under a system of monoculture with few farmers practicing any form of crop rotation.

2.1.2 GLS disease symptoms

Grey leaf spot is known to affect leaf, sheath, husk and stem tissues of maize plants. Symptoms first appear typically around flowering (Ngwira and Pixley, 2000). However, they may be much earlier if conditions favour disease development (Latterell and Rossi, 1983). Initial symptoms appear as small, rectangular, and elongated tan to brown necrotic spots delimited by the major veins on the maize leaf (Sprague and Dudley, 1988). The lesions on the leaves eventually spread to cover the whole plant (Ngwira and Pixley, 2000).

The lesions then turn grey afterwards when fungus grows on the surface of the dead leaf tissue (Ngwira and Pixley, 2000). When the number and size of lesions increases rapidly, they result in extensive death of leaf tissues. This makes leaves to appear blighted.

In addition GLS may infect maize stalks too. This development weakens the stalk thereby causing lodging (Lipps, 1987). Associated with GLS infections are the stalk rots as well. Latterell and Rossi (1983) mentioned that this arises due to early infection of the fungus on maize plants.

2.1.3 Economic importance of GLS

Under ideal conditions for disease development, disease severity has been observed to reach 60-100% plant coverage. This cause's extensive leaf damage by the time the maize crop reaches crop physiological maturity (Ngwira and Pixley, 1996) thus causing yield loses. If maize crop is grown for silage, the extensive leaf damage caused by GLS can reduce the quality of silage (Ward and Nowell, 1997).

Yield losses due to GLS have been reported. For instance, 20% yield reduction has been mentioned in the USA, in Pennsylvania (Aryers et al., 1984) and in Tennessee (Hilty et al., 1979). Others have reported losses of as much as 50% (Strongberg and Donahue, 1986; Strongberg and Flinchum, 1994), whilst losses of between 10-50% have been reported by Gevers and Lake (1994), and Saghai maroof et al (1996). In Africa, yield losses up to 88% have been recorded. This was in Kwa-Zulu Natal in South Africa by Ward et al (1993). In addition 30% losses have been reported to occur in endemic areas

(Ward et al (1993). Latterell and Rossi (1983) also mentioned that non-documented losses have undoubtedly been higher when severe disease results in stalk lodging.

Yield losses due to GLS have been attributed to loss of photosynthetic area, increase in lodging, and premature death (Strongberg and Donahue, 1986; Strongberg and Flinchum, 1994). Due to loss of photosynthetic area, carbohydrates are diverted from the stalk and roots to the grain at greater than normal levels. This causes stems to weaken and often lodge, leading to death of the plant and therefore loss in yield.

2.1.4 GLS disease control.

The disease can partially be controlled through the combined use of crop rotation (Sprague and Dudley, 1988), crop sanitation (Sprague and Dudley, 1988), fungicides (Ward et al., 1995) and use of genetic resistance (Saghai maroof et al., 1996; Sprague and Dudley, 1988; Stromberg and Donahue, 1986; Ngwira and Pixley, 2000). The use of fungicides increases production costs and it is not usually economically feasible to many farmers. In addition the chemical fungicides are also viewed as environmental hazards with possible adverse effect on the farmer's health (Tembo and Pixley, 1998; Nhlane and Caligari, 1996). Therefore, the main solution lies in the use of genetic resistance (Thompson et al., 1987; Elwinger et al., 1990; Singh, 2003) in maize cultivars, which is viewed to be a highly effective and cost efficient solution (Ward et al., 1997). Genetic resistance to GLS can be required as a sole solution or as a contribution to a better-integrated approach in dealing with the disease problem (Tembo and Pixley (1998).

Development of resistant cultivars however needs the understanding of inheritance of resistance. Most published reports have found additive, with less important, but significant non-additive gene action affecting resistance (Gevers and Lake, 1994; Ulrich et al., 1990). However, dominance (Elwinger et al., 1990), recessive and epistatic (Saghai maroof et al., 1996) gene action have been implicated in GLS resistance in maize as well.

Molecular marker analysis done by Bubeck et al (1993) showed significant association between GLS resistance and particular chromosome segments whilst Saghai maroof et al (1996) found only four chromosomes to be associated with GLS resistance for one single population from his studies.

2.1.5 GLS disease evaluations

Evaluations of the disease can be done through artificial inoculation and by natural infections achieved through growing the experiments in hot spot areas to which GLS is endemic. In artificial inoculation as explained by Tembo and Pixley (1998), inoculum is prepared from collected GLS infected leaves, which are kept under cool conditions. Prior to infestation the leaves are ground and the pinch of inoculum is placed in whorl of each plant. This is at 6 to 8 leaf stage when plants are growing with young leaves (Ngwira and Pixley, 2000). Natural infestation requires endemic areas where maize is grown year after year using some form of conservation tillage in which there is increased amount of surface debris left.

Since development of GLS disease is highly influenced by microclimatic conditions (Payne and Waldron, 1983), it therefore means that a strong dependence on the environmental effects makes the assessment of the disease, for both inheritance studies and resistance breeding, very difficult. Although the presence of heavy disease pressure is an essential prerequisite to evaluate the level of GLS resistance, it has been observed that such an optimal condition is difficult to achieve through artificial inoculation or supplementary irrigation. Donahue et al (1991) found that the GLS disease prevails in high relative humidity and with extended leaf wetness, which varies among different locations and climatic conditions. The difficulties in disease evaluation have further limited progress in developing GLS-resistance maize hybrids.

The assessment of GLS disease assessment is done by visual estimates of percent leaf area affected. In most instances ratings are done on mature plants on a plot basis on a scale of 1 (resistance) to 5 (susceptible) with increment of 0.5 on the rating scale (Ngwira and Pixley, 2000; Thompson et al., 1987). The term mature plant refers to an approximate stage of development near physiological maturity. Disease symptoms should be scored at least twice, that is, at mid-silk (flowering) and mid to late grain fill (Ngwira and Pixley, 2000).

2.2 NITROGEN AND THE MAIZE PLANT

2.2.1. Importance of nitrogen

Nitrogen is an essential macronutrient required by all plants and the maize plant being one of them. It is a component of all enzymes and therefore necessary for plant growth and development (Banziger et al., 2000). It contributes about one–sixth of the weight of proteins (enzymes) and is a basic element of nucleic acids. Nitrogen is plentiful in leaves, mainly in photosynthetic enzymes, where it may account for up to 4% of dry weight. Because of nitrogen uptake in the maize plant, biomass production and grain yield have shown a strong correlation to each other. Banziger et al., (2000) showed nitrogen requirement of a maize crop as related to grain yields.

2.2.2 Low soil Nitrogen (Low N)

Nitrogen is an important macronutrient that often limits yields in the lowland tropics. Though application of nitrogen fertilizers and amendments can generally correct the situation, these are often not available and if available, then they are too expensive for resource-poor peasant farmers. Therefore, low nitrogen (Low N) or nitrogen deficiency condition in soil occurs when available nitrogen required for optimal plant growth and development is below optimal-levels of requirements or recommended amounts. The conditions of low soil nitrogen arise due to a number of factors. These include:

(A). Inherent low soil fertility.

Low soil fertility and in particular low nitrogen, is a common feature in tropical soils (Betram, 2003). Most of soils are acidic and therefore, are poor agriculturally mostly due to low soil pH, low nutrient reserves, low nutrient retention capacity and low organic matter (Pandey et al., 1994; Donahue et al 1983; Tisdale et al., 1985; Narro et al., 1996). In addition, production environments for maize are becoming harsher as maize is being displaced to more marginal environments by higher value crops (Beck et al., 1997).

(B). Mono cropping

Small-scale farmers, because of their smallholdings, commonly practice mono cropping without crop rotation (Haggblade and Tembo, 2003). This has led to decline in soil fertility status of soil as a result of depletion of soil organic matter (Haggblade and Tembo, 2003, Banziger and Lafitte, 1997). The continuous use of the same non-restorative fallows means the utilisation of soils that deficient and depleted in nutrients.

(C). Sub-optimal or reduced application of plant nutrients.

According to Banziger et al., 1997 it is now a common practice among small-scale farmers to reduce application of fertilizer in maize. During drought situation, farmers often delay fertilizer application and when they apply, they usually do it in reduced amounts that contribute little to long-term fertility management. Studies done have shown that application of nitrogen can be as much as 36 kg/ha in Brazil (Santos et al., 1996), 14 kg/ha in Malawi (Zambezi and Mwambula, 1996), and an average of 10 kg/ha across Africa (Heisey and Mwangi, 1997). However, nitrogen application averages a mere 7 kg/ha in sub-Sahara Africa (Musya and Diallo).

(D). High cost of inputs is a concern now especially that there are no government subsidies and fertilizers have to be acquired at economic price (Haggblade and Tembo, 2003) and farmers fail to acquire them as it does not justify the producer prices that prevails (Heisey and Mwangi, 1996) or the economic returns (Lafitte and Edmeads, 1994).

Since conditions of low soil nitrogen are prevalent under smallholder farmers, it means that production of maize is done under low input conditions. This results into wide yield gaps between research stations and smallholder farmers. According to Zambezi and Mwambula, (1996); yields of 10 t/ha and less than 1.0 t/ha have been recorded between research stations and smallholder farmers respectively. Other studies have shown yield losses due low nitrogen of about 10 - 55% that of optimal fertilization (Logrono and Lothrop, 1996) and maize yield of 300 to 400kg/ha without fertilizer application (Low and Waddington, 1991).

2.2.3. Maize under Low-N stress

When maize is grown under low N stress, reproductive development and yield is affected (Edmeads et al 2000; Below, 1996). In maize nitrogen is known to influence crop photosynthesis, root growth, and reproductive development and crop development (Banziger et al 2000).

Nitrogen stress reduces crop photosynthesis as it affects leaf area development and leaf photosynthesis rate and it also accelerates leaf senescence. Banziger et al (2000) expressed that about 50% of all leaf N is directly involved in photosynthesis either as enzymes or chlorophyll. When N becomes scarce plants reallocates N from older tissues such as leaves and stalk to younger tissues which are the leaves and grain leading to early senescence of the older, lower tissues. And with increase in N stress, photosynthesis rate is reduced resulting in little assimilates being manufactured.

Under N stress the absolute amount of root for absorption of water and nutrients are reduced. In addition maize develops shallow roots than they usually do when grown under normal fertilization (Banziger et al., 2000). These conditions predispose the plants to greater risks under drought.

Nitrogen stress has influence on the development of maize reproductive structures as well. Since the initiation and development of reproductive structure occurs in distinct phases, each is affected by N stress. It has been found that the number of potential kernel ovules is established early in plant development. The kernel row number is set by the time most tropical maize plants have 12 – 14 leaves while the number of kernel per row by the time plants have 16 - 18 visible leaves (Banziger et al., 2000; Below, 1996).

The number of ovules that ultimately develop into mature kernels is affected by the extent of kernel abortion two weeks bracketing flowering (Below, 1996). Severe N stress delays both pollen shed or anthesis and silking, but the delay in silking is relatively more so that the Anthesis – silking interval (ASI) becomes greater under N stress. Silking delay is correlated with kernel and ear abortion (Banziger et al., 2000; Below, 1996).

Nitrogen stress also influences crop development. At the beginning of the season and especially with fertilizer applied, N exceeds crop demand. However, as the season progresses, more N is taken up. Banziger et al 2000 mentioned that Soil N mineralization is usually less than 1 kg N /ha / day, whereas a healthy maize crop can take up and assimilate 4 to 5 kg N / ha / day, leading to N depletion of the soil and N stress in the plant as the season progresses. Plants adjust to some extent to N stress by re-mobilizing N from older tissues, a mechanism that does not affect yields in case of tissues that contributes little to photosynthesis. Depending on the timing of N stress in growing plant parts, different yield determining factors are affected. Nitrogen stress before flowering reduces leaf area development, photosynthetic rate and the number of ear spikelets (potential grains). Nitrogen stress during flowering stage, results in kernel and ear abortion, whereas stress during grain filling accelerates leaf senescence and reduces crop photosynthesis and kernel weight (Banziger at al, 2000).

2.2.4. Breeding approaches under Low Nitrogen (Low N).

In developing maize varieties, plant breeders have in the past used optimal conditions during screening phase to select for desirable plant type. When few genotypes remain, they are then evaluated under abiotic stress. At this stage selection intensity is often low and therefore progress in breeding for tolerance to abiotic stress is poor (Banziger et al., 2000). Apprehensions on why breeders have not been making selections under abiotic stresses early in breeding stages have been outlined. Among notable reasons according to Banziger et al (2000), and Lafitte and Edmeads (1994) are that heritabilities and genetic variances decrease under abiotic stress as yield levels fall. In addition the genotype x environment interactions under stress is high and this makes it difficult to identify best genotypes with entries changing ranks and sometimes not being significant from one experiment to another as compared to conditions where yields are high.

Since maize in the tropics is continuously exposed to abiotic stress (N-stress), then there is a need to include extensive screening under stress conditions so that yields under favorable and stress conditions are improved (Banziger et al 2000). Therefore, one approach is to select cultivars that are superior in the utilization of available N. This can either be due to enhanced up take capacity or because of more efficiency use of absorbed N in grain production (Lafitte and Edmeads, 1994).

Cultivars that are less responsive to applied N and sometimes that performs better than do N-responsive hybrids or cultivars have been identified (Pollmer et al., 1979; Thirapon et al., 1987). A suggestion by Blum (1988) was that selection for yield in low nitrogen target environments (low soil-N status) should be more effective than selection for yield potential alone.

One approach to increasing the efficiency of selection in low N environments relies on the use of secondary traits (Blum, 1988; Banziger et al., 2000), which are highly heritable, and correlates with grain yield under N stress.

2.2.5 Use of secondary traits.

In a maize-breeding programme, secondary traits are used in identifying tolerant genotypes. Under low N these traits improve precision with which Low N tolerant genotypes or nitrogen use efficient genotypes are identified and they also demonstrate the degree to which Low N stressed the crop. Among the suggested traits are the high plant nitrate uptake (Mollaretti et al., 1987), genetic variation for mobilization of N from leaves and stems to grain (Eghball and Maranville, 1991). Others are the large leaf area and high specific N associated with high maize yields under N stress (Muchow and Davis, 1988), leaf chlorophyll concentration (Hardcre et al., 1984), plant height of N stressed plant (Lafitte and Edmeads, 1988), leaf senescence (Wolfe et al., 1988a), and ears per plant as well as anthesis silking interval (Banziger et al., 2000, Edmeades et al., 1993). The use of adaptive value of secondary traits according to Blum (1998) should begin with an assessment of their relationship to productivity in a field environment. Whenever phenotypic correlations are used to determine the underlying associations between characters, care must be exercised to ensure that the associations are not simply a result of environment differences. Falconer (1989) points out that genetic correlation is more useful than phenotypic correlation in determining the relationships between traits.

Therefore the ideal secondary traits should be ones that genetically associate with grain yields, are highly heritable and genetically variable, and should be cheap and fast to measure. At the same time they should also be stable within the measurement period and as a reliable estimator of yields before final harvest (Edmeads et al., 1998; Banziger et al., 2000 and Lafitte and Edmeads, 1994).

Among the secondary traits used for assessing tolerant genotypes in maize in many National Maize Breeding Programmes under Low N are the anthesis to silking interval (ASI), number of ears per plant (EEP), senescence and grain yield (Banziger et al., 2000).

2.2.5.1 Anthesis to Silking Interval (ASI).

When stress such as drought and low N coincides with flowering, a commonly observed phenomenon in maize is delayed silking resulting in an increase in length of ASI. It has been found that under Low N a shortened ASI contributes significantly to improved grain yield (Banziger and Lafitte, 1997). According to Dow et al., (1984), a shortened ASI in maize is associated with tolerance of stress which occurs around flowering. Many researchers have also reported ASI to be a better trait than yield to select for under low nitrogen stress as well as under drought as its variability increases with increasing stress (Banziger et al., 1997, Edmeads et al., 1993). In addition its heritability does not decline as rapidly as grain yield *per se* under low N stress (Banziger et al., 1997, Edmeads et al., 1993). Analysis of 19 progeny trials indicated that the heritability of ASI (0.52) was slightly greater than for GY (0.46) (Banziger et al., 1997).

In maize genetic correlation between grain yield (GY) and ASI under stress have been reported. Lafitte and Edmeads (1994a, 1994b), obtained correlation values in the range of –0.30 to –0.55 and these were significant (at $p<0.05$) under low N as opposed to high N conditions. Banziger and Lafitte (1997) managed to obtain values ranging from 0.21 and –0.75 in their progeny trials done under low N.

2.2.5.2 Grain yield components.

Grain yield components include number of ears per plant (EPP), number of kernels per ear and the kernel weight (SKW).

The dependence of grain yield under low N on its yield components was well documented by Edmeads et al. (1997a) for several tropical maize populations. Grain yield was linearly related to kernel weight (r = 0.74), and kernels per ear (r = 0.89), whereas the relationship between grain yield and EPP was curvilinear and highly significant (r = 0.94).

High correlations between grain yield and its components are normally found because of lack of independence among them (Blum.1988). EPP is a useful diagnostic tool for low N tolerance because it is easy and fast to measure, and because their relationship with grain yields increases with stress.

Kernel weight is probably important in determining yield only under well fertilized conditions, whereas variability for EPP increases more rapidly with increasing low N stress than the variability for kernels per ear (Bolanos et al., 1993).

2.2.5.3. Leaf senescence.

Leaf senescence is an orderly, active process in which nutrients in a leaf are reclaimed and mobilized to other parts of the plant. Senescence occurs in response to aging, and under constant harsh environmental conditions, it is relatively constant and predictable. Drought, low N, darkness, detachment and hormone abscissic acid are found to be some of the causes (Banziger et al., 2000, Wilkins, 1984 and Mohr and Schofar, 1994). Under N stress leaf senescence is accelerated and plants may show differences in the rates. Plants with delayed or reduced leaf senescence stay green and continue to carry out photosynthesis for an extended period than plants that senescence fast. This is important as such plants will continue to reallocate the much needed assimilates to developing grains and may contribute to production of high kernel number and high kernel weight resulting in more ears and yields.

Leaf senescence in addition may determine maturity in maize plants. Early maturing plants tend to senescence their leaves earlier than late maturity plants.

2.2.5.4. Plant height

Genotypes that allocate assimilates more to vegetative plant parts like leaves and resulting in increased plant heights tend not give higher yields. It is important that an ideal plant height that is not detrimental (i.e. lodging) to economical productivity is selected and attained in genotypes. Stresses like drought and nitrogen have been found to reduce plant height. Under nitrogen stress plant height is reduced.

2.2.6 Low nitrogen fields.

These are fields used to screen genotypes at every stage of breeding. They are depleted of available nitrogen. Depletion involves growing non-leguminous crops with high biomass production and then removing it. According to Banziger at al, (2000) the higher the biomass the more nitrogen is removed from the soil. Under these fields, yields of genotypes should be in the range of 25 – 35 % of those obtained under well-fertilized condition and should also represent an uptake of 20% to 25% of N for maize grown under well fertilizer conditions. With this stress, plant traits affecting yields are different from the ones relating to yields under non- stress conditions and therefore genetic variation for low N tolerance can be observed.

If yields under low N stress are greater that 50% of those obtained under well-fertilized conditions, then they relate more to genotypic yield potential than the mechanism that impacts tolerance to Low N stress and N stress tolerant genotypes cannot be easily discriminated (Banziger at al, 2000. When low N fields are developed they have to be used continuously for several seasons. The aim is to capitalize on results obtained with Low stress of the past season to manage the N stress of the following seasons (Banziger at al, 2000).

The conditions for operating the Low N fields are that the fields should only have limitations in nitrogen and not other factors (i.e. nutrients, water, and soil pH). In these fields no nitrogenous fertilizer either in chemical or organic form should be applied and it is also required that the length of fallow between the previous crop and planting date of maize be reduced. The Stover of the previous crop has to be removed after the harvest so as to avoid nitrogen returning to the soil through organic matter. In the management of the low N site, the fields should not be intercropped or rotated with leguminous crops.

2.3.0 MATING DESIGNS FOR ESTMATING GENETIC VARIANCES

There are a number of mating designs that can be used by the plant breeder to estimate the genotypic variance in a population. The mating designs differ in the genetic material evaluated, which determines to which additive, dominance, and epistatic variance can be estimated.

The mating designs that have been described by Hallauer and Miranda (1988) include the bi-parental progenies, parent-offspring regression, diallel, North Carolina design I, II and III, and line x tester.

A number of criteria must be met for each mating design to obtain valid estimates of genotypic variance (Baker, 1978). Failure to meet one or more of these criteria may result in biased estimates of genotypic variance. A primary criterion for mating designs is that individuals evaluated from a population must be a random sample of all possible genotypes.

2.3.1. North Carolina Design II (or Design II).

North Carolina Design II was developed Comstock and Robinson in 1948. This mating design is used to develop progenies for the purpose of obtaining genetic information from the experimental populations. In developing experimental progenies, different sets of parents are used as males and females. Each male parent is mated to each female, but male parents are not crossed to each other and female parents are also not crossed to each other too. Design II is a cross-classified design in terms of analysis. In this design the genetic expectations for males and females are equivalent to general combining ability (GCA), whilst the male x female interaction is equivalent to specific combining ability (SCA). Since two sets of parents are used in this design, two independent estimates of

GCA are obtained. Appropriate F-test are made for the differences among males and among females and for the interactions of males x females.

Though design II has not been used as extensively in maize as the diallel, Hallauer and Miranda (1988) mentions that it has advantages over the diallel designs if one is interested in estimating components of variance of a reference population. The merits include: (1) more parents can be included for a given level of resources, (2) two independent estimates of σ_A^2 are available, (3) an estimate of σ_D^2 is determined directly from the mean, and (4) a greater number of parents can be included by subdividing parents into sets.

2.4.0. ESTIMATES OF GENETIC VARIANCE AND COMBINING ABILITY.

Development of maize varieties with enhanced resistance and tolerance to biotic and Abiotic stresses require the knowledge of inheritance of the traits and effective screening techniques. Inheritance studies so far have indicated presence of genetic variability in genotypes regarding presence of genes for the resistance of GLS (Thompson et al., 1987; Elwinger et al., 1990) as well as tolerance to low N (nitrogen use efficiency) in maize (Pollmer et al., 1979; Thirapon et al., 1987). Regarding Nitrogen use efficiency, different traits are known to determine tolerant types of genotypes and these only occur or show under stress conditions (Blum, 1988; Banziger et al., 2000). Heritabilities, for such tend to be high compared to grain yield that is known to decrease with stress. Effective selection in the early generation of the segregating materials can be achieved only when additive genetic effects are substantial and heritability is high.

Estimation of genetic parameters of the population is useful in plant breeding process in deciding appropriate breeding strategy that will utilise the genetic presence (Duddly and Moll, 1969; Hallauer and Miranda, 1988). The estimation of genetic variance component is useful in determining whether there is sufficient variation in a population to follow further improvement to take place, as well as to identify the most promising genetic populations. In addition, estimation of genetic variances is useful in the selection of the most rapid and efficient breeding procedure in improving important characters. In estimating the genetic variation among genotypes knowledge of the heritabilities is important as it indicates the probability and extent to which improvement is possible through selection. Heritability can therefore be estimated either by the analysis of variance or through the regression of offspring on parents.

In determining mode of inheritance of grey leaf spot and nitrogen use efficiency, it is important to estimate the general combining ability (GCA), and specific combining ability (SCA) effects. The concept of combining ability is used in connection with testing procedures to study and compare genotypes as well as predict the potential of lines in hybrid combination for many traits especially where the objective is to develop superior hybrids.

The general and specific combining abilities represent the major divisions of types of gene action for quantitative traits (Cukadar-Olmendo et al., 1997; Hallauer and Miranda, 1988). General combining ability of a line refers to the average value of a line estimated on the basis of its performance of that genotype in hybrid combination with other lines and is largely due to additive genetic effects and higher order additive interactions. The importance of the significance GCA is in the selection from the cross, parents that have the highest GCA that may produce the best performing progeny (Cukadar-Olmendo et al., 1997, Hallauer and Miranda, 1988 and Fehr, 1987). Significant GCA effects indicated the greater role of additive gene effects controlling a particular trait.

However the performance of a particular cross may deviate from the average general combining ability of the two parental lines. This deviation is the specific combining ability (SCA) of the cross (Griffing, 1956, Hallauer and Miranda, 1988). SCA is largely a function of non-additive dominance and other types of epitasis (Cukadar-Olmendo et al., 1997). It is not possible to predict the potential of lines in hybrid combination for many traits; therefore, combining ability should be examined when objective is to develop superior hybrids for quantitative traits (Cukadar-Olmendo et al., 1997). Ratios of mean square components associated with variance of GCA and SCA effects are computed to estimate the relative importance of GCA in explaining progeny performance. The closer the ratio is to unity, the greater the predictability of progeny performance based on GCA effects alone and therefore suggests that additive gene effects were relatively more important than non additive gene effects among hybrid combinations. However, significant SCA effects imply the contribution of the non-additive gene effects to variations expressed among hybrids (Cukadar-Olmendo et al., 1997; Hallauer and Miranda, 1988)

CHAPTER THREE

3.0 MATERIALS AND METHODS

The study was conducted in two stages; the first involved the development of the experimental materials while the second was the genetic evaluation of the experimental materials.

3.1 STAGE 1. GENETIC MATERIALS.

Ten inbred lines in advanced generations of inbreeding and twelve Testers (single crosses) from the Zambia National Research Program and CIMMYT – Zimbabwe respectively, were used in this study. The pedigrees and line codes for inbreds as well as testers used in the study are presented in Table1. The inbred lines used in the study were selected for tolerance to low N and resistance to grey leaf spot. These lines have also exhibited various levels of resistance to other prevailing major diseases like maize streak virus, turcicum and rust, and they are also tolerant to drought. The testers were elite materials selected for combining ability and agronomic performance across stress and non-stress environments.

Each inbred line was crossed to twelve single cross testers representing each of the major heterotic pattern or group from CIMMYT-Zimbabwe. Crossing was done by hand pollination at Muzarabani-Zimbabwe (429 masl, 16.37° S, 31.02° E) during the 2003 winter season (dry season). Pollen from the male plants (lines) ware collected using tassel bags and bulked prior to pollination on the female plants (testers). One hundred and ten line x tester combinations (testcrosses) were generated from the crosses while ten line x tester combinations escaped pollination due lack of synchronization. The generated testcrosses were evaluated during the 2003 to 2004 rainy season.

3.2. STAGE 2. EVALUATION

3.2.1 Location and cultural practices

A total of six trials were planted in six locations in Zambia and Zimbabwe respectively (Table 2). Three trials were planted under optimal fertilized (high N) conditions and the remaining with no fertilizer (low N). The locations for low N were sites, which have been developed after depleting the soil of nitrogen for some years (Banziger et al., 2000). These are managed continuously by not applying N fertilizer (either in chemical or organic form), and by cutting and removing the plant biomass after each crop season. The optimum or well-fertilized sites used were sites, which are also hot spots for screening, grey leaf spot disease in Zambia and Zimbabwe.

For the optimal trial sites fertilizer was applied at the rate of 180-80-40 kg per hectare in terms nitrogen, phosphorous and potassium. The 40 kg N per hectare was incorporated as compound D prior to sowing, and 140 kg N per hectare was applied as urea, side dressed about 4-6 weeks after sowing. No chemical N fertilizer was applied to low N experiments but these sites also received the same rate of P and K of 80 and 40 kg/ha respectively.

All trials received standard cultural practices to control soil pest and weeds. Furadan was used prior to planting to control cutworms and black beetles and both herbicides and hand weeding were used to control weeds. Spraying the bases of plants with Antkil as well as Dursban controlled termites, especially at low N at Golden Valley.

Sampling of soils at all trial sites was taken at two soil depths: 0 – 20cm and 20 – 60cm. This was prior to planting and results for the analyses are shown in Appendix A.

3.2.2 Experimental design

The 110 testcrosses were evaluated with four check entries in an alpha (0,1) lattice design with two replicates (Patterson and Williams, 1976) with incomplete block sizes of six plots for testcrosses. The experimental unit consisted of one 5m long row in Zambia and one 4m long row in Zimbabwe. In all experiments, the rows were spaced at 0.75m except for high N trial at Golden Valley that was row spaced at 0.90m. Planting between hills was done with a spacing of 0.50m. Each hill was over planted and later thinned to 2 plants per hill when seedlings reached 4-leaf stage. Two borders rows were planted around each experiment.

Table1: Description of 10 Lines and 12 Testers used in the Design II for Testcross formations.

Line Code	Origin	Pedigree	Heterotic Group
1	Zambia	N3-1 X N3 offtype-4-1-3-3-2-1-1	
2	Zambia	8535-23-1-2-2	
3	Zambia	Cam sel 25-2-4	
4	Zambia	Cam sel 25-2-5	
6	Zambia	Cam sel 25-3-3	
7	Zambia	Vol / 87923 – x 757-3-2-1-2-3-1	
8	Zambia	Vol / 87923–x –757–3–2– 1 –2 –3 -2	
9	Zambia	M87/87923-X-769-2-5-2-3	
10	Zambia	(CIMMYT) line 14-1	
11	Zambia	L12 M1 (220GY) –150-3-3-1-1	
Tester Code		Pedigree	
1	CIMMYT	CML 312/ CML440	A
2	CIMMYT	CML 312/ INTA-191-2-1-2-BBBB	A
3	CIMMYT	CML 441/ CML442	A
4	CIMMYT	CML 312/ CML 442	A
5	CIMMYT	CML 440/ CML 443	A
6	CIMMYT	CML 442/ CML 445	A
7	CIMMYT	CML 448/ DRB-F2-60-1-1-1-BBBB	B
8	CIMMYT	CML 444/ DRB-F2-60-1-1-1-BB	B
9	CIMMYT	CML 444/ CML 448	B
10	CIMMYT	CML 395/ CML 488	B
11	CIMMYT	CML 444/ CML 489	B
12	CIMMYT	CML 395/ CML 489	B

Table 2: Description of Sites where 110 line x tester cross combinations were evaluated

Experiment	Country	Site	Altitude	Latitude	Longitude	Fertilizer level	Soil type
1	Zambia	Golden Valley	1170masl	14.17°S	28.37°E	High N	Clay loam
2	Zambia	Golden Valley	1170masl	14.17°S	28.37°E	Low N	Clay loam
3	Zambia	Kabwe	1207masl	14.27°S	28.28°E	Low N	Sand loam
4	Zambia	Mount Makulu	1281masl	15.53°S	28.25°E	High N	Sand clay loam
5	Zimbabwe	Cimmyt-Harare	1489masl	17.80° S	31.02° E	Low N	Medium Grained Sand clay
6	Zimbabwe	ART-Farm	1489masl	17.80° S	31.02° E	High N	-

High N= Optimum fertilizer; Low N= No fertilizer (low N fields)

3.3. DATA COLLECTION

3.3.1 Field weight: The weight of ears harvested from each plot was measured in the field using hanging scales (CARDINAL, Model No HSDC 20 Kg in Zimbabwe and SALTER ENGLAND, Model 23563 25kg x 100g in Zambia).

3.3.2 Grain yield: Harvested ears were shelled to obtain grain weight per plot in kilogram. Grain weights were then adjusted to 12.5% grain moisture and converted to tones per hectare using the formular:

$$GY\ (t/ha) = \frac{\text{grain weight (per plot)} \times (100 - \text{moisture}) \times 10,000}{87.5 \times \text{plot size} \times 1000}$$

3.3.3 Moisture content (MOI): The moisture content of a sample of kernels for each sample plot was measured with a hand-held moisture meter (Dickey-John Mult-Grain, Model. 46233-12223A)

3.3.4 Ears Per Plant (EPP): Number of ears per plant at harvest, measured as number of ears with a minimum of one fully developed grain divided by the number of plants.

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

3.3.6 Silking Date (**SD**): Measured as number of days after planting when 50% of the plants produced silk.

3.3.7 Anthesis Silking Interval (ASI): Determined by the difference in days between Silking date and Anthesis date

3.3.8 Plant Height (PH): Measured as average height in centimeters between the base of a plant and the flag leaf of the same plant on 10 randomly selected plants.

3.3.9 Ear Height (EH): Measured as average height in centimeters between the base of a plant and the insertion of the uppermost ear of the same plant on 10 randomly selected plants.

3.3.10 Ear Position (EPO): Calculated in percentage as a ratio of ear height to plant height.

3.3.11 Stem lodging (SLODGE): measured, as percentage of plants that showed stem lodging, i.e. those stems that were broken below the main stem previous to harvest time.

3.3.12 Root lodging (RLODGE): measured as percentage of plants that showed root lodging, i.e. those stems that were inclined by more than 45° at harvest time.

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

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

3.3.15 Maize streak virus (MSV): Score for the severity of maize streak virus symptoms rated on a scale from 1 (= clean, no infection) to 5 (= severely diseased).

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

3.3.17 Ear rot (EROT): percentage of ears that were rotten.

3.3.18 Leaf senescence: Leaf senescence was visually estimated under low N stress on plot basis as the proportion of live green vs senesced dried leaves. This measure was taken in all trials on 3 occasions 4-5 weeks after flowering (or grain filling) using a scale of 1-10 described by Banziger et al (2000) (Table 3).

Table 3: Scale used in scoring for leaf senescence

SCALE	% FOR DEAD LEAF AREA
1	10 % dead leaf area
2	20 % dead leaf area
3	30 % dead leaf area
4	40 % dead leaf area
5	50 % dead leaf area
6	60 % dead leaf area
7	70 % dead leaf area
8	80 % dead leaf area
9	90 % dead leaf area
10	100 % dead leaf area

Source: Banziger et al (2000)

3.3.19. 100 Kernel weight (gm): 100 kernels for each entry were counted at random and weighed using SARTORIUS AG GOTTINGEN Type BL 6000 Serial 91105058 scale. The weights were adjusted to 12.5% moisture.

3.3.20 Single Kernel weight (mg): Weight of single Kernel was calculated as follows:

Single Kernel Weight (SKW) = (HSW/100)* 1000

Where:

HSW = Hundred seed weight (gm)

3.3.21 Number of Kernels per Ear: This was calculated as follows:

Kernels per = ((100 * FSGW) / FHSW) / NEH

Where: FSGH = fresh shelled grain weight (gm)

FHSW = fresh hundred seed weight (gm)

NEW = Number of ears harvested

3.4. ANALYSIS.

Analyses of variance were computed for each location or site separately using spatial analysis software ASREML or REMLTOOL (Burgueno et al., 2000). This was to generate means and mean square (standard) errors. In the analysis, the mixed model was assumed with genotypes (testcrosses) considered as fixed while incomplete blocks were taken as random variables. Test of significance for entries were determined using appropriate mean squares.

A combined analysis of variance was computed using PROC GLM in SAS (SAS, 1997). In the combined analysis sites or environmental effects were treated as random effects and crosses as fixed effects.

General combining ability (GCA) and Specific combining ability (SCA) estimates were calculated according to the line x tester model using adjusted means and pooled error mean square. Check entries were not included in the analysis and each site was considered as a separate environment. In addition parents where pollination was not completed due to lack of synchronization were also dropped from the analysis. The combining ability analysis was carried out using array totals over replications following the procedure of Kempthorne (1957) related to methods of Comstock and Robinson (1952). The mean squares due to lines and testers were tested against the mean squares due to lines x testers. The mean squares due to lines x testers and other interactions were tested against the pooled error mean squares. In addition mean squares due Nlevel was tested against mean squares due to site(Nlevel) while that of Site(Nlevel) was done by mean squares due to site x line x tester(Nlevel).

The simple linear (genetic) correlation of GY for lines and testers with secondary traits was performed by regressing GY on the secondary traits using the formular described by Steel and Torrie (1980) and Gomez and Gomez (1984). The formular used is:

$$r = \sum xy / [(\sum x^2)(\sum y^2)]^{1/2}$$

Where: r = correlation coefficient,

$\sum xy$ = Corrected sum of cross products,

$\sum x^2$ = Corrected sum of squares,

$\sum y^2$ = Corrected sum of squares.

Test of significance of correlation coefficients was done using the 2-tailed "t" test formular described by Steel and Torrie (1980):

$$t = \frac{r}{((1-r^2)/(n-2))^{1/2}}.$$

where: r = number of replication; n = number of parents

The components of genetic variance were calculated using the following formular explained by Mather and Jinks (1971):

$\sigma_f^2 = 1/8Dr$; $\sigma_m^2 = 1/8Dr$; $\sigma_{fm}^2 = 1/16Hr + Eb$; $\sigma_w^2 = 1/4Dr + 3/16Hr + Eb$

Where: Dr = additive genetic variance; Hr = dominance; Eb = non-heritable error

Heritability estimates (narrow sense) were also obtained through the formular described by Mather and Jinks (1971):

$$h^2 = 1/2DR / (1/2DR + 1/4HR + Ew + Eb);$$

Where: DR = Additive variance

HR = Dominance variance

Ew + Eb = Error variance

CHAPTER FOUR

4.0. RESULTS

4.1 GENERAL

The season in which the evaluation of the testcrosses was conducted was characterized by dry spells at the beginning and end of the rainy season. Golden valley, Mount Makulu and Kabwe sites received 564.8mm, 1014.2mm, and 623.0 mm of rainfall respectively. The mean monthly temperatures recorded for the sites were 23.6, 23.7 and 21.1 ^{o}C. The rainfall amounts received at Golden Valley and Kabwe sites were below average for the sites. On two occasions hailstorm was experienced at Mount Makulu and this caused lodging and leaf damage to plants. Only the experiment at ART farms in Zimbabwe received irrigation each time there was moisture stress. Appendix B shows 2003/04 season meteorological data for the sites.

4.2. ANALYSES OF VARIANCE

Combined analyses of variance across environments for all measured variables are presented in Tables 4, 6 and 7. Appendix C shows summary results for the same variables in terms of significance differences (probability levels) for the 9 x 9 as well as 10 x 7 line and tester analysis. This was after dropping parents, that is, lines and testers together or testers only where crossing of parents was not complete due lack of synchronization. Since maximum information regarding line and tester performance could be obtained from a 9 x 9 line and tester analysis, discussion in this report, therefore, is based on this analysis.

4.3 GRAIN YIELD (GY)

Differences (P< 0.01) for grain yield across all sites were observed between Nlevel and among Site(Nlevel), lines, testers and entry (crosses) and the interaction Nlevel x tester (Table 4 and Appendix C). Under low N conditions differences were observed among Site(Nlevel), lines, testers as well as Site(Nlevel) x tester interaction (Appendix D). Similarly the same factors differed for grain yield under high N (Appendix E)

Higher GY was recorded under high N compared to low N (8.01 t/ha vs. 1.56 t/ha) (Table 7). Highest grain yield was recorded at ART Farm (high N site) while Kabwe (low N site) gave the lowest grain yield (9.10 t/ha vs. 0.78 t/ha) (Table 5 and Appendix F to K).

Tables 6 and 7 show means of grain yield for parents. The grain yield across environment due to testers ranged from 4.5 to 5.05 t/ha (Table 6) while under low N and high N the yields ranged from 1.25 to 1.72 and 7.51 to 8.48 t/ha (Table 7) respectively. Tester 9 produced highest grain yield while the least yield in crosses was tester T2. Under low N, T7 produced higher yield while the lowest was from T3. At optimal conditions the lowest and highest grain yield was produced by T5 and T12.

For lines, grain yield ranged from 4.35 to 5.56 t/ha (Table 6). Line L11 followed by L1 were the highest while the lowest was L2 at both nitrogen levels (Table 7).

Table 8 shows performance of Testers under varying nitrogen levels. Under low N tester T7 and T9 produced higher yields while T3 and T8 had lower yields. Under high N conditions T9 maintained the higher yield while tester T7 was moderate. The highest yielding testers under high N were T9 and T12. This observance of differential response of the testers to varying nitrogen levels confirms significance of the interactions.

Significant interactions were also observed between Site(Nlevel) and testers (Table 9). Tester performance differed in different environments (sites). Grain yield at site 3 (Kabwe) was generally poor while site 5 (ART Farm) was good. While T9 and T12 consistently had higher yields in all environments (both low N and high N), the converse was true for testers T3 and T5. Despite of T1 producing good yield under low N the yield under high N was generally low. Similarly T8 gave higher yield under low N compared to high N in different sites. Most testers showed moderate response to changing environments regarding yields (T4, T6 and T7).

4.4. ANTHESIS DATE (AD)

Analysis of variance on Table 4 and Appendix C show differences among Site(Nlevel), line, tester and entry for the days to 50% anthesis. AD was also different between Nlevel x tester.

Differences ($P<0.05$) were also observed among Site(Nlevel), line, tester as well as the line x tester, Site(Nlevel) x line and Site(Nlevel) x tester interaction under low N (Appendix D). However, differences at optimal conditions were observed among Site(Nlevel), lines, testers and Site(Nlevel) x tester interaction respectively (Appendix E).

Testcrosses took an average of 73.6 days to shade pollen at low N compared to 71.4 days under optimal conditions. Among sites, Golden Valley (high N) had the least 50 % days to anthesis (65.6 days) compared to CIMMYT-Harare (75.9 days) (Table 5).

Means of anthesis days for parents (lines and testers) are shown on Table 6 and 7. Combined analysis showed 50% days to anthesis ranging from 71 to 74 days for T5 and T12 respectively. At both nitrogen levels testers T1 and T5 were earlier to shade pollen while later pollen shading was from T8, T9 and T12.

In lines, L2 was the earliest to shade pollen under low N as well as under high N. Anthesis days due to L5 and T5 were early while L7, L8, L10, L11 and T12 were later.

Response of testers to variation in soil nitrogen fertility is shown on Table 10. Moderate response to nitrogen changes were observed in six testers except for testers T8, T9 and T12. The changes in anthesis days were slight and on average it was than two days.

4.5. SILKING DATE (SD)

Table 4 and Appendix C show analysis of variance for silking. Silking differed ($P< 0.05$) among Site(Nlevel) and between line, tester and entry (crosses) and for Nlevel x line. No differences were observed for other factors.

Under low N silking day's were different between Site(Nlevel), Nlevel, line tester, as well as line x tester, Site(Nlevel) x line, Site(Nlevel) x tester interactions (Appendix D).

However, at optimal fertility differences were noted between Site(Nlevel), line, tester, as well as Site(Nlevel) x tester.

Genotypes at Golden Valley took 66 days to produce silk while at Kabwe site it took 79.8 days. At high N conditions genotypes produced silking earlier as compared to low N (73 vs. 78 days). Among testers T12 (81days) took long to silk while the earliest was T1 (77 day) under low N. At optimal conditions differences in silking days was slight although T5 (71 days) was the earliest.

In lines the earliest to produce pollen was L2 while L11 was the later one at reduced fertility. At optimal condition most lines took almost same number of days to silk pollen.

Lines differed in performance in terms of variation in fertility (Table 11). Line L6 and L8 appeared to be the most stressed lines compared to the others.

4.6. ANTHESIS SILKING INTERVAL (ASI).

There were significant differences ($P<0.01$) for anthesis-silking interval between Site(Nlevel), among lines as well as Nlevel x line interaction (Table 4 and Appendix C).

Differences were also noted under low N for ASI between Site(Nlevel), line, tester and the interactions line x tester, Site(Nlevel) x line and Site(Nlevel) x tester (Appendix D). At high N significant differences were noted among Site(Nlevel) as well as line and tester (Appendix E).

Golden Valley (high N) had the least days of ASI (0.98 days) while the largest ASI (7.30 days) was recorded at Golden Valley (low N) (Table 5).

Table 7 show means of lines and testers. ASI for lines ranged from 1.27 days under optimum compared to 4.7 days under nitrogen stress (Table 7). Under low N ASI most lines averaged 4 days though L8 had slight lower ASI. Under optimal conditions L10 and L9 had same dates of flowering days in terms of anthesis and silking.

The interactions of lines and Nlevel are shown on Table 12. Line L8 had the most response due changing fertility while the most stable lines were L4, L7 and L9. Other lines like L2, L10 and L11 had moderate response to nitrogen variations.

4.7. EARS PER PLANT (EPP).

Table 4 and Appendix C show differences ($P<0.01$) for EPP among Nlevel, Site(Nlevel) and lines and testers. Under high N differences were observed between line and tester (Appendix E).

Table 5 show means of EPP. More ears per plant were attained at ART Farms while Kabwe had the least. At optimal conditions the average ears per plant was 1.03 ears compared to 0.74 ears reduced fertility (Table7).

Among lines, the highest and the lowest ears per plant were attained in L1 (0.81 ears) and L6 (0.68 ears) under low N. At optimal fertilizer a total of six lines produced at least an average of one ear with the exception of L2, L7 and L8 which produced less than one.

4.8. PLANT HEIGHT (PH)

Plant height differed ($p<0.001$) between Site(Nlevel), line, tester and entry (crosses) as well as between Nlevel x line (Table 4 and Appendix C). At nitrogen stress (Appendix D) differences were between Site(Nlevel), line, tester, line x tester and Site(Nlevel) x line as well Site(level) x tester. However, at optimal differences were found between Site(Nlevel), line, tester and the interaction Site(Nlevel) x tester.

Among the sites, highest plant height in genotypes was attained at ART Farm compared to Kabwe (2.45 vs. 98.94 cm) (Table 5).

A tester with highest plant height was T8 seconded by T12 while the least height was recorded by T5 under high N (Table 7). Plant height under Low N fertility ranged between 138.01 for T5 to 156.11 cm for T8. In lines, L1 and the L11 attained higher heights and this was at both nitrogen levels (Table 7).

Interactions of lines and Nlevel regarding plant heights are shown on Table 13. Most response in plant height to variation in fertility was observed in T3. Majority of lines remained stable except for L9 which produced moderate response to changes in nitrogen.

Table 4. Analysis of Variance for grain yield, anthesis, silking, anthesis-silking interval, ears per plant and plant height Across all 9 x 9 lines and testers grouped in 3 low N and 3 high N sites in Zambia and Zimbabwe

SOURCE	DF	GY	AD	SD	ASI	EPP	PH
NLEVEL	1	50.60^{**}	616.53^{ns}	3811.53^{ns}	1390.91^{ns}	10.55^{***}	639310.98^{ns}
SITE(NLEVEL)	4	155.53^{***}	1409.77^{***}	1229.05^{***}	275.62^{***}	0.12^{***}	152167.05^{***}
LINE **(GCA)**	8	2.05^{*}	51.22^{***}	65.37^{***}	8.02^{***}	0.04^{***}	2533.12^{***}
TESTER **(GCA)**	8	6.34^{***}	47.58^{***}	58.36^{***}	2.83	0.031^{**}	3476.63^{***}
NLEVEL X LINE	8	1.76^{ns}	3.79^{ns}	10.37**	6.98^{***}	0.015^{ns}	409.11^{***}
NLEVEL X TESTER	8	1.98^{*}	4.96^{*}	5.92^{ns}	0.45^{ns}	0.015^{ns}	166.01^{ns}
LINE X TESTER **(SCA)**	64	0.89^{ns}	2.91^{ns}	4.21^{ns}	2.13^{ns}	0.0093^{ns}	126.78^{ns}
NLEVEL X LINE X TESTER	64	0.87^{ns}	1.72^{ns}	2.35^{ns}	1.81^{ns}	0.012^{ns}	98.59^{ns}
SITE(NLEVEL) X LINE	32	1.02^{ns}	3.71^{ns}	7.14^{ns}	2.81^{ns}	0.017^{ns}	128.83^{ns}
SITE(NLEVEL) X TESTER	32	1.91^{ns}	3.00^{ns}	4.47^{ns}	1.21^{ns}	0.0099^{ns}	126.20^{ns}
SITE(NLEVEL) X LINE X TESTER	256	0.76^{ns}	2.28^{ns}	4.11^{ns}	2.08^{ns}	0.011^{ns}	107.71^{ns}
POOLED ERROR	526	1.16	3.31	6.79	3.07	0.021	262.16
LSD		0.865	1.457	2.086	1.404	0.116	12.956
MEAN		4.79	72.5	75.5	3.0	0.88	186.2
CV		22.56	2.51	3.45	58.47	16.51	8.70
# LOW N SITES		3	3	3	3	3	3
# HIGH N SITES		3	3	3	3	3	3

DF=degree of freedom; GY=grain yield; AD=anthesis date; SD=silking date; ASI=anthesis silking interval; EPP=ears per plant; PH=plant height

*, **, *** Significant at 5%, 1% and 0.1%; ns = non significant at 5%

Table 5. Means of grain yields and secondary traits at six sites where crosses were evaluated.

Site	Location	NLEVEL	Measured Traits											
			GY	AD	SD	ASI	EPP	PH	GLS	HT	RUST	SENESCNCE	SKW	KERNELS PER EAR
			t/ha	days	days	days	no	cm	1-5	1-5	1-5	10-00%	gm	no
1	Golden Valley	High N	8.47	65.64	66.62	0.98	1.03	237.81	2.47	2.34	-	-	348.73	608.21
2	Golden Valley	Low N	1.32	70.23	77.53	7.30	0.75	148.19	-	2.09	-	41.59	210.79	258.82
3	Kabwe	Low N	0.78	75.09	79.88	4.83	0.67	98.94		2.16	-	43.70	206.67	128.35
4	Mount Makulu	High N	5.92	74.01	75.79	1.78	1.00	185.02	1.40	1.52	-	-	313.75	458.66
5	ART Farm	High N	9.10	74.71	75.88	1.17	1.04	245.15		1.21	2.00			
6	CIMMYT Harare	Low N	2.49	75.92	77.86	1.95	0.78	201.13	-	-	-	64.19	257.07	281.34

GY= grain yield; AD =anthesis date; SD = silking date; ASI = anthesis silking date; EPP = Ears per plant; PH = plant height; GLS = grey leaf spot Et = *Exeserohilum turcicum*; SKW = single kernel weight.

TABLE 6. MEANS OF LINES AND TESTERS FOR THE GRAIN YIELD AND SECONDARY TRAITS ACROSS ENVIRONMENT.

FACTOR		GY t/ha	AD days	SD days	ASI days	EPP No	PH cm	SKW mg	Kernels Per ear No	SENESC 10-100%	GLS 1-5score	Et 1-5score	Rust 1-5scor
LINES	1	5.01	71.84	74.87	2.99	0.94	201.81	291.95	367.59	47.02	2.46	1.85	2.01
	2	4.35	70.54	73.35	2.84	0.88	181.87	279.10	355.50	44.14	1.62	1.91	2.05
	4	4.83	72.89	76.00	3.14	0.88	183.58	270.49	390.35	44.29	1.86	1.80	1.78
	6	4.57	72.80	75.90	3.11	0.85	184.77	265.50	372.71	48.11	1.82	1.85	1.93
	7	4.67	73.16	76.13	2.98	0.86	179.43	269.70	387.60	45.18	2.01	1.93	2.12
	8	4.75	73.15	76.35	3.26	0.88	181.33	272.43	388.93	44.52	1.96	1.99	2.32
	9	4.64	71.95	74.60	2.58	0.89	181.56	267.40	362.75	45.76	1.85	1.84	2.23
	10	4.69	73.02	75.64	2.66	0.87	183.12	274.66	371.03	39.19	1.40	1.88	1.76
	11	5.56	73.56	76.64	3.13	0.89	198.17	304.41	384.04	41.65	2.28	2.24	1.37
TESTERS	1	4.60	71.53	74.29	2.73	0.88	182.43	276.78	363.64	45.10	2.01	1.88	1.94
	3	4.54	72.78	76.20	3.46	0.87	187.33	265.30	366.8	47.20	1.80	2.26	1.21
	4	4.90	72.59	75.55	3.02	0.86	185.78	276.65	400.61	42.55	2.47	1.86	1.24
	5	4.52	71.01	73.69	2.66	0.91	171.47	263.24	381.62	47.78	1.52	1.83	2.17
	6	4.82	72.15	75.57	3.41	0.87	187.51	280.03	377.38	46.26	2.20	1.95	1.13
	7	4.87	72.10	74.84	2.76	0.93	187.29	271.70	376.89	42.42	1.80	1.93	2.38
	8	4.79	73.16	76.22	3.08	0.86	197.06	284.30	361.50	44.95	1.64	2.14	2.46
	9	5.05	73.47	75.76	2.29	0.90	185.89	270.28	394.92	41.72	1.92	1.66	2.46
	12	5.00	74.14	77.35	3.27	0.85	190.88	307.01	356.93	41.88	1.90	1.77	2.57
	LSD	0.865	1.457	2.086	1.404	0.116	12.956	26.623	71.705	11.331	0.647	0.457	0.977
	MEAN	4.79	72.5	75.5	3.0	0.88	186.2	252.0	375.6	45.6	1.9	1.9	2.0
	CV %	22.56	2.51	3.45	58.47	16.51	8.70	10.95	21.78	28.35	28.78	23.37	24.93

GY= grain yield; AD= anthesis date; SD= silking date; ASI= anthesis silking interval; EPP= ears per plant; PH= plant height; SKW= single kernel weight; SENESC= leaf senescence; GLS= grey leaf spot; Et= *Exserohilum turcicum*

TABLE 7.MEANS OF LINES ND TESTERS ON GRAIN YIELD AND SECONDARY TRAITS UNDER LOW N (LEVEL 0) AND HIGH N (LEVEL1).

NLEVEL		GY	AD	SD	ASI	EPP	PH	SKW	K/EAR	SENESC	GLS	HT	RUST
		t/ha	days	days	days	No	cm	mg	No	10-100%	1-5	1-5	1-5
0		1.56	73.67	78.30	4.66	0.74	149.91	224.75	227.71	50.04	-	2.14	-
1	LINE	8.01	71.42	72.70	1.27	1.03	222.45	229.80	523.50	38.82	1.92	1.70	1.95
0	1	1.81	72.56	77.33	4.74	0.81	163.90	247.26	225.76	49.21	-	2.04	-
0	2	1.32	71.97	76.39	4.52	0.77	148.36	219.29	221.11	52.65	-	2.14	-
0	4	1.48	74.11	78.85	4.78	0.72	148.25	221.69	245.43	49.45	-	2.09	-
0	6	1.46	73.66	78.33	4.70	0.68	147.36	215.46	223.27	50.52	-	2.13	-
0	7	1.56	74.24	78.91	4.67	0.72	144.50	225.08	226.26	48.37	-	2.17	-
0	8	1.67	74.49	79.55	4.14	0.72	144.55	214.26	240.96	50.92	-	2.26	-
0	9	1.38	73.21	77.52	4.15	0.74	147.10	212.19	218.77	50.76	-	2.09	-
0	10	1.46	74.55	78.83	4.40	0.72	145.60	21.46	212.78	47.83	-	2.00	-
0	11	1.90	74.27	78.95	4.82	0.74	159.61	255.10	235.10	50.61	-	2.34	-
	TESTER												
0	1	1.67	72.42	76.69	4.22	0.76	147.81	219.27	229.67	50.62	-	2.10	-
0	3	1.25	73.95	79.09	5.26	0.70	153.61	211.95	212.05	50.70	-	2.50	-
0	4	1.54	73.47	78.29	4.93	0.70	150.19	222.91	246.61	48.59	-	2.03	-
0	5	1.54	72.56	76.52	3.87	0.79	138.01	207.12	253.89	47.97	-	2.06	-
0	6	1.61	73.17	78.79	5.58	0.74	153.71	226.32	228.40	51.72	-	2.15	-
0	7	1.72	72.99	77.05	4.15	0.77	150.73	215.37	245.87	48.63	-	2.26	-
0	8	1.48	74.28	79.00	4.77	0.72	156.11	240.61	190.33	50.10	-	2.37	-
0	9	1.71	74.53	78.24	3.65	0.76	147.90	219.99	246.79	51.07	-	1.76	-
0	12	1.52	75.70	81.01	5.48	0.69	151.15	259.25	195.80	50.93	-	2.02	-
MEAN		1.56	73.67	78.3	4.66	0.74	149.91	224.75	227.71	50.04	-	2.14	-
LSD		1.30	4.72	6.97	4.62	0.36	38.94	49.66	169.54	21.07	-	0.99	-
CV%		72.93	5.61	7.79	86.85	42.85	22.72	19.33	65.13	36.83	-	33.29	-

TABLE 7. CONT/.. MEANS OF LINES AND TESTERS ON GRAIN YIELD AND SECONDARY TRAITS UNDER LOW N (LEVEL 0) AND HIGH N (LEVEL1).

NLEVEL	LINE	GY	AD	SD	ASI	EPP	PH	SKW	KNEAR	SENESC	GLS	HT	RUST
		t/ha	days	days	days	No	cm	mg	No	10-100%	1-5	1-5	1-5
0		1.56	73.67	78.30	4.66	0.74	149.91	224.75	227.71	50.04	-	2.14	-
1		8.01	71.42	72.70	1.27	1.03	222.45	229.80	523.50	38.82	1.92	1.70	1.95
1	1	1.81	71.12	72.41	1.24	1.06	239.72	336.64	509.42	44.84	2.46	1.67	2.01
1	2	7.38	69.12	70.31	1.17	0.99	215.38	338.90	489.80	35.64	1.62	1.69	2.05
1	4	8.18	71.67	73.14	1.49	1.05	218.91	319.29	535.27	39.13	1.86	1.51	1.78
1	6	7.69	71.94	73.47	1.53	1.02	222.18	315.55	522.16	45.70	1.82	1.57	1.93
1	7	7.77	72.09	73.34	1.29	0.99	214.35	314.30	548.90	41.98	2.01	1.68	2.12
1	8	7.83	71.81	73.15	1.38	0.99	218.12	330.60	536.90	38.11	1.96	1.71	2.32
1	9	7.90	70.68	71.68	1.00	1.03	216.03	322.60	506.73	40.75	1.85	1.58	2.23
1	10	7.93	71.50	72.44	0.93	1.02	220.64	336.86	529.28	30.55	1.40	1.76	1.76
1	11	9.22	72.85	74.32	1.43	1.04	236.72	353.71	532.99	32.68	2.28	2.14	1.37
	TESTER												
1	1	7.52	70.64	71.90	1.25	1.01	217.05	334.30	497.60	39.58	2.01	1.66	1.94
1	3	7.82	71.62	73.30	1.66	1.03	221.04	318.60	521.60	43.70	1.80	2.01	1.21
1	4	8.26	71.71	72.81	1.11	1.02	221.37	330.39	554.61	36.50	2.47	1.70	1.24
1	5	7.51	69.45	70.87	1.45	1.03	204.94	319.37	509.34	47.59	1.52	1.61	2.17
1	6	8.03	71.13	72.34	1.23	1.00	221.31	333.75	526.35	40.80	2.20	1.75	1.13
1	7	8.01	71.21	72.62	1.37	1.09	223.86	328.02	507.90	36.21	1.80	1.59	2.38
1	8	8.09	72.04	73.44	1.39	1.00	238.01	327.90	532.60	39.81	1.64	1.91	2.46
1	9	8.39	72.41	73.28	0.94	1.04	223.88	320.57	543.05	32.36	1.92	1.55	2.46
1	12	8.48	72.58	73.70	1.07	1.00	230.61	354.77	518.06	32.82	1.90	1.52	4.57
MEAN		8.01	71.42	72.7	1.27	1.03	222.45	229.8	523.5	-	1.92	1.7	1.95
LSD		2.73	1.91	2.14	1.64	0.18	23.21	59.67	122.39	-	1.08	1.07	0.99
CV%		29.83	2.34	2.58	113.56	15.67	1971.78	22.72	20.45	-	40.27	44.96	25.56

Table 8. Means of grain yield (t/ha) for 9 testers under no fertilizer (low N) and with fertilizer (high N) for (N(Level) x tester.

	TESTERS									
NLEVEL	1	3	4	5	6	7	8	9	12	Mean
LOW N	1.67	1.25	1.54	1.54	1.61	1.72	1.48	1.71	1.52	1.56
HIGH N	7.52	7.82	8.26	7.51	8.03	8.01	8.09	8.39	8.48	8.01
MEAN										4.79
$LSD_{(0.05)}$										0.865
CV (%)										22.56

Table 9. Means of grain yield (t/ha) for 9 testers under no fertilizer (low N) and with fertilizer (high N) for Site(Nlevel) x tester

	TESETRS									
SITE	1	3	4	5	6	7	8	9	12	Mean
1	8.40	8.54	8.48	7.80	8.04	8.73	8.94	8.94	9.20	8.56
2	1.64	1.00	1.25	1.28	1.31	1.79	1.16	1.51	1.28	1.36
3	0.92	0.62	0.80	0.73	0.87	0.88	0.68	0.83	0.74	0.79
4	5.61	5.34	6.46	5.13	6.29	6.11	6.51	6.19	6.86	6.06
5	8.51	9.95	9.84	9.60	9.76	9.20	8.83	10.05	9.39	9.42
6	2.45	2.41	2.59	2.60	2.64	2.50	2.60	2.54	2.54	2.54
MEAN										4.79
$LSD_{(0.05)}$										0.865
CV (%)										22.56

Sites: 1= Golden Valley; 2 = Golden Valley; 3 = Kabwe; 4 = Mount Makulu; 5 = ART Farms; 6 = CIMMYT- Harare

Table 10. Means of 50% days to anthesis for 9 testers under no fertilizer (low N) and with fertilizer (high N) for N(Level) x tester

	TESTERS									
NLEVEL	1	3	4	5	6	7	8	9	12	Mean
LOW N	72.42	73.95	73.47	72.56	73.17	72.99	74.28	74.53	75.70	73.67
HIGH N	70.64	71.62	71.71	69.45	71.13	71.21	72.04	72.41	78.58	71.42
MEAN										72.5
$LSD_{(0.05)}$										1.457
CV (%)										2.51

Table 11. Means of 50% days to silking for 9 lines under no fertilizer (low N) and with fertilizer (high N) for N(Level) x line

	LINES									
NLEVEL	1	2	4	6	7	8	9	10	11	Mean
LOW N	77.33	76.39	78.85	78.33	78.91	79.55	77.52	78.83	78.95	78.30
HIGH N	72.41	70.31	73.14	73.47	73.34	73.15	71.68	72.44	74.32	72.70
MEAN										75.5
$LSD_{(0.05)}$										2.086
CV (%)										3.45

Table 12: Means of anthesis silking interval (ASI) in days for 9 lines under no fertilizer (low N) and with fertilizer (high N) for N(Level) x line

	LINES									
NLEVEL	1	2	4	6	7	8	9	10	11	Mean
LOW N	4.74	4.52	4.78	4.70	4.67	4.14	4.15	4.40	4.82	4.66
HIGH N	1.24	1.17	1.49	1.53	1.29	1.38	1.00	0.93	1.44	1.27
MEAN										3.0
$LSD_{(0.05)}$										1.404
CV (%)										58.47

Table 13: Means of plant height (cm) for 9 testers under no fertilizer (low N) and with fertilizer (high N) for N(Level) x line

	LINES									
NLEVEL	1	3	4	5	6	7	8	9	12	Mean
LOW N	163.90	148.36	148.25	147.36	144.50	144.55	147.10	145.60	159.61	149.91
HIGH N	239.72	215.38	218.91	222.18	214.35	218.12	216.03	220.64	236.72	222.45
MEAN										186.2
$LSD_{(0.05)}$										12.956
CV (%)										8.70

4.9 SINGLE KERNEL WEIGHT (SKW)

Table 14 and Appendix C show analysis of variance for single kernel weight (SKW). Significant differences (P<0.01) for SKW were obtained between Nlevel, Site(Nlevel), line, tester and entry (crosses) and between Nlevel x tester interaction.

Differences at low N (Appendix D) were observed among Site(Nlevel), line, tester and the interactions between line x tester, Site(Nlevel) x line, and Site(Nlevel) x tester. At high N condition (Appendix E) differences were between Site(Nlevel), line and tester.

Higher single kernel weight was recorded at high N compared to low N (229.9 vs. 224.75 gm) while the least was at Golden Valley (low N site) which recorded 206.67gm (Table5).

Table 7 show means of lines and testers. The highest SKW in testers under optimal fertility was by T12 (354.77 gm) while T3 (318.60gm) was the least. At low N SKW ranged from 207.12gm for T5 to 259.25gm for T12.

In lines, L11 had higher SKW followed by L2 while the L7 under high N was the lowest under high N. The least SKW under low N was attained by L10 (212.19gm) while L11 maintained the highest SKW.

Interactions of testers and Nlevel are shown in Table 15. T12 gave higher single weight at both nitrogen levels while T8 and T9 had poor response. More responses to changing nitrogen levels were in T1 and T8. Other testers remained stable like the case of T3 and T6.

4.10. NUMBER OF KERNELS PER EAR

Differences for this variable was among Nlevel, Site(Nlevel), line, tester and entry (crosses). Differences were also noted between Site(Nlevel) x line interaction (Table 14 and Appendix C).

Under low N ($P<0.01$) were differences between Site(Nlevel), line, tester and the interactions between line x tester as well as Site(Nlevel) x tester (Appendix D). Differences under optimal conditions were only observed between Site(Nlevel) (Appendix E).

Table 7 show means of lines and testers. Lower number of kernels per ear was recorded under low N compared to high N (224.75 vs. 29.80). Among sites more number of kernels per ear was produced by genotypes at Mount Makulu while the least was at Kabwe.

Among testers, T4 produced more kernels per ear while the least was T1 at optimal conditions. However, under nitrogen stress T5 was the highest while T8 was the least (Table 7). The number of kernels per ear in lines ranged from 212.78 kernels (L10) to 245.45 kernels (L4) under low N while at high fertility the range was 489.80 kernels (L2) to 548.90 kernels (L7).

4.11 LEAF SENESCENCE (SENESC)

Analysis of variance for leaf senescence is shown in Table 14 and Appendix C. There were differences ($P<0.01$) among Site(Nlevel), line, tester and entry (crosses) as well as the interaction between Site(Nlevel) x line and Site(Nlevel) x tester. Under low N (Appendix D) differences were among Site(Nlevel), line, tester and the interactions Site(Nlevel) x line and Site(Nlevel) x tester.

Senescence was recorded both under low N and high N. It was earlier observed around flowering and during grain filling stage in trials subjected to nitrogen stress (low N). Under well-fertilized condition, leaf senescence occurred late and after physiological maturity.

Mean values for leaf senescence are shown in Tables 5 and 7. Among sites the highest leaf senescence was recorded at CIMMYT Harare (64.19%) while the least was at Golden Valley (41.595). Among testers, T5 had lower leaf senescence compared to T9 (47.97 vs. 51.07%) under low N. In lines, L10 seconded by L7 had the least scores while the highest score of 52.65% was attained by L2.

Genotypes with lower leaf senescence stayed green relatively longer than the ones with higher leaf senescence.

TABLE 14. MEAN SQUARES FOR SINGLE KERNEL WEIGHT, NUMBER OF KERNELS PER EAR AND SENESCENCE ACROSS ALL 9 LINES AND 9 TESTERS GROUPED IN 3LOW N AND 3 HIGH N IN ZAMBIA AND ZIMBABWE

SOURCE	DF	SKW	KERNELS PER EAR	DF	SENESCENCE
NLEVEL	1	1330230.5^{**}	10556115^{**}	1	12230.43^{ns}
SITE(NLEVEL)	4	42348.12^{***}	580778.85^{***}	3	10032.99^{***}
LINE (GCA)	8	9113.71^{***}	12150.22^{**}	8	216.57^{***}
TESTER (GCA)	8	8920.31^{***}	8410.89^{**}	8	288.51^{***}
NLEVEL X LINE	8	1106.01^{ns}	11264.86^{ns}	8	326.66^{***}
NLEVEL X TESTER	8	2227.10**	3447.22^{ns}	8	312.39^{***}
LINE X TESTER (SCA)	64	702.18^{ns}	6334.44^{ns}	64	52.77^{ns}
NLEVEL X LINE X TESTER	64	710.74^{ns}	4665.55^{ns}	64	58.97^{ns}
SITE(NLEVEL) X LINE	32	781.23^{ns}	3828.06^{ns}	24	42.11^{ns}
SITE(NLEVEL) X TESTER	32	942.25^{ns}	4962.11^{ns}	24	86.14^{ns}
SITE(NLEVEL) X LINE X TESTER	254	609.91^{ns}	4642^{ns}	192	46.29^{ns}
POOLED ERROR	338	922.49	6692.05^{ns}	495	167.11
LSD		26.623	71.705		11.331
MEAN		252.0	375.6		45.6
CV		10.95	21.78		28.35
#LOW N SITES		3	3		3
#HIGH N SITES		2	2		2

*,**,*** significant at 5%, 1% and 0.1%

Table 15: Means of single kernel weight (gm) for 9 testers under no fertilizer (low N) and with fertilizer (high N) for N(Level) x tester

	TESTERS									
NLEVEL	1	3	4	5	6	7	8	9	12	Mean
LOW N	219.27	211.95	222.91	207.12	226.32	215.37	240.61	219.99	259.25	224.75
HIGH N	334.30	318.60	330.39	319.37	333.75	328.02	327.90	320.57	354.77	229.80
MEAN										252.0
$LSD_{(0.05)}$										26.623
CV (%)										10.95

4.12 DISEASES

Grey leaf spot (GLS), *Exserohilum turcicum* (Et) and rust were observed in the trials. GLS was recorded in two trials grown under high N at Golden Valley and at Mount Makulu in Zambia. Turcicum affected all trials planted in Zambia while rust was only recorded at ART Farms in Zimbabwe.

4.12.1. Grey Leaf Spot (GLS)

Analysis of variance for GLS disease is shown in Table 16 and Appendix C. Highly significant differences ($P<0.01$) for GLS were observed between Site(Nlevel) and among lines and testers. Similar differences for GLS were obtained between the same factors under high N (Appendix E). Disease establishment occurred late and after the grain filling stage.

The highest disease score at Golden Valley (2.47) while Mount Makulu had lower disease score (1.40) (Table 5). Among testers the highest score of 2.47 was in T4 seconded by T6 with the score of 2.20. The least score of 1.52 was obtained in T5.

In lines the disease ranged between 1.40 (L10) to 2.46 (L1). Another line lower disease score was L2 (1.62).

4.12.2. *Exserohilum turcicum*

Differences ($P<0.01$) were also observed for *Exserohilum turcicum* between Site(Nlevel), line and tester (Table 17 and Appendix C). Under high N differences were between

Site(Nlevel), line, tester, and the interactions Site(Nlevel) x line and Site(Nlevel) x tester (Appendix E). However, under low N differences was only between lines (Appendix D).

Among sites the least disease score was at ART Farm (1.21) followed by Mount Makulu (1.52). The highest score was obtained at Golden Valley (Table 5).

Means of disease scores for lines are on Table 7. Among testers T9 a lowest score (1.76) while T3 (2.50) was the highest under low N. Under high N T3 (2.01) was the highest with least score attained in T12. Among lines the disease score ranged between 2.00 and 2.34 under nitrogen stress. At high N L11 had higher score and the rest of the lines had the scores ranging between 1.5 and 1.7 (Table 7). Disease incidence happened to be higher on low N compared to high N (Table 7).

4.12.3. RUST

Table 18 and Appendix C show analysed data for rust. Rust disease differences were noted among lines, testers and entry. Among the testers the least disease score of 1.13 was in T6 while T12 was the highest with the score of 4.57. In lines L11 followed by L10 and L4 had lower disease incidence (Table 7).

TABLE 16. MEAN SQUARES FOR GREY LEAF SPOT ACROSS ALL 9 LINES AND 9 TESTERS GROUPED 2 HIGH N SITES IN ZAMBIA.

SOURCE	DF	GLS
SITE(NLEVEL)	1	50.07***
LINE (GCA)	8	1.48***
TESTER (GCA)	8	1.82***
LINE X TESTER (SCA)	64	0.15^{ns}
SITE(NLEVEL) X LINE	8	0.25^{ns}
SITE (NLEVEL)X TESTER	8	0.31^{ns}
SITE(NLEVEL)XLINE X TESTER	64	0.16^{ns}
POOLED ERROR	212	0.29
LSD		0.647
MEAN		1.9
CV		28.78
#LOW N SITES		-
#HIGH N SITES		2

*, **, *** Significant at 5%, 1% and 0.01%; ns = non significant differences

TABLE 17. MEAN SQUARES FOR TURCICUM ACROSS ALL 9 LINES AND 9 TESTERSGROUPED IN 2 LOW N AND 2 HIGH N SITES IN ZAMBIA.

SOURCE	DF	TURCICUM
NLEVEL	1	18.59^{ns}
SITE(NLEVEL)	3	18.94***
LINE (GCA)	8	1.431***
TESTER (GCA)	8	0.79***
NLEVEL X LINE	8	0.16^{ns}
NLEVEL X TESTER	8	0.21^{ns}
LINE X TESTER (SCA)	64	0.10^{ns}
NLEVELX INEXTESTER	64	0.083^{ns}
SITE(NLEVEL) X LINE	24	0.26^{ns}
SITE(NLEVEL)XTESTER	24	0.21^{ns}
SITE(NLEVEL)XLINEX TESTER	192	0.10^{ns}
POOLED ERROR	495	0.21
LSD		0.457
MEAN		1.9
CV		23.37
#LOW N SITES		2
#HIGH N SITES		2

*, **, *** Significant at 5%, 1% and 0.01%; ns = non significant differences

TABLE 18. MEAN SQUARES FOR RUST ACROSS ALL 9 LINES AND 9 TESTERS GROUPED IN 3 LOW N AND 3 HIGH N SITES IN ZAMBIA AND ZIMBABWE

SOURCE	DF	RUST
LINE (GCA)	8	3.22***
TESTER (GCA)	8	0.73^{**}
LINE X TESTER (SCA)	64	0.21^{ns}
POOLED ERROR	6	0.24
LSD		0.977
MEAN		2.0
CV		24.93
#LOW N SITES		-
#HIGH N SITES		1

*, **, *** Significant at 5%, 1% and 0.01%; ns = non significant differences

4.13. COMBINING ABILITY

Mean squares due to general combining ability (GCA for lines and GCA for testers) were significant for all variables measured (Tables 4, 14, 16, 17, and 18). However, the mean squares due to specific combining ability (SCA line x tester) were not significant for the same traits.

4.13.1. GCA for lines

Estimates of GCA effects for lines for various traits are presented in Table 19.

Positive and significant GCA effects for GY were exhibited in L1 (except under high N) and L11 while L2 was negative and significant in all environments. Negative and significant GCA effects were also found in L9 (low N) and in L6 (high N and across environment).

Most lines showed significant GCA effects for AD and SD with three lines (L1, L2 and L9) being negative and one line (L11) being positive in all testing environments. At low nitrogen condition L6 was not significant while L1 and L10 were not significant for the two traits at high fertility.

Positive and significant GCA effects for plant height were observed in L1 and L11 while the rest of the lines were negative and significant with the exception of L6 (high N and across environment) and L2 and L4 (low N).

GCA effects for Nitrogen Use Efficient (NUE) traits are shown in Table 19. Superior GCA for EPP and SKW were obtained from L1 and L11 while L6 and L7 were poor combiners for the two traits in all environments. The GCA effects for number of kernels per ear were positive and high for L8, L10 and L11 in all environments whereas the rest of the lines had either their GCA effects negative in all environments or a combination of positive and negative depending on N level. Low and negative significant GCA values for leaf senescence were showed by L7 and L10 while L2 was a poor combiner for leaf senescence. The rest of the lines had moderate leaf senescence.

Good combiners for GLS were L2, L6, and L10 while the poor combiners were L1 and L11. The remaining lines showed moderate GCA effects for GLS. For turcicum L11 (low N and across environment) and L8 (low N) showed positive and significant GCA effects. At high N all lines showed moderate GCA effects to turcicum.

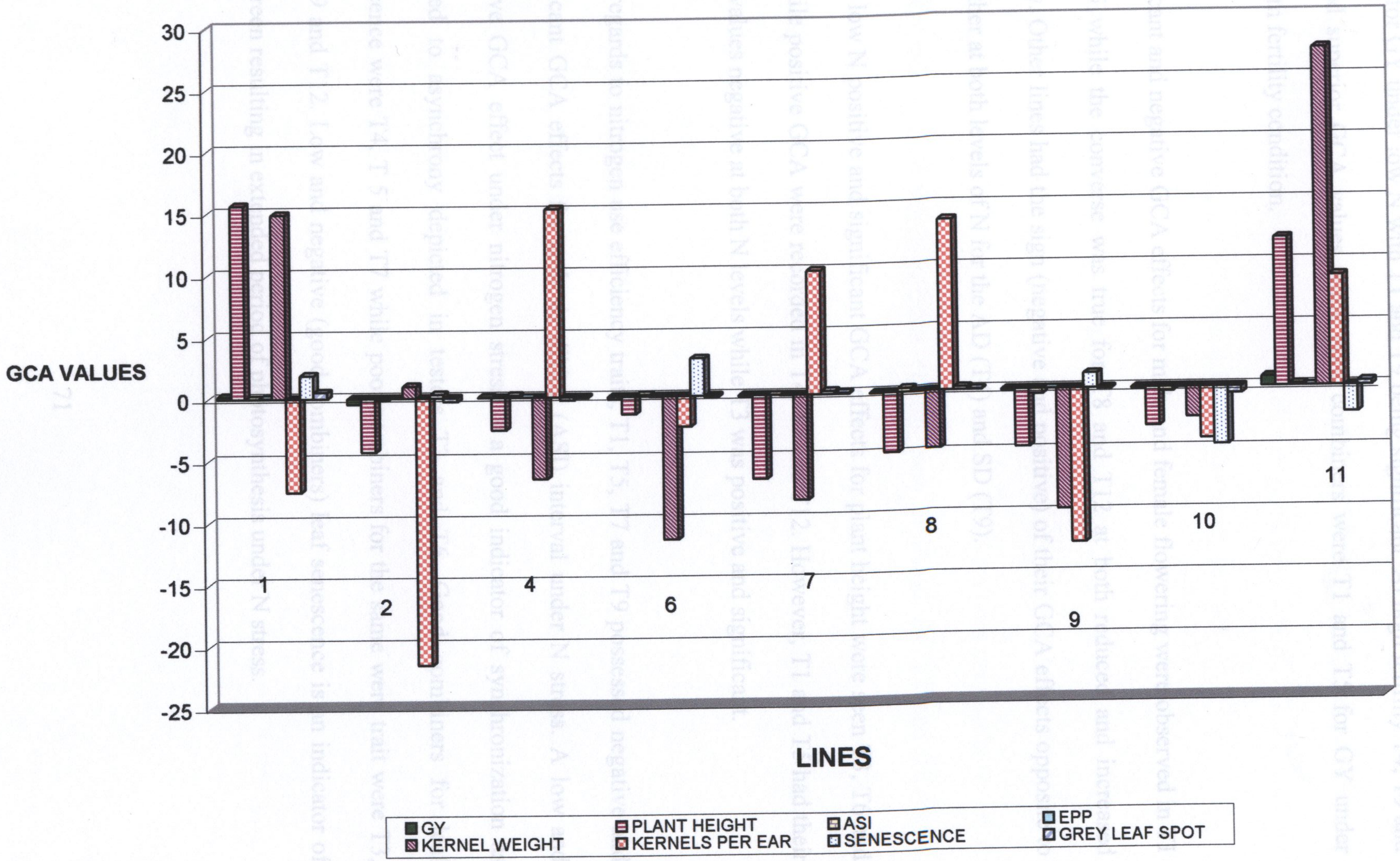
Figure 1 show general picture of GCA effects of the traits for lines across environments. Lines L1 and L11 performed well due to high GCA effects for GY, PH, EPP, SKW, and number of kernels per ear but were poor combiners in GLS. Good combiners for GLS were L2, L6 and L9.

Table 19. GCA of 9 lines evaluated in a Design-2 under low and high N.

Site	Line	Grain Yield	General agronomic traits AD	SD	PH	NUE Traits ASI	EPP	SKW	KNEAR	SENESC	Diseases GLS	HT	RUST
Across	1	0.23**	-0.71**	-0.63**	15.63**	0.02	0.06**	14.88**	-7.56	1.91*	0.54**	-0.06*	0.06
Across	2	-0.44**	-2.00**	-2.14**	-4.31**	-0.12	0.00	0.97	-21.59**	0.30	-0.30**	-0.01	0.10
Across	4	0.04	0.35**	0.50**	-2.60**	0.17**	0.00	-6.58**	15.20**	-0.23	-0.05	-0.14**	-0.17
Across	6	-0.21*	0.26*	0.41**	-1.41	0.15**	-0.03**	-11.57**	-2.43	3.04**	-0.10*	-0.08**	-0.03
Across	7	-0.12	0.62**	0.63**	-6.76**	0.02	-0.02**	-8.45**	9.98*	0.27	0.09	0.00	0.16
Across	8	-0.04	0.60**	0.85**	-4.85**	0.29**	-0.01*	-4.64*	13.79**	0.25	0.04	0.05	0.37
Across	9	-0.14	-0.60**	-0.90**	-4.62**	-0.39**	0.00	-9.67**	-12.40**	1.21	-0.06	-0.09**	0.28
Across	10	-0.09	0.47**	0.14	-3.06**	-0.30**	-0.01*	-2.41	-4.12	-4.63**	-0.52**	-0.02	-0.19
Across	11	0.78**	1.02**	1.14**	11.98**	0.16*	0.01*	27.34**	8.90*	-2.11*	0.37**	0.34**	-0.58
S.E¹		**0.0891**	**0.1182**	**0.1400**	**0.9431**	**0.0662**	**0.007**	**2.434**	**4.7967**	**0.8395**	**0.062**	**0.033**	**-**
Low N	1	0.25**	-1.11**	-0.97**	13.99**	0.08	0.08**	22.51**	-1.96	-0.83	-	-0.10**	-
Low N	2	-0.24**	-1.71**	-1.90**	-1.56	-0.13	0.03**	-5.46**	-6.60	2.62**	-	0.00	-
Low N	4	-0.08	0.44**	0.55**	-1.67	0.12	-0.02*	-3.07	17.71**	-0.58	-	-0.05*	-
Low N	6	-0.10	-0.01	0.04	-2.55*	0.04	-0.05**	-9.30**	-4.45	0.48	-	-0.01	-
Low N	7	0.00	0.57**	0.62**	-5.42**	0.02	-0.02*	0.32	-1.46	-1.66*	-	0.03	-
Low N	8	0.11	0.81**	1.25**	-5.37**	0.48**	-0.02*	-10.49**	13.25	0.88	-	0.12**	-
Low N	9	-0.18**	-0.46**	-0.78**	-2.81**	-0.51**	0.00	-12.57**	-8.95	0.73	-	-0.05	-
Low N	10	-0.10	0.87**	0.54**	-4.31**	-0.26*	-0.01	-12.30**	-14.94	-2.21**	-	-0.14**	-
Low N	11	0.34**	0.60**	0.66**	9.70**	0.16	0.00	30.35**	7.38	0.57	-	0.20**	-
S.E²		**0.067**	**0.128**	**0.204**	**1.195**	**0.129**	**0.011**	**2.082**	**7.750**	**0.697**	**-**	**0.029**	**-**
High N	1	0.21	-0.30	-0.29	17.27**	-0.04	0.04**	6.82**	-14.38*	6.02**	0.54**	-0.03	0.06
High N	2	-0.64**	-2.30**	-2.38**	-7.07**	-0.11	-0.03**	9.22**	-32.70	-3.18*	-0.30**	-0.02	0.10
High N	4	0.17	0.25	0.45*	-3.54**	0.22**	0.02**	-10.53**	11.47*	0.31	-0.05	-0.19	-0.17
High N	6	-0.33	0.52**	0.78**	-0.27	0.25**	-0.01*	-14.27**	-1.64	6.88**	-0.10	-0.13	-0.03
High N	7	-0.24	0.67**	0.64**	-8.10**	0.02	-0.03**	-15.98**	26.31**	3.16*	0.09	-0.02	0.16
High N	8	-0.18	0.39*	0.45*	-4.33**	0.10	0.00	0.78	13.10	-0.71	0.04	0.01	0.37
High N	9	-0.11	-0.74**	-1.01**	-6.42**	-0.27**	0.00	-7.22*	-17.07	1.93	-0.06	-0.12	0.28
High N	10	-0.09	0.07	-0.25	-1.81*	-0.34**	-0.01*	7.04*	5.48	-8.27**	-0.52**	0.06	-0.19
High N	11	1.21**	1.43**	1.62**	14.27**	0.16**	0.01*	23.89*	9.19	-6.14**	0.37**	0.44	-0.58
S.E³		**0.145**	**0.182**	**0.179**	**0.806**	**0.058**	**0.006**	**3.153**	**5.694**	**1.316**	**0.062**	**0.492**	**-**

NOTE: 1, 2 and 3 denotes standard error across, low N and high N environments

FIGURE 1. GCA EFFECTS FOR LINES



4.13.2 GCA for testers.

Table 20 shows GCA effects for traits for testers. Four testers showed positive GCA effects for GY under low N with T1 and T9 being significant. At high fertility T4, T9 and T12 had superior GCA values while poor combiners were T1 and T5 for GY under optimum fertility condition.

Significant and negative GCA effects for male and female flowering were observed in T1 and T5 while the converse was true for T8 and T12 at both reduced and increased fertility. Other lines had the sign (negative and positive) of their GCA effects opposite to each other at both levels of N for the AD (T4) and SD (T9).

Under low N positive and significant GCA effects for plant height were seen T3, T6 and T8 while positive GCA were recorded in T4, T7 and T12. However, T1 and T5 had their GCA values negative at both N levels while T3 was positive and significant.

With regards to nitrogen use efficiency traits, T1, T5, T7 and T9 possessed negative and significant GCA effects for anthesis-silking (ASI) interval under N stress. A low and negative GCA effect under nitrogen stress is a good indicator of synchronization as opposed to asynchrony depicted in testers T3 and T6. Good combiners for leaf senescence were T4, T 5 and T7 while poor combiners for the same were trait were T3, T6, T9 and T12. Low and negative (good combiners) leaf senescence is an indicator of stay green resulting in extended period of photosynthesis under N stress.

Positive and significant GCA effects for grain yield components were exhibited by T5, T7 and T9 in all environments for ears per plant. Under N stress neutral GCA effect was depicted by T6 while T1 was positive. High and positive effects for single kernel weight were recorded by T6, T8 (except high N) and T12. T4 and T9 showed positive and significant GCA effects for number of kernels per ear. Under low N, T3, T8 and T12 were negative with significant GCA effect for number of kernels per ear.

Most testers showed that they were good combiners for GLS and turcicum. The best combiners for GLS were T3, T5, T7 and T8 while testers with moderate GCA effects were T9 and T12. The remaining testers (T1, T4 and T6) were poor combiners for GLS. For turcicum positive and significant effects were exhibited by T3 and T8 in all environments. Good combiners were T9 and T12. At low N other testers with superior GCA effects were T4 and T5 while T1 and T6 were neutral. At high N most showed moderate effects to turcicum.

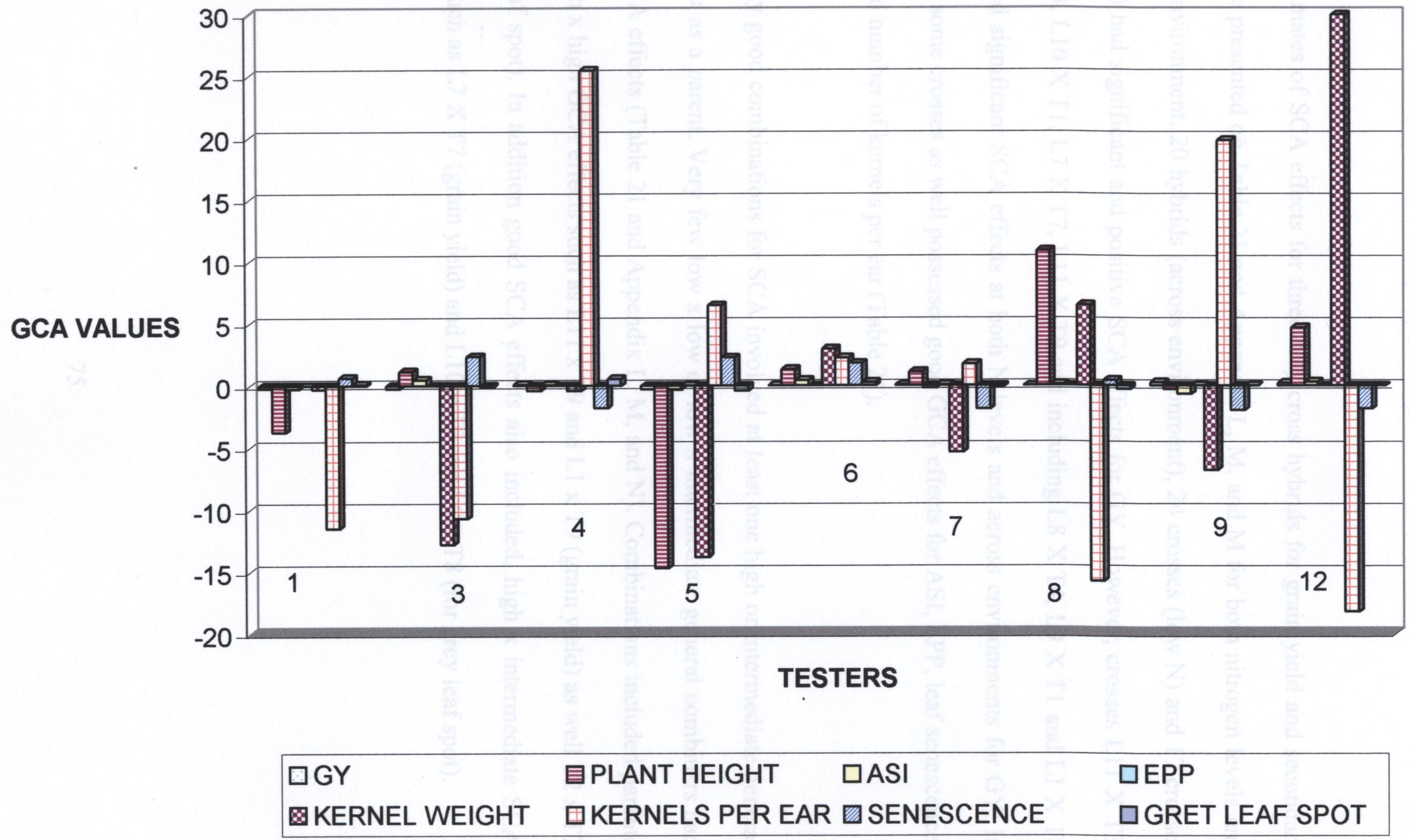
Figure 2 illustrates GCA effects for traits for each tester across environments. T8, T9, and T12 showed high GCA values for more traits. Variations for traits measured were high. However, T8, T9 and T12 showed consistency in performance due to desirable GCA for GY, PH and SKW. Low and negative GCA for ASI was exhibited by T5 and T9 while good combiners for GLS were T3, T5, T7 and T8.

Table 20.GCA of 9 testers evaluated in a Design-2 under low and high N.

Site	Tester	Grain Yield	General agronomic traits AD	SD	PH	NUE Traits ASI	EPP	SKW	KNEAR	SENESC	Diseases GLS	HT	RUST
Across	1	-0.19**	-1.0**	-1.2**	-3.8**	-0.2	0.00	-0.3	-11.5*	0.7	0.1*	0.0	0.0
Across	3	-0.25**	0.2*	0.7**	1.1	0.5**	-0.02*	-12.8**	-10.7*	2.4**	-0.1*	0.3**	-0.7
Across	4	0.12	0.0	0.1	-0.4	0.1	-0.02*	-0.4	25.5**	-1.8*	0.6**	0.0	-0.7
Across	5	-0.26**	-1.5**	-1.8**	-14.7**	-0.3*	0.03**	-13.8**	6.5	2.3**	-0.4**	-0.1**	0.2
Across	6	0.03	-0.4**	0.1	1.3	0.4*	-0.01	3.0	2.2	1.8*	0.3**	0.0	-0.8
Across	7	0.08	-0.4**	-0.7**	1.1	-0.2	0.05**	-5.4**	1.7	-1.9**	-0.1*	0.0	0.4
Across	8	0.00	0.6**	0.7**	10.9**	0.1	-0.02*	6.5**	-15.7**	0.4	-0.3**	0.2**	0.5
Across	9	0.26**	0.9**	0.3	-0.3	-0.7**	0.02*	-6.8**	19.8**	-2.0**	0.0	-0.2**	0.5
Across	12	0.21**	1.6**	1.9**	4.7**	0.3	-0.03**	29.9**	-18.2**	-1.9	0.0	-0.2**	0.6
S.E[1]		**0.07**	**0.1**	**0.2**	**0.9**	**0.2**	**0.01**	**2.0**	**5.1**	**0.7**	**0.1**	**0.0**	**-**
Low N	1	0.11**	-1.3**	-1.6**	-2.1**	-0.4**	0.02	-5.5*	2.0	0.6	-	0.0	-
Low N	3	-0.31**	0.3	0.8**	3.7**	0.6**	-0.04**	-12.8**	-15.7**	0.7*	-	0.4**	-
Low N	4	-0.02	-0.2	0.0	0.3	0.3	-0.03*	-1.8	18.9**	-1.4**	-	-0.1*	-
Low N	5	-0.02	-1.1**	-1.8**	-11.9**	-0.8**	0.05**	-17.6**	26.2**	-2.1**	-	-0.1*	-
Low N	6	0.05	-0.5*	0.5	3.8**	0.9**	0.00	1.6	0.7	1.7**	-	0.0	-
Low N	7	0.16**	-0.7**	-1.2**	0.8	-0.5**	0.03*	-9.4**	18.2**	-1.4**	-	0.1*	-
Low N	8	-0.08*	0.6**	0.7*	6.2**	0.1	-0.02	15.9**	-37.4**	0.1	-	0.2**	-
Low N	9	0.15**	0.9**	-0.1	-2.0	-1.0**	0.03*	-4.8*	19.1**	1.0**	-	-0.4**	-
Low N	12	-0.04	2.0**	2.7**	1.2	0.8**	-0.04*	34.5**	-31.9**	0.9*	-	-0.1	-
S.E[2]		**0.03**	**0.2**	**0.3**	**1.2**	**0.2**	**0.02**	**2.5**	**5.0**	**0.4**	**-**	**0.0**	**-**
High N	1	-0.49**	-0.78**	-0.80**	-5.40**	-0.03	-0.02**	4.48	-26.2**	0.76	0.09	-0.04	-0.01
High N	3	-0.19	0.19	0.61**	-1.41	0.39**	0.01*	-11.2**	-1.14	4.88**	-0.12*	0.31**	-0.74
High N	4	0.25*	0.28*	0.11	-1.08	-0.16*	-0.01*	0.57	30.81**	-2.32*	0.56**	-0.01	-0.71
High N	5	-0.51**	-1.97**	-1.83**	-17.52**	0.18**	0.01*	-10.4**	-14.5	8.77**	-0.39**	-0.09	0.21
High N	6	0.01	-0.29*	-0.35**	-1.14	-0.04	-0.03**	3.93	2.55	1.98	0.28**	0.05	-0.82
High N	7	0.00	-0.21	-0.07	1.41	0.10	0.07**	-1.80	-15.9*	-2.61*	-0.12*	-0.11*	0.43
High N	8	0.08	0.62**	0.74**	15.56**	0.11	-0.02**	-1.68	11.18	0.99	-0.28**	0.21**	0.51
High N	9	0.38**	0.99**	0.59**	1.43	-0.34**	0.01*	-9.25**	19.26**	-6.46**	0.01	-0.15**	0.51
High N	12	0.47**	1.16**	1.00**	8.16**	-0.21**	-0.02**	24.95**	-5.74	-6.00**	-0.02	-0.18**	0.62
S.E[3]		**0.1**	**0.1**	**0.1**	**0.9**	**0.1**	**0.0**	**3.2**	**7.5**	**1.1**	**0.06**	**0.1**	

NOTE: 1, 2 and 3 denotes Standard error across, low N and high N environments

FIGURE2. GCA EFFECTS FOR TESTERS



4.13.3. Specific combining ability (SCA)

Mean squares due to specific combining ability (SCA) were not significant ($p>0.05$) for all traits measured (Table 4, 14, 16, 17, and 18).

The estimates of SCA effects for three-way cross hybrids for grain yield and secondary traits are presented on Table 21 and Appendix L, M, and M for both nitrogen levels and across environment. 20 hybrids (across environment), 24 crosses (low N) and 17 crosses (high N) had significant and positive SCA effects for GY. However, crosses L11 X T3, L4 X T4, L10 X T1, L7 X T7, L11 X T9 and including L8 X T4, L9 X T1 and L1 X T8 possessed significant SCA effects at both N levels and across environments for GY. In addition some crosses as well possessed good GCA effects for ASI, EPP, leaf senescence, GLS, and number of kernels per ear (Table 21).

Generally good combinations for SCA involved at least one high or intermediate general combiner as a parent. Very few low x low or low x intermediate general combiners had good SCA effects (Table 21 and Appendix L, M, and N). Combinations included parents with high x high GCA effects such as L11 x T9 and L1 x T9 (grain yield) as well L2 x T7 (grey leaf spot). In addition good SCA effects also included, high x intermediate SCA effects such as L7 X T7 (grain yield) and L10 x T9 and L9 x T8 (for grey leaf spot).

Table 9 Three way Hybrids with desirable specific combining ability effect (SCA) for selected traits

	ACROSS ENVIRONMENT		LOW N		HIGH N	
GRAIN	11 x 3	9 x 1	4 x 6	6 x 5	11 x 3	7 x 7
YIELD	4 x 6	1 x 1	6 x 4	10 x 1	1 x 9	11 x 9
	11 x 9	6 x 4	1 x 8	4 x 4	2 x 7	6 x 12
	7 x 7	6 x 12	11 x 5	2 x 8	7 x 4	8 x 4
	2 x 7	4 x 5	1 x 1	10 x 9	1 x 5	9 x 1
	1 x 8	7 x 4	11 x 9	2 x 9	9 x 12	1 x 8
	10 x 1	2 x 3	6 x 7	9 x 5	4 x 6	10 x 8
	9 x 12	8 x 5	11 x 3	9 x 1	4 x 5	6 x 9
	1 x 9	4 x 4	2 x 1	7 x 12	10 x 1	
	8 x 4	8 x 3	7 x 7	9 x 6		
			8 x 5	8 x 4		
			1 x 7	7 x 3		
ASI	7 x 8	9 x 12	7 x 8	1 x 12	11 x 9	1 x 4
	2 x 5	9 x 7	7 x 3	6 x 4	4 x 8	7 x 7
	2 x 9	8 x 9	2 x 5	6 x 6	1 x 3	6 x 12
	4 x 4	1 x 4	4 x 4	4 x 6	9 x 12	11 x 4
	7 x 3	4 x 6	2 x 9	9 x 8	2 x 9	6 x 1
	7 x 5	6 x 6	8 x 9	9 x 12	7 x 5	
	11 x 9		7 x 5	11 x 5	8 x 4	
			9 x 7	1 x 4	10 x 12	
EPP	9 x 8	10 x 3	11 x 9	9 x 4	9 x 8	
	1 x 7	11 x 6	7 x 3	1 x 12	8 x 1	
	2 x 12	6 x 5	9 x 1	10 x 3	2 x 12	
	11 x 9	11 x 12	1 x 7	10 x 5	8 x 12	
	7 x 3		2 x 1	8 x 3	8 x 7	
			8 x 5	2 x 12	11 x 3	
			9 x 8	11 x 6	7 x 4	
			11 x 12	4 x 6	7 x 6	
			6 x 5	10 x 4	4 x 5	
			4 x 8	4 x 4		

Table 9. Cont/. Three way Hybrids with desirable specific combining ability effect (SCA) for selected traits

	ACROSS ENVIRONMENT		LOW N		HIGH N	
GLS	7 x 5	2 x 7			7 x 5	2 x 7
	11 x 12	10 x 9			11 x 12	10 x 9
	6 x 1	7 x 6			6 x 1	7 x 6
	8 x 1	9 x 6			8 x 1	9 x 6
	9 x 8	4 x 9			9 x 8	4 x 9
	1 x 1	2 x 12			1 x 1	2 x 12
SENESCENCE			11 x 1	10 x 9		
			9 x 4	2 x 8		
			4 x 7	9 x 7		
			7 x 7	1 x 7		
			1 x 8	11 x 8		
			6 x 4	4 x 3		
			7 x 1			
KERNEL	7 x 12	4 x 3	7 x 12	2 x 9	10 x 1	4 x 4
WEIGHT	8 x 12	11 x 12	11 x 6	2 x 1	4 x 3	7 x 6
	10 x 1	10 x 3	1 x 4	9 x 3	8 x 12	6 x 8
	11 x 6	8 x 1	9 x 9	1 x 8	7 x 9	10 x 5
	1 x 4	4 x 4	6 x 3	11 x 1	9 x 1	
	9 x 9	9 x 1	10 x 3	8 x 12	8 x 1	
	10 x 5	6 x 3	4 x 12	2 x 4		
	7 x 9	7 x 6	6 x 5			
KERNELS	4 x 6	4 x 3	6 x 4	2 x 8	7 x 5	2 x 3
PER	10 x 9	11 x 1	7 x 3	10 x 9	4 x 6	1 x 4
EAR	9 x 6	11 x 9	7 x 7	4 x 3	11 x 9	10 x 7
	6 x 7	2 x 8	4 x 6	10 x 12	10 x 9	9 x 12
	8 x 9	4 x 5	9 x 6	2 x 9	8 x 9	
	6 x 4	7 x 8	6 x 7	1 x 1	11 x 1	

4.14. CORRELATION

Linear genetic correlations (r_g) of grain yield (GY) and secondary traits for lines and testers are shown on Table 22.

Significant genetic correlations were observed between GY and many of the secondary traits measured in both lines and testers (except for leaf senescence). Anthesis-silking interval, silking, plant height, ears per plant, and kernel weight all measured under low N were either negative or positive, and significantly associated with grain yield except for kernel weight ($r = -0.06^{ns}$) regarding testers, which was non significant. There was no association between leaf senescence and anthesis with GY under low N for both lines and testers.

Grey leaf spot, turcicum and rust all correlated with grain yield except turcicum ($r = -0.26^{ns}$) and rust ($r = 0.23^{ns}$) with testers at optimal conditions.

There were significant correlation involving ears per plant ($r = 0.32^{*}$) and number of kernels per ear ($r = 0.42^{**}$) for lines under low N.

Correlation values for ASI was high in lines and testers under low N while plant height ($r = 0.73^{**}$) and kernel weight ($r = 0.85^{**}$) values were high in lines only. On the other hand, significant correlation values for ears per plant and number of kernels were observed in testers.

4.15. Heritability

Table 23 shows narrow sense heritability estimates for measured traits. Both heritability estimates were generally high for grain yield, anthesis, silking, plant height, and single kernel weight under N stress and optimal conditions. In addition heritabilities for grey leaf spot, turcicum and rust were also high.

Low heritabilities were realized for anthesis silking interval, leaf senescence and number of kernels per ear and ears per plant under nitrogen deficiency.

Values of heritabilities for grain yield, anthesis silking interval, plant height, single kernel weight as well as number of kernels per ear tended to be smaller across environments than in either N environments except for anthesis, silking and the three diseases.

Table 22. Average genetic correlations across, low N and high N between grain yield secondary traits for 9 testers and 9 lines

	Tester			Line		
Trait	**Across**	**Low N**	**High N**	**Across**	**Low N**	**High N**
Anthesis	0.71^{***}	-0.28^{ns}	0.89^{***}	0.55^{**}	0.26^{ns}	0.65^{***}
Silking	0.55^{**}	-0.45^{**}	0.80^{***}	0.57^{**}	0.38^{*}	0.65^{**}
ASI	-0.18^{ns}	-0.55^{**}	-0.66^{***}	0.37^{*}	0.60^{***}	0.28^{ns}
Plant height	0.50^{**}	-0.28^{*}	0.68^{***}	0.77^{***}	0.73^{***}	0.73^{***}
EPP	-0.12^{ns}	0.67^{***}	-0.09^{ns}	0.40^{**}	0.32^{*}	0.56^{**}
SKW	0.54^{**}	-0.06^{ns}	0.44^{**}	0.82^{***}	0.85^{***}	0.57^{**}
Kernels per ear	0.32^{*}	0.53^{**}	0.67^{***}	0.47^{**}	0.42^{**}	0.32^{*}
Senescence	-0.86^{**}	-0.08^{ns}		-0.29^{ns}	-0.19^{ns}	
GLS	0.39^{*}		0.36^{*}	0.69^{***}		0.6^{***}
Et	-0.56^{**}	-0.06^{**}	-0.26^{ns}	0.73^{***}	0.50^{**}	0.74^{***}
Rust	0.35^{***}		0.23^{ns}	-0.68^{***}		-0.75^{***}

EPP= ears per plant; SKW= single kernel; GLS= grey leaf spot; Et =*Exserohilum turcicum*;
*, **, *** Significant at 5%, 1% and 0.1%; ns = non significant at 5%

Table 23. Narrow Sense Heritability estimates for Grain yield and Secondary traits for Across, Low N and High N Environments

TRAIT	ACROSS	LOW N	HIGH N
	Narrow sense	Narrow sense	Narrow sense
Grain Yield	0.44	0. 51	0.51
Anthesis	0.79	0.73	0.84
Silking	0.73	0.51	0.84
Anthesis silking interval	0.35	0.44	0.51
Plant height	0.45	0.68	0.89
Ears per plant	0.45	0.38	0.56
Single kernel weight	0.45	0.81	0.62
Number of kernels per ear	0.31	0.42	0.41
Leaf senescence	0.45	0.29	-
Grey leaf spot	0.73	-	0.73
Turcicum	0.62	0.59	0.62
Rust	0.89	-	0.89

4.16 LINE AND TESTER HYBRID PERFORMANCE

Suitable hybrids with enhanced performance both under low N and high N can be identified based on their performance under the two environments (low N and high N) as well as the combined information from their test environment.

Results show that there were differences among entries (hybrids) for most of the traits evaluated (Appendix C). Under low N (Appendix O), the highest grain yield of 2.27 t/ha was produced by L1 x T1. However, a total of 11 hybrids (Table 24) exhibited superior trait combinations and had disease score of less than 2.0 for turcicum. At high N (Appendix P) the highest grain yield was 10.2t/ha from L9 x T12. Based on mean performance, 8 hybrids with disease scores for GLS, turcicum and rust of less than 2.0 were the better performing ones at well-fertilized conditions (Table 25). With regards to across environment (Appendix Q), 5 hybrids produced better combinations including yield (Table 26). However, 2 entries L10 x T9 and L11 and T9 were found to be among the best performing entries at both nitrogen levels.

Table 24: Best performing hybrids under Low Nitrogen

LINE	TESTER	GY	AD	SD	ASI	EPP	PH	GLS	ET	RUST	SENESCE	SKW	Kernels per ear
10x	9	1.79	75.6	79.1	3.6	0.78	146.4	.	1.765	.	44.86	193.82	276.37
4x	6	2.03	74.1	77.7	3.9	0.74	148.1	.	1.865	.	44.87	220.91	301.03
8x	1	1.84	72.5	77.1	4.2	0.77	165.6	.	1.915	.	45.37	236.93	239.44
1x	8	1.91	70.5	74.9	3.9	0.78	142.4	.	2.165	.	46.93	220.05	229.74
8x	9	1.76	73.8	76.0	2.4	0.79	154.2	.	2.045	.	47.20	199.24	258.27
10x	6	1.83	75.8	79.0	3.3	0.73	143.9	.	1.935	.	47.50	218.02	236.40
11x	9	1.77	76.0	80.1	4.4	0.83	146.9	.	2.045	.	47.63	230.02	179.93
4x	4	1.65	72.7	76.0	3.2	0.74	150.9	.	1.955	.	48.32	219.14	277.84
10x	5	1.67	75.7	78.5	2.8	0.77	150.3	.	1.765	.	49.11	219.50	228.21
10x	12	2.08	75.1	79.1	3.8	0.74	163.7	.	1.905	.	49.96	234.82	295.70
8x	3	1.61	70.2	74.6	4.5	0.86	142.6	.	1.985	.	50.02	213.22	232.20

GY=grain yield; AD= anthesis date; SD= silking date; ASI= anthesis silking interval; EPP= ears per plant; PH= plant height; GLS= grey leaf spot; Et= *Exserohilum turcicum*; SKW= single kernel weight

Table 25: Best performing hybrids under High Nitrogen

LINE	TESTER	GY	AD	SD	ASI	EPP	PH	GLS	ET	RUST	SENESCE	SKW	Kernels per ear
10 x	9	8.32	72.2	72.8	0.50	1.05	227.7	1.10	1.44	1.98	22.79	328.0	611.8
1 x	9	8.63	70.2	71.4	1.25	0.99	219.3	1.31	1.67	2.04	31.695	343.7	505.2
11 x	9	9.12	71.7	71.7	-0.18	0.97	230.3	1.32	1.49	1.87	30.17	355.6	587.1
2 x	7	8.66	73.7	75.5	1.89	1.06	216.7	1.52	1.97	0.97	46.285	328.8	546.9
11 x	12	9.28	73.8	75.8	1.88	1.01	250.7	1.64	1.84	1.43	20.38	395.5	444.2
10 x	4	8.26	73.6	74.9	1.35	1.04	218.9	1.71	1.47	2.04	32.34	309.7	534.0
1 x	5	8.13	71.6	73.0	1.42	1.04	214.0	1.90	1.69	1.50	47.755	328.6	478.9
2 x	12	9.47	73.0	74.9	1.70	1.11	232.3	1.91	2.20	0.79	31.91	336.1	559.4

GY= grain yield; AD= anthesis date; SD= silking date; ASI= anthesis silking date; EPP= ears per plant; PH= plant height;
Et= *Exserohilum turcicum;* SKW= single kernel weight

Table 26: Best performing hybrids across environment

LINE	TESTER	GY	AD	SD	ASI	EPP	PH	GLS	ET	RUST	SENESC	SKW	Kernels per ear
11 x	9	5.45	73.85	75.88	2.11	0.90	188.62	1.32	1.71	1.87	40.65	292.80	383.51
10 x	9	5.05	73.91	75.95	2.06	0.92	187.04	1.10	1.57	1.98	36.03	260.89	444.08
10 x	4	4.97	74.29	76.66	2.52	0.92	183.45	1.71	1.55	2.04	44.34	261.44	393.30
6 x	4	4.94	71.31	73.85	2.46	0.95	171.17	1.81	1.75	2.05	47.30	254.00	436.84
1 x	9	4.93	71.81	74.02	2.31	0.87	179.53	1.31	1.78	2.04	41.58	274.13	355.66

GY= grain yield; AD=anthesis date; SD= silking date; ASI= anthesis silking interval; EPP= ears per plant; PH= plant height; GLS= grey leaf plant; Et= *Exserohilum turcicum*; SKW= single kernel weight

CHAPTER FIVE

5.0. DISCUSSION

Performance of lines and testers differed significantly. Differences were due to variations in nitrogen levels and differences in testing sites (locations). Differences observed in testcrosses also represented real genetic differences among genotypes. The results imply that the genotypes tended to produce dissimilar response when grown in different environments. Therefore, rankings were not the same for lines and testers when grown under low N and high N environments. This would be expected given the differences in the degree of selection and improvements done to the genotypes.

Selection of suitable lines and testers in this case becomes critical. It is therefore crucial to consider traits that impact greater performance on maize under stress. This is important since the final product has to be grown in low N soils, important in limiting yields, which are frequently found in farmer's fields where fertilization is not commonly used and organic matter is rapidly mineralized (Banziger and Lafitte, 1997). Development of maize germplasm with high nitrogen use efficiency and resistance to disease is hence crucial if productivity of maize-based farming system is to be sustained or increased.

In this study addition of fertilizer in particular nitrogen enhanced growth and development in the genotypes as expected. Similar reports have been made by Kumwenda and Benson, 1998 and Ikerra et al 1998 in their study involving maize response to increased nitrogen fertilizer levels. However, the converse was true under nitrogen stress (low N). Grain yield was reduced by as much 80% relative to high fertility levels. In addition anthesis date on average was delayed by 6 days and nitrogen stress also retarded plant height on the whole in both lines and testers. In general nitrogen deficiency had a negative impact on the kernel weight, number of kernels per ear, ears per plant, and leaf senescence.

Many researchers have made similar observations of yield reduction in maize grown under nitrogen stress. Yield reductions of 37-78 % (Banziger and Edmeads, 1998), 51-65% (Betran et al., 2003), and 68% (Lafitte and Edmeads, 1995) for maize grown under low N have been reported. Such level of intensity of stress observed for low soil nitrogen fall within the range of stress levels applied during selection of populations and inbreds for tolerance to low N (Bolanos and Edmeads, 1993a; Lafitte and Edmeads, 1994). Therefore, different lines and testers differed in there *per se* performance in crosses when grown under low N and when under high fertility. For example L1, L7, L8 and L11 did well in crosses under low N while for testers it was T1, T6, T7 and T9. At high fertility lines L1, L4, L11, and most testers (except T1, T3 and T5) performed better in crosses. However, only L1, L11 and T6, T7 and T9 had better performance at both N levels.

Differences in performance of genotypes under stress relative to non-stress environments simply indicate that other traits were responsible for good performance. These traits known as adaptive secondary traits are responsible for the differential expression between (only expressed under stress) stress and non-stress environments and are genetically variable and they correlate with grain yield (Bolanos et al., 1993; Bolanos and Edmeades, 1996; Banziger and Lafitte, 1997, Betram et al., 2003). Some adaptive traits include anthesis-silking interval, ears per plant, and leaf senescence.

Anthesis as well as silking (days) in both parents was influenced by N deficiency. However, it was silking that was mostly delayed compared to anthesis. Girardin et al (1987) and Banziger et al (2000) have reported similar results when flowering in maize coincides with nitrogen deficiency. In this study silking was extended by 6 days on the average while there was little effect on anthesis.

The delay in silking thus increased the anthesis-silking interval. ASI averaged 4.7 days under stress. On average most lines showed slightly lower ASI days than testers relative to the mean. Extended ASI resulted in late and fewer extrusion of silk produced. In some crosses plants failed to produce silk especially at Kabwe site were N stress was high. This resulted in barrenness, reduced ears per plant and as well as number of kernels per ear. All this happened due to reduced (or no) pollination or lack of synchronization between male and female flowers, which was impaired due to increased ASI. This could have contributed to T12 and L4 producing fewer ears per plant. In addition, the fewer grains per ear in T8, T12, L9, and in L10 could have resulted from increased ASI. Reduced ears per plant and number of kernels per ear all affect grain yield in maize, as they are the most important yield components.

Nitrogen is an important macronutrient and plays a major role in photosynthesis. N stress accelerated leaf senescence and variations in the genotypes were observed. Lower leaf senescence scores were attained in testers T4 and T5 while for lines it was in L4, L7 and L10. Others had either moderate or high leaf senescence. High senescence caused reduction in photosynthesis area diminishing assimilates allocated to new developing parts like kernels. Diminishing assimilates contributed to reduction in number of kernels per ear and eventually the number of ears per plant such as the ones noted in T12 and L6. In addition lower kernel weight may have been caused by reduced period of grain filling, as may have been the case in most lines and testers with the exception of L1, L7, L11, T8 and T12. Reduction in ears per plant, fewer number of kernels per plant and lowering of kernel weight was mainly due to kernel abortions at developmental stage when assimilates to developing grains reduced substantially (Bolanos et al., 1993b; Banziger et al., 2000). Parents with delayed leaf senescence managed to continue photosynthesis contributing to longer duration of grain filling and high grain yield under low N status.

Nitrogen also had an effect on plant height one of the important agronomic traits. Increased plant height may indicate plants having adequate number and well developed leaves important for photosynthesis. Generally most lines showed lower heights except for L1 and L11. Lower heights are expected from inbred lines that have been selfed for many generations. In this study increased height resulted in increased yield as was the case in L1 and L11. This concurs with findings of Beck et al., 1989 and Lafitte and Edmeads, 1988 that height reductions were accompanied by yield reductions.

The diseases observed in the trials included GLS, turcicum and rust. GLS and rust occurred at optimal condition while turcicum infections happened both at high N and N stress. The diseases occurred in different sites. The occurrence of the diseases especially GLS was necessary to determine the potential of genotypes to resist the onset and progress of GLS, to determine the magnitude of genetic factors that contribute to resistance. Since sites used in this study may have all the elements favored for pathogen such as continuous production of maize, the disease occurrence and the replicated evaluation of experiments made it possible to assess performance of the genotypes to the disease. The disease scores observed might have not been higher since the establishment of GLS was late. However, disease infection and development varied between genotypes. T5 and L10 showed lower disease scores compared to L1, L7, L8 L11, and T1, T4 and T6. In the former, parents were to resistance to GLS while the later parents were moderately resistant. Late establishment of GLS in maize has been mentioned by many researchers and in many instances leads to minimal yield losses, as disease infection does not end in high leaf damage to affect photosynthesis. In addition parents that showed high disease score to GLS such as L1 and L11 also showed similar trends to *Exserohilum turcicum.* The converse was true for those that did not. In case of leaf rust, the observations were that susceptible parents in this case to GLS and Exserohilum *turcicum* were the ones that exhibited resistance to the disease. The pattern of disease occurrence may indicate that GLS and rust were highly influenced by high fertility levels (especially increased N) and lush growths of plants where as for *Exserohilum turcicum* both high fertility and N stress were important for the disease to develop. However, N stress on the whole had higher influence on turcicum disease infection, as the disease pressure on stressed plants happened to be higher. Regarding studies on reducing incidence and severity of GLS in maize, Patricia et al (1999) found GLS to be associated with maize with increased application of nitrogen (>120 kg/ha) and potassium (>150 t/ha), which resulted in earlier appearance of GLS and increased leaf blighting. Therefore, low N stress may not be ideal conditions for selecting resistant maize genotype to GLS.

Significant genetic correlations (r_g) were observed between grain yield and many secondary traits for lines and testers measured under high N and low N except for anthesis and leaf senescence under nitrogen stress. However, correlations were lower for ears per plant and number of kernels per ear. This indicates that higher grain yields were associated with traits that had higher correlations whilst traits such as ears per plant and number of kernels per ear had minimal contribution to yield due to their low correlations. Though there was no correlation between grain yield and leaf senescence studies by Banziger and Lafitte, 1997; Lafitte and Edmeads, 1994a and 1994b) and Edmeads et al., 1997a have indicated high relationship of leaf senescence to yield.

Realized narrow sense heritability estimate (0.51) for grain yield were generally larger for grain yield under low N and high N but was low for across environments. While it has been observed that heritabilities of grain yield often declines under stress (Blum, 1988; Banziger and Lafitte, 1997), the result in this study only agrees with that of Lafitte and Edmeads, 1994 who obtained higher heritability (0.58) for grain yield under nitrogen stress. The observed low heritabilities for ears per plant, number of kernels per ear, anthesis silking interval and leaf senescence indicate that these traits were not highly heritable in the progenies. This is in disagreement with other studies where these traits have been found to have high heritability than grain yield (Banziger and Lafitte, 1997; Banziger et al., 1997 and Edmeads et al. (1997a)

Combining ability mean squares for GCA for lines and testers were highly significant for all traits measured except for SCA for line x tester which was not for the same variables. In addition mean squares for GCA for lines and testers were much higher than that of SCA (line x tester). This indicated the preponderance of additive gene action rather than non-additive genes for influencing the traits in the germplasm studied. Several studies involving inheritances have revealed dosage effect or predominance of additive gene actions (Stangland et al., 1983; Zambezi et al., 1986, and Nigussie and Zelleke, 2001). In studies involving inheritance of GLS, Gevers and Lake, 1994 and Ulrich et al., 1990 found mainly additive gene actions being involved. On the contrary studies by Elwinger et al., (1990) and Saghai maroof et al., (1996) indicated that inheritance was non-additive and that dominance as well as epistasis was important in their testing materials. Therefore, the result has breeding implications in that the parents with good general combining ability (GCA) and *per se* performance can be crossed to develop high yielding populations and hybrids that can be recommended and be used directly by farmers.

GCA effects for measured traits for lines and testers are shown in Table 19 and 20. Positive and significant effects for GY observed in L1, L11, and T9 at both N levels and across environments significantly increased grain yield while L2 significantly reduced yield. L9 and T3 significantly reduced yield under low N while L6, T1 and T5 did so under high N. In additional EPP and SKW were significantly increased by L1 and L11 as opposed to L6 L7 and T3. Parents L4, T4and T9, increased number of kernels per ear. Under low N L7 L10, T4, T5, and T7 significantly contributed to duration of photosynthesis, as they remained green longer compared to L12, T3 and T12. In terms of diseases L2, L6, L10 and testers TT3, T5, T7 and T8 significantly reduced GLS as opposed to L1, L11, T1, T4 and T8. For turcicum L8 (low N and across environment), L11 (low N) as well as T3 and T8 increased turcicum disease. Since GLS and turcicum are under additive gene action, it important that lines that consistently performed but lacked superior GCA effects were improved further for GLS and turcicum resistance by backcrossing to resistant genotypes.

Negative GCA for male and female flowering shown by L1, L2, L9 and T1, T5, T6 and T7 may indicate early maturity in the parents. T1, T5, L2 and L9 with reduced plant height also had grain yields for the reason that earliness has inverse relation with grain yield (Bolanos and Edmeads, 1993b). In general, L11 and T12 contributed to lateness in tasselling and silking, and to increased height and grain yield. It is common for maturity and plant height to be associated with higher grain yield (Hallauer and Miranda, 1988). However, L1, T6 and T7 may have reduced days to flowering but this did not affect grain yield.

Despite SCA not being significant, crosses with desirable SCA effects generally involved parent combinations with at least one high or intermediate general combiner as a parent. Very few low x low or low x intermediate general combiners had good SCA effects (Table 21 and Appendix L, M and N). This reveals that the productive lines under low N, high N and across environment involved lines and testers with high x high and high x low general combining ability (GCA) status respectively for important agronomic and physiological traits related to nitrogen use efficiency as well as productivity traits and resistance to GLS. The least productive lines and testers all had low and negative GCA status cross combinations with respect to nitrogen tolerance, resistance to diseases and productivity traits.

The highest yielding hybrids across locations were L 9 x T12 (6.04 t/ha), followed by L10 X T12 (6.00 t/ha). Under low N the highest yielder was L1 x T1 (2.27 t/ha) while at high N, L9 x T 12 (10.20 t/ha) was the highest. However, some hybrids (L11 x T9 and L10 x T9) performed well in terms of low disease pressure (>2.0), low leaf senescence and ASI, more EPP as well as more grain yield across all environments indicating that it is possible to combine stress tolerance and plant performance in terms of yield potential in maize hybrids. Similar results have been reported with temperate maize hybrids where improvements for tolerance to abiotic and biotic stresses have been associated with the ability to maximize yield under non-stress growing conditions (Duvick, 1997). High performance of some crosses was as the result of reduction in barrenness and the increase in the grain number and kernel weight, which were also accompanied by a reduction in the anthesis-silking interval (ASI) and a delay in leaf senescence (Bolanos and Edmeads, 1993b, Edmeads et al., 1999). In addition these hybrids showed highly and moderate resistant GLS, turcicum and rust.

CHAPTER SIX

6.0. CONCLUSION

The results of the study have demonstrated the importance of North Carolina mating design II analysis in identifying lines and testers with good combining abilities that help develop hybrids suitable for desirable traits. Additive gene action rather non-additive gene action involved all characters studied. In addition grey leaf spot incidence associated with increased high N and not with low nitrogen. This may entail that low nitrogen stress may not provide suitable environment for selecting and screening maize resistant to GLS.

Lines (L12M1(220GY)–150-3-3-1-1and N3-1XN3offtype-4-1-3-3-2-1-1) and testers (CML444/DRB-F2-60-1-1-1-BB and CML444/CML 448) consistently performed well. These parents had high and positive GCA effects for grain yield, plant height, and ears per plant. They were also good combiners for kernel weight, the number of kernels per ear and had reduced leaf senescence and a short or negative anthesis-silking interval (except line: L12M1(220GY)–150-3-3-1-1).

High and negative GCA for GLS were exhibited by lines (Line 14-1 and 8535-23-1-2-2) and testers (CML 444/ DRB-F2-60-1-1-1-BB and CML 440/ CML 443) while the highly susceptible parents were lines (L12M1(220GY)–150-3-3-1-1 and N3-1XN3offtype-4-1-3-3-2-1-1) and tester (CML 312/CML 442).

Hybrids involving lines L12M1(220GY)-150-3-3-1-1x CML444/CML448 and Line 14-1 x CML444/CML 448 were among the top performing hybrids across low N and high N conditions.

6.1. RECOMENDATIONS

Lines (L12M1(220GY)–150-3-3-1-1and N3-1XN3offtype-4-1-3-3-2-1-1) which were superior in their combining ability but lacked tolerance to grey leaf spot should improved further through backcrossing them to genotypes with high resistance to GLS.

All the best three way hybrids in this study should be evaluated further and released with their special attributes of tolerance to low N and resistance to GLS.

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Appendix A: Soil Analysis Results for Sites used in Evaluations

Site	Depth cm	Texture	p^H	Organic C%	N %	P ppm	K me%	Ca me%	Mg me%	Cu ppm	Zn ppm	Fe ppm	Mn ppm
Kabwe Low N	0 – 20	SL	5.1	0.53	0.04	41	0.21	0.8	0.4	2.0	5.0	42	98
	20 - 40	SL	4.9	0.27	0.02	28	0.18	1.0	0.5	3.0	7.0	51	123
Mt. Makulu	0 – 20	SCL	7.1	1.52	0.11	7	0.46	17.5	1.2	5.0	5.0	77	300
	20 - 40	SCL	7.2	1.00	0.07	3	0.21	13.4	1.2	5.0	7.0	66	225
Golden Valley	0 – 20	CL	5.9	1.10	0.08	31	0.74	4.9	3.4	7.0	4.0	51	123
Low N	20 - 40	CL	5.7	1.01	0.08	13	0.41	2.6	1.8	7.0	3.0	55	120
Golden Valley	0 – 20	CL	6.8	1.45	0.10	13	0.20	6.6	4.6	19.0	4.0	75	462
	20 - 40	CL	6.8	1.46	0.10	11	0.14	10.0	5.5	19.0	3.0	86	457
CIMMYT	0 – 30	SC	6.1			26	0.14	9.05	2.85				
Harare	30 - 60	SC	6.2			5	0.08	7.10	2.36				

Texture key

C = Clay
S = Sand
L = Loam
LS = Loamy Sand
SCL = Sand Clay Loam
SC = Sand Clay

p^H – $CaCl_2$

Below 4.0 .... Extremely Acidic
4.0 ....Strongly Acidic
5.0 .... Medium Acidic
7.0 .... Neutral
Above 7.0 .... Alkaline

Appendix B: Annual rainfall (mm) and mean temperature (c ^{o}) for the 2003/2004 season in Zambia at Golden Valley, Mount Makulu, Kabwe and in Zimbabwe at CIMMYT- Harare.

	Golden Valley		Mount Makulu		Kabwe		Harare	
	Rainfall MM	Temperature ^{o}C	Rainfall MM	Temperature ^{o}C	Rainfall MM	Temperature ^{o}C	Rainfall	Temperature
Month / year								
October 2003	6.8	22.8	38.1	24.1	-	-		-
November 2003	65.8	25.3	31.0	26.2	90.3	23.8		-
December 2003	108.0	23.8	291.3	23.4	77.8	21.4		-
January 2004	154.0	23.3	91.3	23.2	217.2	20.3		-
February 2004	138.5	23.6	246.0	22.6	110.5	20.5		-
March 2004	89.6	23.9	182.7	22.8	120.2	21.7		-
April 2004	2.1	22.2	33.8	23.8	7.0	19.1		-
May 2004	-	-	-	-	-	-		-
Mean		23.6		23.7		21.1		
Totals	564.8		1014.2		623.0			-

APPENDIX C. ANOVA showing probability levels for all traits across all 114 entries and for 6 sites grouped in 3 low N and 3 high N sites

	Grain	General agronomic traits												NUE Traits						Diseases				
Dependent	Yield	AD	SD	MOI	PH	EH	EPO	SH	SLODG	RLODG	HCOV	TEXT	PN	EN	ASI	EPP	KW100	SKW	KNEAR	SENESC	GLS	HT	RUST	EROT
NLEVEL	0.005	0.538	0.148	0.567	0.105	0.105	0.144	0.726	0.492	0.524	.	0.447	0.011	0.001	0.097	0.001	0.005	0.005	0.013	0.338	.	0.389	.	0.858
SITE(NLEVEL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000
ENTRY	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.249	0.224	0.880	0.020	0.000	0.001	0.009	0.078	0.004	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.023
NLEVEL*ENTRY	0.137	0.755	0.966	0.443	0.121	0.005	0.495	0.630	0.363	0.989	0.703	0.060	0.385	0.324	0.235	0.071	0.037	0.036	0.257	0.000	.	0.366	.	0.315
ENTRY*SITE(NLEVEL)	0.991	0.999	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.	0.886	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.998	1.000	.	0.998

ANOVA showing probaility levels for all traits across all 9 lines and 9 testers for 6 sites grouped in 3 low N and 3 high N sites

	Grain	General agronomic traits												NUE Traits						Diseases				
Dependent	Yield	AD	SD	MOI	PH	EH	EPO	SH	SLODG	RLODG	HCOV	TEXT	PN	EN	ASI	EPP	KW100	SKW	KNEAR	SENESC	GLS	HT	RUST	EROT
NLEVEL	0.005	0.545	0.153	0.548	0.110	0.104	0.140	0.701	0.426	0.513	0.095	0.421	0.009	0.001	0.088	0.001	0.005	0.005	0.013	0.350	.	0.394	.	0.815
SITE(NLEVEL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000
LINE	0.023	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.285	0.474	0.039	0.000	0.028	0.002	0.000	0.001	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.182
TESTER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.366	0.118	0.284	0.493	0.000	0.002	0.000	0.210	0.005	0.000	0.000	0.071	0.000	0.000	0.000	0.013	0.052
LINE*TESTER	0.502	0.198	0.595	0.322	0.240	0.129	0.339	0.739	0.478	0.617	0.103	0.772	0.250	0.597	0.422	0.868	0.367	0.360	0.204	0.373	0.802	0.889	0.672	0.147
NLEVEL*LINE	0.053	0.149	0.019	0.061	0.000	0.000	0.497	0.002	0.086	0.605	0.115	0.004	0.074	0.080	0.001	0.238	0.105	0.104	0.014	0.000	.	0.279	.	0.364
NLEVEL*TESTER	0.028	0.048	0.227	0.068	0.161	0.011	0.002	0.600	0.385	0.392	0.573	0.011	0.017	0.448	0.987	0.219	0.001	0.001	0.647	0.000	.	0.137	.	0.766
NLEVEL*LINE*TESTER	0.550	0.962	0.999	0.855	0.723	0.927	0.947	0.984	0.272	0.982	0.970	0.821	0.708	0.302	0.738	0.307	0.335	0.336	0.450	0.186	.	0.988	.	0.256
SITE*LINE(NLEVEL)	0.667	0.300	0.391	0.770	0.992	0.884	0.949	0.965	0.728	0.998	.	0.005	0.983	0.827	0.602	0.714	0.706	0.708	0.971	1.000	0.556	0.231	.	0.980
SITE*LINE*TEST(NLEV)	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.	0.976	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	0.996	1.000	.	0.994
SITE*TESTER(NLEVEL)	0.016	0.619	0.926	0.215	0.993	0.725	0.739	0.607	0.887	0.491	.	0.509	1.000	0.997	0.999	0.994	0.434	0.439	0.847	0.974	0.397	0.460	.	0.969
ALL SITE INTERACTIONS	0.994	0.998	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	.	0.697	1.000	1.000	1.000	1.000	0.999	0.999	1.000	1.000	0.989	1.000	.	0.999

ANOVA showing probability levels for all traits across all 10 lines and 7 testers for 6 sites grouped in 3 low N and 3 high N sites

	Grain	General agronomic traits												NUE Traits						Diseases				
Dependent	Yield	AD	SD	MOI	PH	EH	EPO	SH	SLODG	RLODG	HCOV	TEXT	PN	EN	ASI	EPP	KW100	SKW	KNEAR	SENESC	GLS	HT	RUST	EROT
NLEVEL	0.004	0.518	0.145	0.539	0.108	0.100	0.133	0.734	0.330	0.570	0.176	0.481	0.008	0.001	0.092	0.002	0.005	0.005	0.014	0.397	.	0.325	.	0.809
SITE(NLEVEL)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	.	0.000
LINE	0.044	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.336	0.288	0.022	0.000	0.069	0.004	0.030	0.000	0.000	0.000	0.020	0.000	0.000	0.000	0.000	0.117
TESTER	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.556	0.113	0.379	0.323	0.000	0.094	0.015	0.286	0.018	0.000	0.000	0.043	0.000	0.000	0.000	0.200	0.154
LINE*TESTER	0.604	0.181	0.387	0.266	0.133	0.000	0.079	0.745	0.288	0.574	0.020	0.302	0.140	0.539	0.471	0.441	0.769	0.762	0.452	0.342	0.662	0.624	0.717	0.334
NLEVEL*LINE	0.062	0.081	0.021	0.437	0.005	0.000	0.311	0.005	0.118	0.868	0.081	0.002	0.069	0.121	0.003	0.101	0.095	0.094	0.005	0.000	.	0.424	.	0.247
NLEVEL*TESTER	0.044	0.028	0.236	0.012	0.315	0.026	0.019	0.147	0.146	0.422	0.487	0.007	0.114	0.597	0.960	0.478	0.001	0.001	0.555	0.000	.	0.134	.	0.904
NLEVEL*LINE*TESTER	0.665	0.931	0.998	0.628	0.901	0.717	0.875	0.987	0.241	0.997	0.888	0.495	0.694	0.266	0.873	0.220	0.477	0.478	0.529	0.059	.	0.957	.	0.373
SITE*LINE(NLEVEL)	0.272	0.042	0.070	0.356	0.887	0.987	0.927	0.963	0.712	0.975	.	0.184	0.945	0.592	0.924	0.856	0.410	0.411	0.937	1.000	0.850	0.294	.	0.913
SITE*LINE*TEST(NLEV)	0.991	0.997	1.000	1.000	0.917	1.000	1.000	1.000	1.000	1.000	.	0.963	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	0.996	1.000	.	0.987
SITE*TESTER(NLEVEL)	0.083	0.704	0.892	0.532	0.948	0.896	0.912	0.609	0.821	0.833	.	0.522	0.999	0.998	0.950	0.995	0.402	0.405	0.852	0.993	0.518	0.723	.	0.977
ALL SITE INTERACTIONS	0.905	0.975	1.000	1.000	0.927	1.000	1.000	1.000	1.000	1.000	.	0.907	1.000	1.000	1.000	1.000	0.999	0.999	1.000	1.000	0.996	1.000	.	0.998
# Low N Sites	3	3	3	3	3	3	3	3	2	2	1	2	3	3	3	3	2	2	2	5	2	3		3
# High N Sites	3	3	3	3	3	3	3	1	3	3	1	1	3	3	3	3	3	3	3	5		2	1	2

APPENDIX D. ANOVA TABLE FOR GRAIN YIELD AND SECONDARY TRAITS UNDER LOW N

1	Variable	Factor	DF	SS	MS	F-Value	Pr < F
1	GY	Dependent	Variable:	GY			
2	GY	SITE(NLEVEL)	2	129.22177	64.610883	49.916433	7.083E-19
3	GY	LINE	8	4.489522	0.5611903	2.6664432	0.0136182
4	GY	TESTER	8	8.2630775	1.0328847	4.907655	9.405E-05
5	GY	LINE*TESTER	64	13.469695	0.210464	1.0934109	0.3309033
6	GY	SITE*LINE(NLEVEL)	16	2.8792135	0.1799508	0.9348875	0.5316259
7	GY	SITE*TESTER(NLEVEL)	16	8.664042	0.5415026	2.8132358	0.0006353
8	GY	SITE*LINE*TEST(NLEV)	128	24.637943	0.1924839	0.1487073	1
		POOLED ERROR	242	313.2402	1.294381		
25	AD	Dependent	Variable:	AD			
26	AD	SITE(NLEVEL)	2	1547.8951	773.94754	45.224307	2.056E-17
27	AD	LINE	8	239.9214	29.990175	142.49551	9.228E-38
28	AD	TESTER	8	179.66955	22.458694	106.71038	5.203E-34
29	AD	LINE*TESTER	64	182.69802	2.854656	14.830622	1.309E-36
30	AD	SITE*LINE(NLEVEL)	16	89.739079	5.608692	29.138499	5.349E-35
31	AD	SITE*TESTER(NLEVEL)	16	31.625931	1.976621	10.26902	2.871E-16
32	AD	SITE*LINE*TEST(NLEV)	128	382.83844	2.990925	0.1747696	1
		POOLED ERROR	242	4141.4743	17.11353		
33	SD	Dependent	Variable:	SD			
34	SD	SITE(NLEVEL)	2	315.38601	157.69301	4.2320003	0.0156126
35	SD	LINE	8	433.04355	54.130443	257.19574	1.324E-45
36	SD	TESTER	8	219.73262	27.466578	130.50487	1.297E-36
37	SD	LINE*TESTER	64	293.11705	4.5799538	23.793958	7.171E-48
38	SD	SITE*LINE(NLEVEL)	16	192.57597	12.035998	62.529894	1.844E-52
39	SD	SITE*TESTER(NLEVEL)	16	80.650426	5.0406516	26.187393	9.082E-33
40	SD	SITE*LINE*TEST(NLEV)	128	833.53373	6.5119823	0.1747618	1
		POOLED ERROR	242	9017.4161	37.26205		
41	ASI	Dependent	Variable:	ASI			
42	ASI	SITE(NLEVEL)	2	1067.1557	533.57787	32.570706	2.977E-13
43	ASI	LINE	8	109.52919	13.691149	65.052213	8.556E-28
44	ASI	TESTER	8	16.816163	2.10202	9.9875513	6.624E-09
45	ASI	LINE*TESTER	64	228.54323	3.570988	18.552139	7.643E-42
46	ASI	SITE*LINE(NLEVEL)	16	82.071901	5.129494	26.648951	3.959E-33
47	ASI	SITE*TESTER(NLEVEL)	16	32.41902	2.026189	10.526538	1.261E-16
48	ASI	SITE*LINE*TEST(NLEV)	128	483.47354	3.777137	0.2305643	1
		ERROR	242	3964.4779	16.38214		
		POOLED ERROR					
65	EPP	Dependent	Variable:	EPP			
66	EPP	SITE(NLEVEL)	2	0.4004617	0.2002309	1.9911542	0.1387684
67	EPP	LINE	8	0.2730815	0.0341352	0.1621902	0.9950065
68	EPP	TESTER	8	0.2790593	0.0348824	0.1657405	0.994621
69	EPP	LINE*TESTER	64	1.0536	0.0164625	0.0855266	1
70	EPP	SITE*LINE(NLEVEL)	16	0.4904642	0.030654	0.1592549	0.999925
71	EPP	SITE*TESTER(NLEVEL)	16	0.2375753	0.0148485	0.0771413	0.9999996
72	EPP	SITE*LINE*TEST(NLEV)	128	2.2206988	0.0173492	0.1725256	1
		POOLED ERROR	242	24.335568	0.1005602		

APPENDIX D CONT/. ANOVA TABLE FOR GRAIN YIELD AND SECONDARY TRAITS UNDER LOW N

73 PH	Dependent	Variable:	PH				
74 PH	SITE(NLEVEL)	2	426729.49	213364.75	183.85176	2.769E-49	
75 PH	LINE	8	5907.2667	738.4083	3508.4779	1.724E-81	
76 PH	TESTER	8	10423.882	1302.9852	6191.0122	2.285E-89	
77 PH	LINE*TESTER	64	6604.401	103.1938	536.11653	2.73E-131	
78 PH	SITE*LINE(NLEVEL)	16	2670.5006	166.9063	867.11824	4E-122	
79 PH	SITE*TESTER(NLEVEL)	16	2775.705	173.4816	901.2785	3.46E-123	
80 PH	SITE*LINE*TEST(NLEV)	128	17283.051	135.0238	0.1163471	1	
	POOLED ERROR	242	280847.29	1160.526			
113 SENESC	Dependent	Variable:	SENESC				
114 SENESC	SITE(NLEVEL)	2	25578.88	12789.44	37.644023	5.831E-15	
115 SENESC	LINE	8	374.08331	46.76041	222.17771	1.214E-43	
116 SENESC	TESTER	8	469.39582	58.67448	278.7863	1.089E-46	
117 SENESC	LINE*TESTER	64	1929.013	30.14083	156.58884	1.888E-97	
118 SENESC	SITE*LINE(NLEVEL)	16	275.69475	17.23092	89.51876	2.312E-61	
119 SENESC	SITE*TESTER(NLEVEL)	16	944.65409	59.04088	306.73152	9.47E-94	
120 SENESC	SITE*LINE*TEST(NLEV)	128	4824.2106	37.68915	0.110933	1	
	POOLED ERROR	242	82218.75	339.7469			
121 SKW	Dependent	Variable:	SKW				
122 SKW	SITE(NLEVEL)	2	123846.02	61923.011	32.803939	2.477E-13	
123 SKW	LINE	8	55708.893	6963.6116	33086.949	1.21E-112	
124 SKW	TESTER	8	53263.869	6657.9836	31634.786	5.08E-112	
125 SKW	LINE*TESTER	64	28642.588	447.5404	2325.0797	5.95E-172	
126 SKW	SITE*LINE(NLEVEL)	16	12018.397	751.1498	3902.4033	1.03E-163	
127 SKW	SITE*TESTER(NLEVEL)	16	17265.266	1079.0791	5606.0746	9.19E-174	
128 SKW	SITE*LINE*TEST(NLEV)	128	46044.126	359.7197	0.1905628	1	
	POOLED ERROR	242	456816.14	1887.67			
129 KNEAR	Dependent	Variable:	KERNELS PER EAR				
130 KNEAR	SITE(NLEVEL)	2	1207846.2	603923.12	27.455731	1.794E-11	
131 KNEAR	LINE	8	118845.74	14855.717	70585.549	3.58E-123	
132 KNEAR	TESTER	8	24740.463	3092.558	14694	2.28E-101	
133 KNEAR	LINE*TESTER	64	232108.38	3626.693	18841.539	4.46E-230	
134 KNEAR	SITE*LINE(NLEVEL)	16	49474.023	3092.126	16064.336	5.38E-203	
135 KNEAR	SITE*TESTER(NLEVEL)	16	116776.08	7298.505	37917.483	7.4E-227	
136 KNEAR	SITE*LINE*TEST(NLEV)	128	409786	3201.453	0.1455454	1	
	POOLED ERROR	242	5323092.5	21996.25			
157 HT	Dependent	Variable:	HT				
158 HT	SITE(NLEVEL)	1	0.1586722	0.1586722	0.3125665	0.5768863	
159 HT	LINE	8	6.6645111	0.8330639	3.9582251	0.0007423	
160 HT	TESTER	8	1.6616222	0.2077028	0.9868803	0.4546489	
161 HT	LINE*TESTER	64	6.8620667	0.1072198	0.5570325	0.9949372	
162 HT	SITE*LINE(NLEVEL)	8	1.3679333	0.1709917	0.8883427	0.5283688	
163 HT	SITE*TESTER(NLEVEL)	8	0.5566444	0.0695806	0.3614877	0.9389037	
164 HT	SITE*LINE*TEST(NLEV)	64	6.8128	0.10645	0.2096946	1	
	POOLED ERROR	161	81.730523	0.507643			

APPENDIX E. ANOVA TABLE FOR GRAIN YIELD AND SECONDARYTRAITS UNDER HIGH N

1 Variable	Factor	DF	SS	MS	F-Value	Pr < F
2 GY	Dependent	Variable:	GY			
3 GY	SITE(NLEVEL)	2	492.91087	246.45543	43.140261	9.462E-17
4 GY	LINE	8	26.048058	3.2560073	2.079261	0.0508349
5 GY	TESTER	8	58.295507	7.2869383	4.6533822	0.0001622
6 GY	LINE*TESTER	64	100.22045	1.5659445	1.167553	0.2285916
7 GY	SITE*LINE(NLEVEL)	16	29.823397	1.8639623	1.3897522	0.1567039
8 GY	SITE*TESTER(NLEVEL)	16	52.585579	3.2865987	2.450456	0.0028841
9 GY	SITE*LINE*TEST(NLEV)	128	171.67605	1.3412192	0.2347708	1
	POOLED ERROR	242	1382.5187	5.712887		
26 AD	Dependent	Variable:	AD			
27 AD	SITE(NLEVEL)	2	4091.2001	2045.6	732.75951	2.12E-103
28 AD	LINE	8	200.23743	25.029679	14.035856	1.478E-11
29 AD	TESTER	8	240.67732	30.084665	16.870533	3.682E-13
30 AD	LINE*TESTER	64	114.1291	1.783267	1.1353261	0.2700459
31 AD	SITE*LINE(NLEVEL)	16	29.154824	1.822176	1.1600978	0.3089028
32 AD	SITE*TESTER(NLEVEL)	16	64.514002	4.032125	2.5670732	0.0017801
33 AD	SITE*LINE*TEST(NLEV)	128	201.05078	1.570709	0.5626476	0.9998234
	POOLED ERROR	242	675.57664	2.791639		
34 SD	Dependent	Variable:	SD			
35 SD	SITE(NLEVEL)	2	4600.8495	2300.4248	656.14016	1.848E-98
36 SD	LINE	8	172.91915	21.614894	10.856595	1.622E-09
37 SD	TESTER	8	294.61533	36.826916	18.497195	5.264E-14
38 SD	LINE*TESTER	64	127.42054	1.990946	1.1565383	0.2422284
39 SD	SITE*LINE(NLEVEL)	16	36.200903	2.262556	1.3143163	0.1981375
40 SD	SITE*TESTER(NLEVEL)	16	62.54137	3.908836	2.2706385	0.0060103
41 SD	SITE*LINE*TEST(NLEV)	128	220.3482	1.72147	0.4910074	0.9999941
	POOLED ERROR	242	848.45103	3.505996		
42 ASI	Dependent	Variable:	ASI			
43 ASI	SITE(NLEVEL)	2	35.324402	17.662201	8.492235	0.0002726
44 ASI	LINE	8	10.497067	1.3121333	3.4746684	0.0021871
45 ASI	TESTER	8	9.5174148	1.1896769	3.1503906	0.0045477
46 ASI	LINE*TESTER	64	24.168215	0.3776284	0.9529305	0.5782342
47 ASI	SITE*LINE(NLEVEL)	16	8.1561605	0.50976	1.2863597	0.2155458
48 ASI	SITE*TESTER(NLEVEL)	16	6.5056568	0.4066036	1.0260483	0.4340763
49 ASI	SITE*LINE*TEST(NLEV)	128	50.72398	0.3962811	0.1905375	1
	POOLED ERROR	242	503.31305	2.079806		
66 EPP	Dependent	Variable:	EPP			
67 EPP	SITE(NLEVEL)	2	0.0815835	0.0407918	1.5658007	0.2110298
68 EPP	LINE	8	0.1845342	0.0230668	4.0749403	0.0005734
69 EPP	TESTER	8	0.1112527	0.0139066	2.4567151	0.0218738
70 EPP	LINE*TESTER	64	0.3622807	0.0056606	1.12624	0.2825832
71 EPP	SITE*LINE(NLEVEL)	16	0.0797276	0.004983	0.9914109	0.4702041
72 EPP	SITE*TESTER(NLEVEL)	16	0.0814091	0.0050881	1.0123216	0.4482353
73 EPP	SITE*LINE*TEST(NLEV)	128	0.6433465	0.0050261	0.1929294	1
	POOLED ERROR	242	6.3045114	0.0260517		

APPENDIX E CONT/. ANOVA TABLE FOR GRAIN YIELD AND SECONDARYTRAITS UNDER HIGH N

74 PH	Dependent	Variable:	PH			
75 PH	SITE(NLEVEL)	2	181938.71	90969.354	220.54759	2.947E-55
76 PH	LINE	8	17630.616	2203.827	18.036347	9.027E-14
77 PH	TESTER	8	18717.337	2339.6671	19.148077	2.494E-14
78 PH	LINE*TESTER	64	7820.0361	122.1881	1.5196032	0.0232626
79 PH	SITE*LINE(NLEVEL)	16	1452.1019	90.7564	1.1287	0.3359112
80 PH	SITE*TESTER(NLEVEL)	16	1262.8386	78.9274	0.9815876	0.4806793
81 PH	SITE*LINE*TEST(NLEV)	128	10292.206	80.4079	0.1949422	1
	POOLED ERROR	242	99817.837	412.4704		
98 HT	Dependent	Variable:	HT			
99 HT	SITE(NLEVEL)	2	56.688551	28.344275	48.499755	1.939E-18
100 HT	LINE	8	5.9248741	0.7406093	9.8059822	8.954E-09
101 HT	TESTER	8	7.1446741	0.8930843	11.824816	3.612E-10
102 HT	LINE*TESTER	64	4.8336815	0.0755263	0.6947475	0.9470039
103 HT	SITE*LINE(NLEVEL)	16	4.9436049	0.3089753	2.8421877	0.0005623
104 HT	SITE*TESTER(NLEVEL)	16	4.7040494	0.2940031	2.704462	0.0010033
105 HT	SITE*LINE*TEST(NLEV)	128	13.914928	0.1087104	0.1860138	1
	POOLED ERROR	242	141.42988	0.584421		
124 SKW	Dependent	Variable:	SKW			
125 SKW	SITE(NLEVEL)	2	45546.487	22773.244	8.357767	0.0003091
126 SKW	LINE	8	26262.098	3282.7622	3.4066728	0.002549
127 SKW	TESTER	8	35661.869	4457.7336	4.6259944	0.0001721
128 SKW	LINE*TESTER	64	61672.133	963.6271	1.1152161	0.2989304
129 SKW	SITE*LINE(NLEVEL)	16	12981.24	811.3275	0.9389581	0.5271833
130 SKW	SITE*TESTER(NLEVEL)	16	12886.862	805.4289	0.9321316	0.5347396
131 SKW	SITE*LINE*TEST(NLEV)	126	108873.09	864.0721	0.317114	1
	POOLED ERROR	242	659401.6	2724.8		
132 KNEAR	Dependent	Variable:	KERNELS PER EAR			
133 KNEAR	SITE(NLEVEL)	2	1115269.1	557634.57	48.642064	1.752E-18
134 KNEAR	LINE	8	69748.556	8718.569	1.3677918	0.2277173
135 KNEAR	TESTER	8	69007.375	8625.922	1.3532571	0.2342737
136 KNEAR	LINE*TESTER	64	407948.36	6374.193	1.0440217	0.4121511
137 KNEAR	SITE*LINE(NLEVEL)	16	73024.002	4564	0.7475323	0.7405842
138 KNEAR	SITE*TESTER(NLEVEL)	16	42011.443	2625.715	0.4300628	0.971967
139 KNEAR	SITE*LINE*TEST(NLEV)	126	769283.11	6105.422	0.5325716	0.9999472
	POOLED ERROR	242	2774297.7	11464.04		
158 GLS	Dependent	Variable:	GLS			
159 GLS	SITE(NLEVEL)	1	50.077808	50.077808	83.775776	2.303E-16
160 GLS	LINE	8	11.849079	1.4811349	9.5171956	1.454E-08
161 GLS	TESTER	8	14.58119	1.8226488	11.711631	4.291E-10
162 GLS	LINE*TESTER	64	9.9601432	0.1556272	0.9292891	0.61492
163 GLS	SITE*LINE(NLEVEL)	8	2.0441753	0.2555219	1.525785	0.1659931
164 GLS	SITE*TESTER(NLEVEL)	8	2.519842	0.3149803	1.8808256	0.0784812
165 GLS	SITE*LINE*TEST(NLEV)	64	10.718025	0.1674691	0.2801612	1
	POOLED ERROR	162	96.83712	0.59776		

APPENDIX E CONT/.. ANOVA TABLE FOR GRAIN YIELD AND SECONDARYTRAITS UNDER HIGH N

176 RUST	Dependent	Variable:	RUST			
177 RUST	SITE(NLEVEL)	0	0	.	.	.
178 RUST	LINE	8	25.778891	3.2223614	2.057775	0.0533029
179 RUST	TESTER	8	5.9032691	0.7379086	0.4712227	0.8719818
180 RUST	LINE*TESTER	64	14.037531	0.2193364	0.8824178	0.6968646
181 RUST	SITE*LINE(NLEVEL)	0	0	.	.	.
182 RUST	SITE*TESTER(NLEVEL)	0	0	.	.	.
183 RUST	SITE*LINE*TEST(NLEV)	0	0	.	.	.
	ERROR	80	19.88504	0.248563		

APPENDIX F. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS GOLDEN VALLEY UNDER HIGH N

ENTRY	GY t/ha	AD days	SD days	ASI days	EPP #	PH cm	GLS 1-5	HT 1-5	SENESC 10-100	SKW mg	KERNELS PER EAR
1	10.69	64.53	64.50	-0.04	1.10	254.43	3.07	2.15	29.30	361.11	650.81
2	7.44	60.74	60.97	0.49	0.95	225.60	1.77	2.39	46.15	368.44	492.08
3	9.42	58.63	65.04	6.03	1.10	233.98	2.61	2.39	27.01	381.69	538.25
4	7.02	65.10	65.75	0.88	1.05	226.92	2.29	1.90	33.15	321.61	626.64
5	8.40	65.52	66.82	1.10	1.05	230.76	2.64	1.90	46.84	342.97	567.55
6	8.66	64.32	65.30	1.06	1.00	222.46	2.54	2.61	38.16	353.91	530.53
7	7.48	65.04	65.67	0.54	1.10	222.62	3.12	1.92	31.75	346.75	572.41
8	7.85	62.55	64.23	1.50	0.95	209.87	3.00	2.01	34.65	317.98	632.84
9	11.02	65.41	66.94	1.68	0.99	231.14	1.56	1.69	22.58	357.29	650.76
10	6.99	68.11	70.19	1.93	1.00	245.45	3.62	2.89	27.60	396.64	568.97
11	8.81	65.38	65.88	0.41	0.95	261.86	3.59	2.28	28.80	412.28	546.84
12	7.24	64.43	65.80	1.39	0.95	242.01	2.70	1.69	30.22	303.35	627.07
13	9.54	65.03	66.30	1.47	1.05	242.07	2.03	2.16	24.86	389.76	577.54
14	7.66	65.97	66.62	0.45	1.00	233.96	2.51	2.22	25.47	352.67	584.70
15	7.44	66.59	67.77	1.43	1.05	234.56	2.82	1.29	34.72	344.33	587.26
16	8.58	64.51	65.59	1.53	1.10	222.84	3.22	1.86	23.75	362.98	633.43
17	9.52	64.88	66.82	1.54	1.10	234.00	1.61	2.25	15.56	397.86	573.83
18	9.44	66.27	67.45	1.05	1.00	264.09	2.70	2.33	39.68	354.06	684.81
19	7.86	62.76	65.78	2.45	1.10	219.27	2.41	2.55	18.41	336.73	603.97
20	6.44	65.36	67.39	1.92	1.20	219.46	1.34	2.37	30.96	365.01	526.76
21	9.04	66.93	69.07	1.97	1.00	238.46	2.92	2.10	42.38	344.14	592.66
22	8.63	66.07	68.23	2.01	1.05	228.54	2.36	2.31	61.52	328.77	578.57
23	8.53	65.57	66.64	0.94	1.05	225.13	1.98	2.73	41.54	313.82	612.35
24	8.17	67.56	68.50	1.06	0.95	229.40	1.98	2.22	44.70	354.71	591.48
25	7.70	66.56	67.61	1.48	1.10	230.54	2.63	2.26	52.59	336.98	590.21
26	6.86	67.88	68.98	1.47	0.95	229.97	2.09	2.85	24.35	277.23	738.70
27	10.58	66.29	69.10	2.15	1.15	247.90	2.80	2.90	22.42	367.04	712.11
28	10.47	66.91	68.16	1.05	1.04	265.20	4.03	1.96	38.90	317.60	694.49
29	7.04	62.71	63.83	0.98	0.85	228.24	2.74	2.79	28.67	346.72	623.77
30	9.13	66.26	67.68	1.03	1.05	258.46	3.20	2.23	33.63	322.14	645.01
31	7.90	66.51	67.44	1.03	1.10	234.28	2.73	1.96	40.31	336.04	623.20
32	8.95	66.47	66.98	0.47	1.10	243.36	2.95	1.76	37.26	309.56	659.02
33	8.73	67.39	65.83	-1.05	0.94	227.59	3.17	1.99	20.00	344.36	666.39
34	8.48	65.92	66.84	0.91	1.00	240.04	2.45	2.38	26.79	339.62	647.91
35	6.86	64.13	62.62	-2.03	1.00	225.88	2.58	1.68	26.93	332.79	611.84
36	8.73	68.66	68.78	0.48	1.05	235.57	2.42	2.31	21.77	333.97	609.95
37	9.17	68.04	69.75	1.54	0.95	258.72	4.12	3.30	29.25	333.60	729.62
38	8.81	62.43	62.75	1.07	1.05	237.92	1.96	2.22	58.26	347.03	587.19
39	7.19	56.61	57.40	0.91	0.95	201.68	1.08	2.81	39.64	352.30	513.12
40	7.61	60.25	61.99	1.55	1.00	219.62	2.04	2.37	37.86	333.05	592.67
41	8.65	61.65	63.31	1.88	1.15	197.60	2.19	2.10	44.50	302.51	646.39
42	6.32	63.69	65.91	2.09	1.05	210.16	2.31	1.71	35.58	315.01	565.96
43	7.08	63.79	65.19	1.41	0.95	216.53	2.41	2.27	40.81	300.51	605.46
44	7.50	64.50	65.92	1.48	1.06	204.26	2.24	2.25	62.34	327.60	589.29
45	7.73	64.62	65.23	0.94	1.10	212.32	2.24	2.05	42.37	347.65	542.50
46	6.87	64.53	64.52	0.03	1.05	221.00	1.49	1.91	25.56	378.87	517.24

APPENDIX F. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS GOLDEN VALLEY UNDER HIGH N

ENTRY	GY t/ha	AD days	SD days	ASI days	EPP #	PH cm	GLS 1-5	HT 1-5	SENESC 10-100	SKW mg	KERNELS PER EAR
47	10.01	65.84	67.49	1.56	0.95	230.91	2.24	3.19	30.40	422.29	559.92
48	9.12	63.82	65.00	1.01	1.09	254.91	4.07	3.53	42.95	342.87	611.91
49	7.05	63.63	65.01	1.10	0.95	225.47	2.90	2.51	40.98	333.18	540.47
50	9.35	64.40	65.51	1.02	1.10	234.87	2.95	1.77	30.41	317.12	649.20
51	7.93	64.44	65.24	0.54	1.00	234.85	1.84	2.26	69.80	351.84	570.43
52	7.74	65.15	65.44	1.09	1.00	238.74	2.94	2.10	41.92	361.72	550.08
53	8.18	64.75	65.35	0.52	1.05	234.01	2.68	2.43	34.20	338.51	606.09
54	8.09	65.46	65.94	0.93	1.00	242.08	3.64	2.48	48.81	299.68	686.19
55	6.87	65.84	65.74	-0.12	0.85	230.75	2.52	2.67	25.14	435.55	534.93
56	8.01	68.28	69.00	1.07	0.95	254.45	3.51	3.99	21.27	399.48	615.83
57	9.97	65.04	65.97	0.52	1.45	244.91	2.36	2.11	36.48	384.99	472.12
58	8.74	65.50	65.51	0.08	1.05	218.68	1.85	2.20	26.96	365.92	570.10
59	7.63	65.01	67.28	2.06	1.05	233.03	1.95	2.97	16.43	369.04	552.12
60	8.41	65.92	67.36	1.60	1.15	233.19	2.18	2.02	25.70	303.31	598.40
61	7.72	66.32	67.50	1.02	1.05	241.51	1.96	1.79	25.08	312.09	696.70
62	9.15	64.67	66.30	1.58	0.96	231.06	2.87	2.07	38.46	291.83	737.83
63	9.78	65.62	66.50	1.08	1.05	247.67	2.58	2.87	32.04	341.08	654.07
64	6.94	64.69	65.87	0.72	1.15	224.88	2.01	1.91	19.18	362.56	499.19
65	9.00	64.76	66.05	1.04	1.05	247.84	1.70	2.68	18.45	285.39	720.76
66	8.84	67.49	69.44	1.99	1.20	261.63	3.77	3.31	22.75	396.54	596.71
67	11.00	64.80	66.46	1.10	0.95	268.81	3.85	3.18	28.88	377.30	702.81
68	7.88	65.25	67.10	1.57	1.00	246.29	1.35	2.87	34.62	341.94	646.54
69	9.10	64.75	65.71	0.40	1.15	242.48	2.13	2.47	35.49	338.80	543.13
70	9.05	66.34	67.94	1.45	1.00	253.60	1.85	2.01	31.64	319.91	631.53
71	8.24	67.38	68.61	1.47	1.05	254.17	1.99	2.06	49.86	334.18	586.29
72	8.48	66.78	67.41	0.96	0.85	252.25	1.96	2.09	29.49	322.64	750.65
73	7.52	66.65	67.39	1.04	1.00	232.40	1.84	2.60	32.25	327.62	671.81
74	8.65	66.01	67.73	1.56	1.10	253.44	1.55	2.56	44.18	346.49	510.57
75	8.61	67.79	68.72	0.44	1.06	249.58	1.70	2.01	14.60	375.20	682.48
76	11.04	68.51	68.41	0.07	1.05	283.51	2.48	3.23	25.48	396.18	668.62
77	11.15	64.78	65.81	0.98	1.10	268.14	3.42	2.46	38.24	403.62	552.79
78	7.84	62.37	63.67	1.58	1.10	234.45	1.44	2.51	38.86	332.36	653.49
79	8.03	68.05	68.88	1.01	1.09	236.63	2.15	2.14	19.87	353.27	551.97
80	7.67	68.08	68.46	0.92	1.00	231.61	2.48	2.36	30.67	307.22	674.98
81	8.38	67.68	68.29	0.92	1.05	226.70	3.24	2.86	36.68	322.36	683.79
82	9.27	66.17	66.51	0.40	0.95	234.25	3.03	2.53	33.86	315.33	688.55
83	9.07	66.54	65.29	-0.99	1.00	231.37	2.30	2.25	15.89	308.42	636.66
84	9.96	66.11	65.37	-1.04	1.05	243.53	1.02	2.02	23.82	368.58	653.61
85	9.07	68.52	67.66	-0.67	0.95	248.93	2.55	2.76	24.25	304.36	715.10
86	10.16	68.25	68.86	0.87	1.10	248.89	2.73	3.43	30.09	385.32	573.42
87	8.44	64.02	66.15	2.02	0.95	227.18	2.65	2.68	25.93	393.47	550.44
88	8.50	64.87	66.20	1.58	0.90	241.08	1.19	1.86	18.05	378.70	654.12
89	8.35	66.29	67.16	0.83	1.05	229.73	3.05	2.01	24.60	311.66	604.66
90	8.33	65.03	67.63	2.15	1.00	230.29	2.40	1.79	21.25	341.85	621.07
91	7.35	65.16	66.86	1.58	0.89	219.39	2.86	2.70	39.08	330.77	631.32
92	11.06	66.87	66.22	-0.33	1.05	251.01	1.34	2.26	17.25	389.51	659.94

APPENDIX F. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS GOLDEN VALLEY UNDER HIGH N

ENTRY	GY t/ha	AD days	SD days	ASI days	EPP #	PH cm	GLS 1-5	HT 1-5	SENESC 10-100	SKW mg	KERNELS PER EAR
93	9.15	67.63	69.34	1.61	1.15	245.93	2.95	2.96	32.57	318.97	640.62
94	9.37	65.16	65.60	0.50	1.30	260.48	3.51	2.51	38.08	368.06	501.06
95	7.80	67.56	67.25	-0.03	1.05	226.08	2.64	1.90	33.76	340.28	551.61
96	6.74	68.35	69.01	0.83	0.90	236.69	2.37	2.11	39.28	307.51	602.61
97	7.61	69.28	69.32	0.39	1.00	227.94	2.63	2.06	24.36	324.04	607.66
98	7.84	68.07	68.46	0.47	0.89	229.44	2.39	1.94	40.21	300.15	659.76
99	6.22	68.40	66.64	-1.62	1.05	232.53	2.48	2.30	44.94	285.05	536.49
100	10.44	65.65	65.50	-0.16	0.96	254.13	1.86	1.87	24.35	375.23	664.97
101	10.21	65.45	66.97	1.12	1.05	272.50	3.25	2.35	45.73	370.12	617.41
102	8.91	65.87	65.73	0.04	1.10	240.62	2.19	2.27	34.19	364.12	572.20
103	7.64	67.69	69.13	1.45	1.00	243.35	1.52	2.01	16.32	386.51	534.50
104	7.62	65.99	66.68	0.44	0.95	230.86	2.46	1.81	24.73	390.94	653.77
105	7.45	66.38	68.13	1.49	0.94	250.25	2.64	2.18	38.25	333.65	581.02
106	8.17	67.46	68.59	0.95	1.00	236.80	2.45	1.85	28.91	315.77	678.18
107	10.96	66.78	68.02	1.01	0.95	233.62	2.46	1.98	22.82	397.31	668.72
108	9.08	67.02	66.38	-0.44	0.90	232.12	2.40	2.25	26.47	408.71	575.94
109	10.61	67.25	66.64	-1.08	1.06	243.58	1.38	1.90	22.30	412.32	696.91
110	9.79	69.07	70.70	1.50	1.00	264.05	1.76	2.86	12.29	460.37	551.19
111	8.06	65.66	66.08	0.57	1.20	244.24	2.56	2.59	41.17	377.17	462.26
112	7.24	66.35	67.24	0.95	0.95	255.33	2.74	2.91	23.83	380.26	482.80
113	8.64	63.94	65.29	1.53	1.00	234.46	2.75	2.70	35.06	299.73	668.93
114	5.03	64.94	67.00	2.01	1.05	264.91	3.34	2.99	22.60	386.24	439.30
Mean	8.47	65.64	66.62	0.98	1.03	237.81	2.47	2.34	32.23	348.73	608.21
LSD	2.12	2.63	2.76	1.94	0.17	17.93	1.13	0.91	22.92	67.52	135.65
MSE	0.931	1.708	1.688	0.967	0.007	79.138	0.350	0.225	231.26	1349.840	4796.860
CV	13	2	2	100	8	4	23	20	36	10	11
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Min	5.03	56.61	57.40	-2.03	0.85	197.60	1.02	1.29	12.29	277.23	439.30
Max	11.15	69.28	70.70	6.03	1.45	283.51	4.12	3.99	69.80	460.37	750.65

APPENDIX I. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS
AT GOLDEN VALLEY UNDER LOW N

	GY	AD	SD	ASI	EPP	PH	HT	SENESC	SKW	kernles per ear
	t/ha	d	d	cm	%	%	1-5	1-5	1-5	1-10
1	2.08	67.7	73.8	6	0.90	175	1.4	38.8	246.2	290.1
2	1.05	68.3	76.3	8	0.84	142	2.7	46.2	157.3	195.3
3	1.07	67.9	75.4	7	0.59	143	2.6	43.4	206.6	337.0
4	2.28	68.4	73.6	6	0.80	154	1.8	40.2	192.6	320.1
5	0.91	68.9	76.0	7	0.82	149	1.6	53.2	224.8	244.3
6	2.39	68.6	75.8	7	0.87	140	1.6	45.3	222.4	316.8
7	1.33	69.4	73.6	4	0.92	144	2.0	35.9	185.2	288.9
8	1.65	67.0	72.8	6	0.81	144	2.2	39.8	206.3	289.3
9	1.20	69.9	76.5	6	1.03	147	1.7	39.7	201.8	217.9
10	1.88	69.2	75.8	7	0.87	166	2.3	46.6	206.8	215.6
11	1.04	70.6	78.1	7	0.87	165	1.4	41.8	202.1	170.1
12	0.66	72.6	83.1	10	0.60	143	1.9	35.3	216.4	181.2
13	1.47	71.7	79.3	7	0.62	152	1.6	32.8	215.6	318.1
14	1.77	68.5	77.1	9	0.62	137	1.9	51.3	210.9	300.7
15	1.12	71.2	79.0	8	0.82	144	1.7	41.0	171.0	211.1
16	1.22	69.5	78.0	8	0.79	146	1.5	45.1	210.4	295.9
17	2.19	69.4	76.3	7	0.96	151	1.7	34.7	247.7	248.2
18	1.75	71.1	78.1	7	0.96	168	2.1	48.8	254.2	201.7
19	0.87	68.0	78.9	11	0.72	142	2.7	48.2	194.3	128.8
20	1.24	67.0	73.7	7	1.09	150	2.9	40.3	199.2	353.1
21	0.65	70.5	75.6	5	0.80	162	2.0	32.2	216.8	412.3
22	0.79	70.4	76.5	6	0.40	149	3.0	37.1	168.0	241.4
23	0.75	68.5	76.9	9	0.75	137	2.8	32.8	190.6	287.0
24	0.74	74.1	86.2	12	0.37	143	2.7	53.4	192.0	186.2
25	0.90	72.7	80.1	7	0.64	138	3.0	38.7	192.2	299.2
26	1.09	73.1	77.7	4	0.80	135	2.4	34.0	242.2	273.4
27	1.41	69.3	75.6	7	0.76	171	2.8	49.1	200.2	363.4
28	1.49	68.0	76.6	8	0.77	162	2.5	50.9	241.1	235.0
29	0.96	68.9	76.4	8	0.87	137	2.4	24.8	232.8	321.6
30	0.91	71.4	79.8	8	0.57	171	1.8	40.2	231.4	203.6
31	1.40	69.8	72.9	4	0.68	152	1.8	39.2	197.0	420.6
32	0.79	68.6	75.3	7	0.60	153	2.0	37.0	190.7	302.7
33	1.77	71.0	76.7	6	0.56	141	2.0	32.4	215.7	331.2
34	1.58	71.0	80.0	9	0.85	154	2.3	34.2	188.6	230.6
35	1.28	68.7	76.5	8	0.81	147	1.9	48.4	184.0	277.4
36	0.62	71.6	78.1	7	0.54	156	1.5	32.0	214.8	212.9
37	1.34	70.7	80.5	10	0.83	156	2.0	53.5	269.7	188.1
38	1.46	67.8	72.8	5	0.78	161	2.8	42.8	198.0	227.7
39	1.25	65.8	69.8	4	0.84	138	1.7	35.7	237.9	277.3
40	1.27	70.0	74.7	5	0.97	119	2.0	31.2	192.3	236.0
41	0.96	69.9	72.6	3	1.02	132	2.4	19.6	212.9	538.4
42	1.03	67.7	77.0	9	0.77	133	1.9	42.1	188.7	286.5
43	1.56	69.9	73.7	4	0.80	158	1.5	39.1	194.4	326.9
44	1.01	70.1	77.8	7	0.71	141	1.9	51.0	162.0	295.3
45	0.36	68.6	75.5	7	0.97	117	1.3	45.7	143.7	277.3
46	1.60	68.4	72.6	5	0.79	124	1.5	39.0	170.8	229.1
47	2.31	68.1	74.9	7	0.86	145	2.6	42.0	216.3	321.5

APPENDIX I. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT GOLDEN VALLEY UNDER LOW N

	GY	AD	SD	ASI	EPP	PH	HT	SENESC	SKW	kernles per ear
	t/ha	d	d	cm	%	%	1-5	1-5	1-5	1-10
48	1.40	68.5	78.2	10	0.84	166	1.9	30.7	234.7	242.2
49	1.46	65.0	68.7	3	0.89	165	1.9	47.1	215.0	447.0
50	0.90	68.0	84.6	17	0.47	133	2.2	63.3	211.6	184.6
51	0.76	70.0	75.7	6	0.64	139	2.7	39.1	187.0	266.8
52	1.29	68.1	78.3	10	0.76	134	2.7	29.6	189.2	167.7
53	1.54	67.8	81.0	13	0.70	144	2.1	40.4	208.3	293.6
54	1.25	69.0	74.6	6	0.61	148	1.5	41.4	207.0	248.9
55	1.58	70.2	78.2	8	0.73	150	2.1	34.7	214.9	288.1
56	1.61	73.0	83.0	10	0.58	159	2.5	43.3	286.2	238.0
57	2.32	70.1	76.1	6	0.78	168	1.4	38.1	238.8	295.2
58	1.48	66.1	72.3	6	0.84	142	2.1	42.6	190.2	339.1
59	1.19	68.6	77.2	9	0.69	130	2.5	53.5	190.3	200.5
60	1.69	69.9	75.0	5	0.88	140	2.8	42.7	189.1	337.6
61	1.83	69.7	76.7	7	0.71	152	1.9	30.3	199.3	320.1
62	1.50	69.3	77.8	9	0.78	136	2.8	34.3	200.0	210.7
63	0.98	69.1	80.1	11	0.84	143	3.2	58.1	177.3	173.8
64	1.70	68.8	73.2	5	0.83	144	2.2	41.6	211.9	371.9
65	2.10	69.6	72.7	3	1.00	159	1.5	26.5	182.8	327.6
66	2.49	68.8	74.7	6	0.79	159	2.1	42.5	233.9	323.2
67	1.59	69.8	80.4	11	0.92	167	2.5	33.7	255.6	278.3
68	1.06	67.5	74.3	7	0.72	156	2.0	49.1	242.7	218.5
69	1.71	68.0	74.6	7	0.84	157	2.0	42.7	216.0	244.7
70	0.93	73.7	80.1	6	0.80	136	2.4	28.7	209.0	222.2
71	1.06	71.6	82.3	11	0.59	150	2.4	50.1	207.3	232.1
72	0.93	71.5	80.8	9	0.59	156	2.2	43.9	193.2	242.5
73	0.83	75.2	80.2	5	0.68	137	2.1	35.7	245.5	203.4
74	1.62	68.8	73.9	5	1.04	161	2.8	40.9	225.3	249.8
75	1.22	72.9	82.1	9	0.59	151	2.3	47.8	210.8	191.9
76	1.18	73.7	80.0	6	0.63	165	2.3	44.3	248.9	178.8
77	2.42	68.6	74.1	5	1.01	170	1.6	44.0	212.6	261.7
78	1.74	68.0	74.4	6	0.80	130	1.6	36.4	236.3	296.7
79	1.07	73.8	80.5	7	0.72	134	1.7	49.4	199.9	265.3
80	1.93	70.3	75.5	5	0.71	151	1.6	39.9	203.4	309.3
81	1.09	72.9	77.2	4	0.70	147	1.5	36.9	221.4	218.0
82	1.43	72.5	78.4	5	0.55	149	1.9	53.9	195.8	294.2
83	1.15	68.7	76.3	7	0.73	144	1.3	53.0	164.9	234.3
84	1.41	72.0	78.6	6	0.73	147	1.4	34.9	181.9	272.2
85	1.38	71.9	77.8	6	0.73	159	1.7	42.5	196.1	274.1
86	1.82	69.4	77.9	8	0.83	169	1.7	37.6	229.7	238.6
87	2.08	66.3	71.2	4	0.92	147	2.4	36.3	232.0	261.4
88	1.85	67.7	75.4	8	0.99	150	2.9	39.0	174.4	277.5
89	1.50	69.2	73.5	4	0.70	153	2.0	48.9	182.2	270.1
90	1.19	73.5	79.8	6	0.94	146	2.0	40.4	221.0	198.5
91	1.18	68.2	74.0	5	0.56	140	1.6	45.8	195.3	289.8
92	2.13	69.6	73.9	4	0.85	158	2.1	35.7	198.3	330.9
93	0.72	72.0	79.9	8	0.74	142	1.4	57.6	215.0	174.9
94	1.97	70.6	77.0	7	0.89	164	1.6	47.4	215.9	243.7

APPENDIX I. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT GOLDEN VALLEY UNDER LOW N

	GY	AD	SD	ASI	EPP	PH	HT	SENESC	SKW	kernles per ear
	t/ha	d	d	cm	%	%	1-5	1-5	1-5	1-10
95	0.47	76.2	85.4	9	0.37	132	2.2	37.1	174.7	123.4
96	0.98	71.8	82.0	11	0.57	141	2.1	38.6	216.6	206.5
97	1.05	73.3	83.0	10	0.71	140	2.3	52.5	170.4	216.0
98	0.67	76.9	89.3	12	0.41	132	2.4	37.5	220.2	186.2
99	1.35	70.7	78.8	8	0.69	140	1.7	34.1	213.6	257.6
100	1.61	72.1	81.9	10	0.69	142	1.3	48.4	208.0	220.0
101	1.87	71.8	77.0	6	0.75	165	1.5	23.8	302.1	349.9
102	1.27	72.6	81.2	8	0.58	154	2.6	54.6	252.6	222.4
103	0.45	73.1	83.8	10	0.60	147	2.4	43.8	219.2	188.0
104	0.55	72.9	85.8	12	0.68	131	2.0	44.7	233.7	115.5
105	2.31	69.9	74.4	4	0.80	145	2.1	48.6	198.0	258.5
106	0.81	77.3	83.4	6	0.70	162	1.9	45.6	266.7	223.5
107	0.95	72.6	82.7	10	0.51	143	2.2	58.3	205.0	264.2
108	0.96	71.8	79.3	8	0.59	148	2.0	34.7	208.4	237.1
109	1.44	73.9	80.1	6	0.75	146	2.1	40.5	218.9	167.4
110	1.34	73.9	81.0	7	0.79	142	2.5	51.8	251.6	215.4
111	2.01	68.4	75.9	7	0.90	152	2.9	42.1	240.5	293.4
112	1.70	69.1	80.2	11	0.78	159	2.9	49.7	227.1	153.3
113	1.94	70.2	77.7	7	0.88	135	2.8	36.4	224.2	275.9
114	0.76	70.4	79.1	9	0.83	156	2.0	36.1	224.1	154.1
Mean	**1.35**	**70.23**	**77.53**	**7.30**	**0.75**	**148.19**	**2.09**	**41.59**	**210.79**	**258.82**
LSD	**1.21**	**4.61**	**7.61**	**5.12**	**0.30**	**20.41**	**0.93**	**20.51**	**46.91**	**150.81**
MSE	**0.32**	**5.36**	**14.78**	**6.96**	**0.02**	**336.22**	**0.27**	**229.47**	**713.02**	**7938.5**
CV	**45.**	**3.**	**5.**	**35.**	**20.**	**7.**	**23.**	**25.**	**11.**	**29.**
P	**0.082**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.066**	**0.000**	**0.001**
Min	**0.36**	**65.05**	**68.69**	**2.73**	**0.37**	**117.29**	**1.30**	**19.55**	**143.66**	**115.54**
Max	**2.49**	**77.28**	**89.32**	**16.72**	**1.09**	**175.03**	**3.20**	**63.26**	**302.08**	**538.40**

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT KABWE UNDER LOW N

ENTRY	GY t/ha	AD d	SD cm	ASI cm	EPP %	PH #	HT 1-5	SENESC 1-10	TEXT 1-5	SKW %	KERNELS PER EAR
1	1.255	72.68	78.40	5.16	0.55	98.01	2.12	49.83	1.51	198.85	180.44
2	0.619	68.99	74.59	4.16	0.58	122.08	2.13	52.55	1.57	166.30	199.37
3	0.816	76.05	79.54	3.47	0.86	87.37	2.04	45.66	2.12	209.67	152.43
4	0.667	75.85	79.28	3.63	0.50	103.54	2.32	52.98	2.19	255.05	125.07
5	0.429	76.49	83.58	9.11	0.46	102.39	2.10	38.39	2.23	176.54	124.53
6	1.220	73.14	77.96	3.64	0.57	78.99	1.99	47.87	1.72	220.36	158.62
7	0.649	75.57	83.96	8.92	0.71	83.38	2.56	46.04	2.07	184.68	97.72
8	1.042	73.92	77.87	3.07	0.77	100.24	2.14	40.80	2.22	196.56	141.85
9	1.003	76.77	78.01	2.33	0.63	103.50	2.13	42.16	2.49	191.48	120.58
10	1.377	74.75	78.96	3.30	0.82	116.15	2.80	39.30	1.82	197.62	177.82
11	1.499	74.71	79.42	3.74	0.99	125.22	1.25	34.28	2.54	262.12	153.31
12	1.003	76.75	86.16	8.24	0.76	102.37	2.02	50.02	1.65	184.30	210.45
13	0.665	75.36	80.98	5.48	0.42	100.88	1.85	36.59	1.70	197.20	99.35
14	0.849	74.71	76.57	2.57	0.75	74.23	2.30	37.73	1.71	196.19	161.13
15	0.758	76.86	84.69	6.65	0.87	90.00	1.61	39.60	2.01	235.69	99.22
16	0.798	76.29	78.77	3.01	0.77	109.81	2.16	36.40	1.65	202.34	132.84
17	0.480	77.05	79.64	3.01	0.82	108.43	1.53	43.37	2.14	153.08	102.04
18	0.820	76.45	80.47	5.32	0.85	117.34	2.50	43.46	1.93	245.43	177.06
19	0.747	72.19	78.16	6.34	0.82	98.30	2.29	44.72	2.19	166.09	115.38
20	0.700	75.26	80.24	5.30	0.67	93.17	2.75	47.81	2.90	195.13	131.99
21	0.603	78.43	87.75	10.69	0.43	101.06	2.22	48.29	2.37	215.40	100.67
22	0.238	75.50	76.98	2.39	0.68	75.54	2.09	52.22	1.88	204.31	89.82
23	0.655	76.89	87.02	9.92	0.40	102.44	2.62	43.50	2.25	194.59	87.39
24	0.402	75.60	81.08	5.90	0.61	106.72	2.13	44.87	2.55	167.17	85.19
25	0.578	76.64	80.70	4.00	0.58	98.69	2.39	40.23	2.18	148.81	155.09
26	0.920	73.15	76.70	3.29	0.69	102.62	2.38	41.10	3.06	184.37	153.89
27	0.653	75.06	81.40	6.00	0.72	101.60	2.78	46.60	2.21	191.31	94.32
28	0.790	75.76	78.14	1.73	0.77	105.39	1.97	36.12	2.21	225.99	130.63
29	0.639	74.05	78.16	4.42	0.73	103.84	2.50	47.27	2.19	180.05	113.19
30	0.600	74.90	78.37	4.04	0.29	78.28	2.05	35.20	2.08	208.76	120.21
31	1.344	74.49	78.43	3.00	0.92	105.25	2.15	37.33	2.65	232.71	128.50
32	0.834	75.53	82.36	8.21	0.62	123.59	1.91	37.07	1.85	192.81	140.12
33	0.870	74.73	77.25	3.74	0.84	109.64	1.76	43.40	2.23	198.55	163.17
34	0.424	73.67	81.08	5.72	0.59	87.33	1.78	36.42	2.67	233.99	97.63
35	0.822	74.59	80.77	6.43	0.90	96.67	2.11	44.07	2.14	204.42	88.53
36	0.430	77.24	84.76	9.14	0.60	94.13	2.11	44.21	1.97	220.32	54.22
37	1.038	75.32	82.39	7.76	0.46	102.80	1.91	50.02	1.86	254.26	113.43
38	0.990	71.46	76.02	5.34	0.95	87.83	1.91	41.67	1.50	238.58	225.08
39	0.128	73.19	77.58	4.95	0.57	78.67	2.15	42.60	2.12	182.93	56.77
40	0.616	69.56	75.92	5.10	0.69	101.91	2.63	50.66	1.93	216.43	136.02
41	0.891	72.94	77.42	3.13	0.58	98.89	2.07	43.10	1.99	179.16	155.23
42	1.313	73.17	78.51	3.84	0.83	100.78	2.21	42.12	1.93	188.28	173.38
43	0.230	75.82	77.40	2.41	0.73	62.86	2.34	43.54	1.91	164.35	128.00
44	0.762	76.75	78.44	1.89	0.82	70.66	2.11	38.98	1.42	177.72	119.61
45	0.687	75.41	81.96	6.26	0.60	89.97	2.31	37.77	1.82	171.72	98.56
46	0.595	75.02	78.77	5.28	0.65	85.83	2.05	43.44	1.69	170.24	111.95

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT KABWE UNDER LOW N

ENTRY	GY t/ha	AD d	SD cm	ASI cm	EPP %	PH #	HT 1-5	SENESC 1-10	TEXT 1-5	SKW %	KERNELS PER EAR
47	0.989	71.11	75.98	3.72	0.74	75.14	2.29	39.70	2.13	209.53	189.68
48	1.589	72.90	76.74	3.58	0.76	118.71	1.78	41.84	2.01	247.84	162.49
49	0.460	75.36	79.68	4.10	0.78	105.85	2.09	47.10	2.55	177.60	181.63
50	0.572	76.49	79.30	3.03	0.64	103.19	2.07	38.76	2.21	203.43	143.49
51	0.563	75.34	81.68	5.25	0.72	98.79	2.31	47.16	2.05	189.06	83.43
52	0.949	75.76	85.24	8.14	0.58	102.38	2.46	49.71	1.84	227.39	119.35
53	0.838	75.89	79.87	4.77	0.89	85.87	2.13	38.78	1.93	175.34	130.74
54	0.759	75.81	78.52	3.47	0.84	119.64	2.07	62.09	2.26	191.08	176.35
55	0.546	74.29	84.00	10.04	0.56	81.81	1.89	43.98	2.46	207.68	85.69
56	1.578	75.11	80.62	6.61	0.85	111.07	2.40	45.90	3.10	251.21	142.39
57	0.923	71.62	77.78	5.20	0.75	121.34	2.44	38.42	1.85	211.86	121.56
58	0.678	70.75	75.96	5.43	0.80	85.02	1.91	43.34	2.36	186.19	134.00
59	0.939	73.18	75.21	2.81	0.62	98.95	2.44	55.09	3.25	189.67	144.07
60	1.554	70.95	77.43	6.17	0.80	99.49	1.84	37.93	1.62	193.70	207.53
61	0.994	72.06	77.91	5.44	0.84	101.18	2.55	43.84	2.06	177.42	129.55
62	0.741	74.07	76.14	2.21	0.76	99.67	1.95	43.71	1.88	178.54	82.98
63	0.703	73.31	75.86	2.18	0.66	96.18	2.75	35.70	1.56	161.93	146.31
64	0.803	76.43	81.67	4.54	0.76	78.43	2.24	46.90	1.82	131.44	116.97
65	1.002	74.46	77.23	3.51	0.78	105.55	2.56	46.48	2.23	192.85	150.42
66	0.516	75.41	76.91	3.11	0.49	86.72	2.46	46.01	2.12	209.07	117.56
67	0.917	73.90	78.50	5.73	0.94	124.76	2.58	49.57	1.95	232.85	106.09
68	0.558	73.87	76.37	3.46	0.64	103.27	2.59	42.95	1.92	221.19	112.74
69	0.838	75.47	76.89	3.17	0.66	99.55	2.35	49.34	2.64	157.98	133.22
70	0.841	74.94	81.24	6.61	0.56	108.38	2.08	37.04	1.71	192.89	158.84
71	1.027	75.92	80.86	5.02	0.56	92.51	2.03	47.82	1.44	204.85	117.06
72	0.780	76.21	78.56	2.90	0.60	101.87	2.61	43.50	1.88	240.42	139.34
73	0.449	74.17	80.31	6.07	0.66	95.08	2.55	42.38	1.96	186.25	65.00
74	0.362	73.07	76.39	3.52	0.51	97.03	2.82	49.25	1.89	201.10	58.66
75	0.464	76.50	81.61	4.73	0.66	97.27	2.11	45.13	2.31	238.70	38.99
76	0.737	73.75	77.34	3.95	0.56	118.59	2.24	44.27	1.90	238.83	117.81
77	1.123	74.93	78.91	4.00	0.59	116.91	2.09	50.02	1.81	242.30	120.92
78	0.551	76.14	77.92	2.49	0.52	90.47	1.75	46.91	2.85	211.53	213.87
79	1.281	77.29	78.53	1.96	0.84	110.36	1.59	39.42	1.35	186.26	187.22
80	0.855	77.60	79.74	1.92	0.74	91.55	1.90	43.76	2.10	211.31	162.28
81	0.708	76.56	80.92	3.91	0.70	84.85	2.33	41.42	1.79	183.40	128.52
82	0.435	75.83	81.45	5.17	0.92	72.22	2.00	58.10	2.43	182.65	129.46
83	0.659	75.26	78.63	3.13	0.73	102.53	1.42	47.50	1.92	188.83	134.45
84	0.831	76.84	78.38	1.98	0.81	109.51	2.14	35.29	2.27	192.27	189.56
85	1.019	75.75	79.89	3.20	0.71	110.57	2.14	47.21	2.32	234.67	141.73
86	1.167	75.22	75.74	1.39	0.58	99.75	2.18	35.43	1.94	233.48	138.87
87	1.168	72.93	76.11	2.89	0.71	105.55	2.45	46.82	1.83	216.43	133.55
88	0.472	75.82	79.66	3.51	0.66	110.99	2.17	40.12	2.24	159.04	98.61
89	0.941	75.81	82.78	6.94	0.51	106.40	1.98	41.38	2.04	239.07	164.99
90	1.194	73.48	76.64	2.55	0.83	98.34	2.18	41.35	1.83	187.65	169.86
91	0.953	72.40	81.86	7.79	0.68	98.64	2.39	49.99	1.93	173.90	155.99
92	0.973	73.92	76.17	2.12	0.71	108.32	2.12	35.08	2.30	197.21	156.45

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT KABWE UNDER LOW N

ENTRY	GY t/ha	AD °d	SD cm	ASI cm	EPP %	PH #	HT 1-5	SENESC 1-10	TEXT 1-5	SKW %	KERNELS PER EAR
93	0.851	76.30	83.66	6.98	0.59	108.58	1.86	42.12	1.84	217.61	151.28
94	0.358	76.43	80.49	3.90	0.69	110.99	1.83	39.25	2.16	237.13	77.87
95	0.868	77.09	82.22	3.65	0.57	86.43	2.52	43.93	2.07	261.95	81.93
96	0.026	76.56	81.73	4.59	0.21	103.10	2.36	40.94	2.15	150.07	82.25
97	0.176	76.74	80.75	3.61	0.48	79.17	1.98	47.24	1.98	191.86	92.26
98	0.993	77.32	84.90	7.51	0.52	106.61	2.01	45.36	1.76	216.44	108.44
99	0.291	79.20	88.10	9.59	0.67	92.85	1.62	47.96	2.29	200.65	91.07
100	0.608	74.34	77.85	3.93	0.71	104.11	1.87	39.14	2.36	248.43	134.16
101	0.811	74.39	82.09	7.44	0.68	130.90	1.57	35.35	2.65	278.26	132.05
102	0.810	74.79	78.95	4.89	0.44	106.81	1.54	52.08	2.10	249.01	104.46
103	0.445	79.29	80.45	3.38	0.67	81.13	2.32	52.64	2.02	230.79	181.50
104	0.541	75.98	84.13	8.31	0.37	90.89	2.13	49.79	2.65	265.97	111.46
105	0.622	79.35	85.40	6.89	0.45	108.71	1.92	47.06	1.51	265.31	56.19
106	0.949	76.04	83.46	6.56	0.65	81.80	1.92	42.13	2.40	279.48	186.26
107	0.512	77.88	81.37	4.54	0.55	83.48	2.18	45.85	2.02	252.75	65.15
108	0.498	77.59	84.65	5.63	0.76	104.20	1.98	47.56	2.09	194.91	95.59
109	1.216	76.97	82.60	6.33	0.71	98.06	1.96	37.62	2.57	200.15	156.88
110	0.695	81.00	89.90	11.26	0.67	113.59	2.43	43.37	2.28	296.32	87.56
111	0.791	73.92	79.74	4.15	0.64	97.43	2.13	40.34	1.91	211.10	112.37
112	1.061	74.04	80.06	4.68	0.75	86.99	3.00	43.67	2.08	227.59	162.88
113	0.513	72.51	78.04	5.52	0.48	90.46	2.87	34.94	1.98	208.40	49.35
114	0.855	73.98	78.48	3.26	0.89	94.28	2.02	38.49	2.13	226.04	88.67
Mean	**0.78**	**75.09**	**79.88**	**4.83**	**0.67**	**98.94**	**2.16**	**43.70**	**2.09**	**206.67**	**128.35**
LSD	**0.83**	**3.59**	**6.65**	**5.65**	**0.36**	**32.47**	**0.84**	**14.95**	**0.75**	**54.64**	**106.31**
MSE	**0.13**	**5.62**	**16.01**	**8.09**	**0.06**	**236.38**	**0.24**	**77.22**	**0.15**	**711.83**	**3988.71**
CV	**54.**	**2.**	**4.**	**59.**	**27.**	**17.**	**20.**	**17.**	**18.**	**13.**	**42.**
P	**0.232**	**0.000**	**0.004**	**0.361**	**0.011**	**0.146**	**0.096**	**0.203**	**0.000**	**0.000**	**0.164**
Min	**0.03**	**68.99**	**74.59**	**1.39**	**0.21**	**62.86**	**1.25**	**34.28**	**1.35**	**131.44**	**38.99**
Max	**1.59**	**81.00**	**89.90**	**11.26**	**0.99**	**130.90**	**3.00**	**62.09**	**3.25**	**296.32**	**225.08**

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT MPOUNT MAKULU

UNDER HIGH N

ENTRY	GY t/ha	AD d	SD cm	ASI cm	EPP %	PH #	GLS 1-5	HT 1-5	SENESC 1-5	SKW %	KERNELS PER EAR
1	5.035	75.40	77.50	2.00	1.00	185.78	1.30	1.06	44.77	291.71	408.88
2	4.741	72.47	73.52	1.06	1.00	184.40	1.39	1.15	39.98	367.15	383.24
3	8.182	71.41	72.97	1.44	1.00	179.26	0.98	1.95	49.56	311.83	456.89
4	6.302	75.53	77.42	1.93	1.00	186.30	1.74	1.80	38.26	339.83	441.97
5	5.895	74.97	76.93	2.14	1.00	168.59	1.16	1.68	48.67	302.51	459.10
6	6.093	74.96	76.41	1.44	1.00	176.86	1.66	1.37	47.66	316.41	447.27
7	6.048	71.76	73.46	1.44	1.00	183.76	1.53	1.60	38.28	326.83	469.16
8	6.146	71.09	72.56	1.43	1.00	177.38	1.50	1.24	56.73	313.34	481.13
9	6.633	70.92	72.51	1.57	1.00	178.16	1.06	1.81	40.81	310.81	491.98
10	4.100	73.50	75.50	2.03	1.00	190.41	1.24	2.22	47.07	319.88	507.03
11	5.609	72.46	74.51	1.94	1.00	209.44	1.71	1.06	59.95	331.02	397.60
12	6.236	74.01	76.00	2.03	1.00	189.73	1.71	1.32	41.91	301.56	469.18
13	6.911	74.61	76.57	2.13	1.00	183.38	1.74	1.14	36.80	316.56	501.78
14	6.475	74.59	76.62	1.93	1.05	185.35	1.60	1.12	41.89	306.12	433.27
15	5.300	75.42	76.99	1.54	0.94	174.55	2.03	0.84	43.34	345.93	436.19
16	6.393	73.01	74.52	1.50	1.00	185.69	2.23	0.97	56.45	298.56	503.13
17	6.403	73.57	74.87	1.53	1.00	182.76	1.45	1.55	29.07	329.04	441.99
18	5.985	73.99	75.93	2.01	0.95	213.16	1.57	2.33	48.36	306.34	423.41
19	7.214	70.85	72.50	1.58	1.00	177.10	1.46	1.69	38.71	318.89	500.04
20	3.737	71.90	73.99	2.07	1.00	176.00	0.97	2.76	62.38	278.60	406.97
21	3.172	76.96	78.49	1.67	1.05	172.85	1.00	2.33	40.40	271.26	406.88
22	5.988	74.54	76.48	2.02	1.00	197.14	1.07	2.59	48.22	326.37	406.92
23	5.400	70.94	72.97	2.00	1.00	166.77	1.79	1.43	67.00	305.44	438.66
24	5.920	78.48	80.55	2.13	1.00	180.01	1.05	2.81	47.87	284.10	504.44
25	3.886	71.95	73.93	2.04	0.99	188.44	0.78	2.44	47.72	273.41	422.80
26	4.756	73.11	74.07	0.96	1.00	166.74	0.81	1.95	59.41	287.10	401.94
27	5.748	76.00	78.03	1.94	1.01	197.66	1.01	2.54	41.40	335.24	422.99
28	5.002	72.94	74.93	2.07	0.96	206.52	2.28	1.34	54.20	322.37	430.58
29	5.951	72.05	74.00	1.89	1.05	177.28	1.38	2.03	38.55	355.09	492.24
30	5.610	73.98	75.98	2.10	0.95	193.38	2.78	1.77	52.47	329.83	451.27
31	7.121	73.55	75.00	1.40	1.00	186.13	1.88	0.94	41.49	321.87	500.12
32	5.770	75.00	77.01	2.01	1.00	180.19	1.51	1.14	52.13	293.06	462.93
33	7.347	74.65	76.56	1.95	1.00	178.25	2.29	1.92	41.47	290.16	508.38
34	6.451	74.48	76.44	2.03	1.00	177.25	2.68	1.04	44.12	323.17	560.01
35	7.144	72.12	73.95	1.87	1.00	180.55	1.93	1.18	39.61	303.18	529.08
36	5.519	76.54	77.95	1.66	1.00	170.39	0.95	1.69	36.85	303.53	406.69
37	7.814	74.05	75.54	1.58	1.00	158.78	2.42	2.49	38.77	313.21	571.21
38	4.723	73.52	75.53	1.91	1.05	182.76	0.91	0.94	79.75	292.51	430.95
39	4.630	72.55	74.05	1.52	1.00	146.47	0.97	1.01	31.49	318.24	348.05
40	4.963	72.06	74.05	2.00	1.00	159.85	1.00	1.68	68.35	291.68	356.70
41	5.435	71.07	73.07	1.93	1.00	175.99	1.43	1.27	62.90	267.78	462.57
42	5.216	74.35	76.44	2.07	0.95	170.82	1.10	1.24	45.59	275.43	483.63
43	4.670	72.01	73.54	1.60	1.00	167.25	0.91	1.58	66.50	255.52	511.05
44	3.769	71.00	72.94	1.92	1.00	170.59	1.06	1.14	54.29	283.48	568.84
45	5.263	72.13	74.07	1.87	0.95	160.66	0.90	1.25	56.06	332.92	410.66
46	5.427	72.07	73.56	1.45	1.01	177.02	0.86	1.53	37.76	302.58	445.80

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT MPOUNT MAKULU UNDER HIGH N

ENTRY	GY t/ha	AD d	SD cm	ASI cm	EPP %	PH #	GLS 1-5	HT 1-5	SENESC 1-5	SKW %	KERNELS PER EAR
47	6.992	72.47	73.59	0.87	1.00	178.27	1.12	1.69	42.74	305.40	477.64
48	5.394	74.05	76.00	1.97	1.00	183.36	2.28	0.98	48.83	296.28	415.16
49	5.185	72.07	73.52	1.51	0.95	174.52	0.92	1.56	39.73	328.60	406.81
50	7.115	72.95	74.93	1.94	1.10	188.08	0.96	1.21	35.37	384.88	427.32
51	6.703	73.98	75.97	2.06	1.00	187.10	1.08	1.64	35.61	310.82	681.73
52	6.566	76.77	78.96	2.02	1.00	168.85	1.05	2.04	54.04	287.46	506.42
53	7.666	74.34	76.33	2.03	1.00	179.87	1.48	0.87	29.91	313.19	491.66
54	5.421	74.92	76.43	1.67	1.00	175.00	1.22	1.14	59.72	259.22	478.43
55	6.124	72.05	74.12	2.03	1.00	170.16	1.19	1.67	33.25	360.95	413.73
56	6.401	75.48	77.07	1.38	0.99	183.46	2.30	1.33	42.49	334.85	455.61
57	6.002	75.90	78.07	2.03	1.05	185.43	1.43	1.32	38.85	283.87	540.39
58	5.500	72.46	74.51	2.08	1.00	186.90	1.29	1.29	49.23	282.45	426.21
59	5.327	71.91	73.48	1.33	1.01	185.81	0.99	1.43	56.31	286.84	391.74
60	7.477	72.12	73.51	1.43	1.00	141.09	1.17	1.25	59.09	290.36	513.73
61	5.812	76.56	78.57	1.89	0.95	179.68	1.53	1.04	59.99	253.77	553.97
62	4.392	78.00	80.04	1.96	1.00	175.43	1.11	1.38	39.86	289.33	469.83
63	4.829	74.57	76.03	1.57	1.15	183.38	1.40	1.18	33.84	354.48	328.38
64	7.291	71.77	73.92	2.02	0.95	195.98	1.30	1.00	46.54	324.07	550.44
65	6.250	71.93	73.53	1.47	1.00	197.08	1.01	1.90	38.85	326.72	479.24
66	7.445	73.07	75.03	2.03	1.05	212.66	0.84	2.27	40.40	406.35	440.93
67	7.673	72.53	74.51	2.02	1.00	207.24	1.30	1.59	48.89	323.77	483.04
68	5.551	75.08	77.06	2.06	0.95	171.09	1.00	1.37	38.28	298.61	452.39
69	5.000	73.07	74.52	1.60	1.00	184.09	1.20	1.42	45.91	320.09	392.45
70	6.101	71.88	73.52	1.59	1.00	208.57	1.18	1.60	52.61	302.78	483.17
71	2.838	75.87	77.45	1.42	1.00	188.82	1.53	2.16	52.99	256.11	380.02
72	5.291	75.10	77.07	2.04	0.95	186.03	0.93	2.10	42.91	276.29	521.82
73	7.271	74.51	76.57	1.92	1.00	195.57	1.06	2.21	45.12	330.10	421.41
74	7.044	72.88	74.41	1.58	1.00	183.80	0.84	1.75	39.96	328.06	482.90
75	6.630	73.91	75.99	2.01	1.00	194.12	0.98	2.40	44.52	314.79	503.78
76	10.234	72.43	74.49	2.10	1.00	241.55	2.04	1.62	60.28	379.34	553.38
77	6.373	72.96	74.04	1.08	1.00	198.27	2.03	1.32	37.92	319.69	446.03
78	5.931	72.48	74.43	2.05	1.05	185.77	1.45	1.39	23.71	345.97	457.99
79	5.829	75.91	77.90	1.98	1.00	169.27	1.26	1.25	44.81	267.50	526.22
80	6.119	74.91	76.98	1.97	1.00	187.66	1.08	1.24	42.23	335.01	455.41
81	4.674	77.46	79.00	1.61	1.06	171.17	1.53	0.85	44.85	259.16	494.86
82	6.392	78.99	80.15	1.57	1.00	167.58	1.44	1.26	35.30	288.74	467.03
83	7.079	72.85	75.00	1.91	1.01	182.34	1.26	1.10	38.90	262.78	578.75
84	6.352	73.37	75.44	2.02	1.01	184.64	1.18	1.10	21.76	311.38	479.51
85	6.994	76.60	78.52	1.91	1.00	209.11	1.78	1.17	30.92	328.71	475.85
86	4.816	73.79	75.46	1.54	1.05	206.47	1.63	1.08	54.19	324.20	395.36
87	5.737	71.09	72.96	1.85	0.99	180.21	2.06	1.26	37.74	346.82	481.90
88	5.956	72.47	73.53	1.07	1.05	191.06	0.99	1.68	64.46	233.59	532.46
89	5.477	73.07	75.00	1.94	1.00	182.66	1.51	1.15	38.71	282.08	501.44
90	5.599	73.48	75.48	1.89	1.05	183.32	2.10	1.19	37.72	402.62	371.23
91	2.253	76.57	78.02	1.44	1.00	181.77	1.22	1.21	48.78	310.41	338.99
92	6.286	75.00	76.99	1.98	1.00	186.66	0.99	1.29	45.97	331.05	446.41

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT MPOUNT MAKULU UNDER HIGH N

ENTRY	GY t/ha	AD d	SD cm	ASI cm	EPP %	PH #	GLS 1-5	HT 1-5	SENESC 1-5	SKW %	KERNELS PER EAR
93	4.215	77.54	79.18	1.37	1.00	194.40	1.44	1.89	33.20	362.87	361.80
94	7.441	74.47	76.06	1.52	1.00	211.85	1.69	1.16	47.13	322.93	515.05
95	4.038	78.70	80.49	1.97	0.99	161.21	1.16	1.24	40.81	286.45	359.17
96	4.658	77.03	78.95	2.12	1.00	179.36	1.31	1.44	29.05	305.86	498.54
97	6.328	76.02	78.03	2.00	1.00	177.28	1.42	1.79	31.90	351.66	404.64
98	5.779	78.94	80.55	1.53	1.00	180.42	1.05	1.45	32.22	278.14	421.61
99	3.216	77.90	79.44	1.43	1.15	165.35	1.24	0.98	44.65	294.55	429.54
100	6.429	76.08	78.01	1.94	0.99	198.43	1.84	2.12	27.71	292.58	485.99
101	6.960	73.48	75.46	2.00	1.00	209.93	2.39	1.49	47.15	365.75	404.89
102	6.634	73.09	75.02	2.03	1.00	202.32	1.53	1.22	33.28	376.35	426.23
103	6.703	72.69	74.08	1.39	1.00	208.03	1.24	1.61	25.28	381.79	387.21
104	6.551	78.49	79.54	1.05	1.00	193.38	1.21	1.38	36.69	302.09	453.68
105	6.714	74.48	76.46	2.04	1.00	194.26	1.46	1.06	42.33	309.65	479.22
106	8.026	76.68	78.06	1.44	1.00	177.27	1.27	1.18	35.39	344.09	445.25
107	5.804	73.82	75.61	2.01	0.99	189.51	1.24	1.83	36.57	360.01	516.92
108	7.383	74.03	75.99	1.95	1.00	194.19	1.29	0.96	37.17	380.51	437.92
109	8.140	71.95	73.48	1.56	1.00	194.82	1.25	1.48	38.04	332.15	503.11
110	5.488	74.94	77.49	2.61	1.00	216.40	1.51	1.66	28.47	345.83	467.32
111	7.009	72.92	75.01	1.97	1.00	204.70	1.56	1.48	43.82	291.90	551.67
112	4.408	72.12	74.01	1.90	1.00	200.49	1.18	1.62	51.61	314.01	344.61
113	5.773	73.07	74.98	1.96	1.00	207.12	1.77	1.11	34.04	284.42	482.26
114	5.626	75.03	75.91	0.91	1.00	192.40	1.05	2.74	34.37	332.89	342.08
Mean	**5.92**	**74.01**	**75.79**	**1.78**	**1.00**	**185.02**	**1.40**	**1.52**	**44.04**	**313.75**	**458.66**
LSD	**2.61**	**1.03**	**1.21**	**0.82**	**0.09**	**27.99**	**0.96**	**0.81**	**26.98**	**69.66**	**154.37**
MSE	**1.71**	**0.29**	**0.38**	**0.18**	**0.00**	**198.59**	**0.25**	**0.21**	**264.56**	**1375.0**	**6667.18**
CV	**22.25.**	**0.70.**	**0.81.**	**23.35.**	**4.35.**	**7.64.**	**34.69.**	**26.95.**	**30.93.**	**11.21.**	**16.99.**
P	**0.000**	**0.000**	**0.000**	**0.167**	**0.479**	**0.000**	**0.003**	**0.000**	**0.076**	**0.002**	**0.082**
Min	**2.25**	**70.85**	**72.50**	**0.87**	**0.94**	**141.09**	**0.78**	**0.84**	**21.76**	**233.59**	**328.38**
Max	**10.23**	**78.99**	**80.55**	**2.61**	**1.15**	**241.55**	**2.78**	**2.81**	**79.75**	**406.35**	**681.73**

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT ART FARMS UNDER HIGH N

ENTRY	GY	AD	SD	ASI	EPP	PH	HT	RUST
	t/ha	d	d	cm	%	%	%	1-5
1	8.702	73.90	75.33	1.47	1.11	267.44	1.11	2.26
2	5.591	72.00	72.02	-0.04	0.85	258.54	0.93	2.33
3	5.201	73.39	74.89	1.53	1.04	206.01	1.58	2.37
4	8.773	74.70	75.11	0.50	0.99	230.11	1.48	1.39
5	10.098	74.22	75.20	1.02	1.07	242.79	1.48	1.50
6	6.854	74.87	77.05	2.00	0.91	212.39	1.05	2.06
7	7.963	73.67	75.03	1.49	1.01	240.59	1.46	2.56
8	10.165	72.87	73.93	1.02	1.13	222.47	1.14	1.27
9	8.218	74.36	74.80	0.49	0.97	248.50	1.52	2.04
10	10.234	74.85	76.56	1.52	0.96	236.56	1.29	2.05
11	7.701	74.30	75.67	1.48	1.10	249.74	1.62	2.40
12	7.047	74.16	76.13	2.02	0.99	249.04	1.46	1.38
13	7.553	73.75	75.48	1.48	1.11	253.53	1.05	2.35
14	11.121	74.60	75.03	0.49	0.93	247.16	2.10	3.17
15	8.468	74.57	76.60	2.00	0.96	223.16	0.92	2.65
16	10.376	73.86	75.52	1.50	1.01	243.93	0.93	1.97
17	7.383	75.48	76.60	1.02	0.86	241.20	1.43	2.49
18	7.430	74.14	75.77	1.49	1.21	262.82	1.13	0.98
19	8.074	71.47	73.36	1.98	0.97	220.45	1.03	1.05
20	8.266	72.91	74.48	1.49	1.02	229.92	1.01	1.14
21	9.673	73.73	77.89	4.01	1.09	243.52	1.02	1.13
22	9.164	74.42	75.48	0.98	1.00	243.87	1.62	1.99
23	8.898	74.85	76.52	1.53	0.93	255.28	1.50	1.11
24	11.891	75.18	77.49	2.48	1.22	240.69	0.89	0.97
25	10.006	74.59	75.21	0.54	0.96	236.89	1.63	1.93
26	9.104	75.78	75.52	-0.06	1.03	240.08	2.01	0.94
27	12.078	76.75	77.66	1.01	1.18	251.34	1.15	0.79
28	10.201	74.50	76.07	1.51	1.14	277.97	1.56	2.05
29	7.750	71.86	73.63	1.54	0.92	243.27	1.41	1.08
30	9.100	75.12	76.15	1.01	0.91	272.66	0.93	1.47
31	11.359	75.21	76.07	1.00	1.06	244.63	0.95	0.99
32	11.603	75.77	76.79	1.02	1.10	230.89	0.91	1.05
33	10.556	74.12	75.92	1.99	1.11	229.30	1.53	0.83
34	8.777	75.36	76.19	0.55	0.97	234.17	1.00	1.63
35	10.554	74.30	74.88	0.49	0.96	236.08	1.96	1.08
36	7.067	75.20	76.14	1.03	1.13	243.59	1.12	1.55
37	10.704	77.60	78.58	1.02	1.07	263.00	1.45	0.94
38	9.195	73.12	73.42	0.49	1.19	241.21	1.58	1.99
39	5.949	69.49	71.21	1.52	1.11	214.70	1.44	1.97
40	7.458	70.67	72.64	2.03	1.03	205.68	1.13	1.74
41	9.923	73.71	75.53	2.00	1.11	227.99	0.93	2.05
42	9.998	72.45	74.54	2.03	1.11	242.73	0.94	2.10
43	10.016	74.59	75.64	1.03	1.09	231.34	1.43	2.11
44	9.111	73.72	74.60	0.99	0.99	219.11	1.02	2.45
45	9.287	72.43	73.91	1.50	1.15	222.42	1.05	2.17
46	11.656	72.27	73.87	1.51	0.93	221.99	1.52	2.12
47	11.251	74.66	76.13	1.53	0.99	249.56	1.40	2.53
48	8.982	76.73	77.25	0.46	0.97	258.43	0.87	0.90

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT ART FARMS UNDER HIGH N

ENTRY								
50	11.114	74.17	75.51	1.53	1.04	251.61	1.48	0.91
51	8.909	74.58	74.92	0.47	1.00	263.71	1.04	0.94
52	9.732	73.62	74.20	0.50	1.08	233.91	1.49	1.37
53	10.013	74.38	74.98	0.52	0.96	254.08	1.98	2.07
54	9.569	72.68	73.09	0.52	0.97	235.16	0.93	0.97
55	8.286	74.83	78.02	2.98	1.10	228.19	0.92	1.02
56	12.969	75.92	77.42	1.46	0.92	248.41	1.48	1.15
57	7.059	72.68	73.64	1.00	1.17	267.18	0.96	2.67
58	9.105	71.29	72.56	1.01	0.96	238.03	1.09	2.89
59	6.520	72.26	73.31	1.00	1.09	250.48	1.05	2.61
60	10.659	74.62	75.08	0.50	1.05	247.46	1.00	2.46
61	10.536	74.24	75.76	1.45	1.16	247.94	1.09	2.62
62	10.624	74.38	75.86	1.49	1.02	231.34	1.03	2.55
63	6.953	74.63	76.63	2.00	1.28	256.80	1.09	2.07
64	8.477	73.83	74.86	0.99	1.10	243.61	1.02	2.58
65	7.883	75.62	76.41	0.99	1.23	246.43	1.03	1.84
66	11.491	74.95	76.36	1.51	1.25	256.43	1.12	1.74
67	8.163	74.89	76.40	1.49	0.86	266.39	1.45	2.58
68	10.202	73.15	72.39	-0.52	1.02	250.42	1.08	2.56
69	7.260	74.48	75.51	1.01	0.83	234.33	0.89	3.15
70	9.696	76.03	77.87	1.94	1.12	262.35	1.07	2.52
71	6.977	75.64	77.99	2.48	0.82	260.51	1.12	2.58
72	8.266	75.97	78.07	2.05	0.92	265.18	0.91	2.48
73	10.122	75.80	76.59	0.97	1.04	252.89	1.60	3.00
74	6.500	75.63	76.61	1.01	1.25	271.26	1.42	3.09
75	10.175	75.14	76.24	1.01	1.06	254.98	1.52	2.47
76	9.346	79.16	79.88	0.58	1.03	271.36	1.96	0.89
77	10.601	76.12	76.02	0.05	1.13	268.11	0.90	2.62
78	9.978	72.41	71.86	-0.52	1.01	245.37	0.85	3.13
79	10.922	76.80	78.04	1.06	1.02	250.78	1.03	2.04
80	9.511	75.14	77.01	2.02	1.02	242.04	1.04	2.07
81	8.151	76.83	76.99	0.00	0.95	245.68	0.97	2.93
82	8.500	75.08	76.60	1.52	1.06	239.28	0.92	3.12
83	10.452	74.66	75.08	0.49	1.09	227.74	0.93	3.43
84	8.654	77.20	77.69	0.53	1.10	255.02	1.21	1.98
85	13.676	76.96	77.92	0.97	1.26	259.35	1.50	0.85
86	13.241	73.96	75.34	1.50	1.26	270.51	1.52	2.01
87	6.715	72.46	74.39	1.96	1.12	232.97	0.90	2.54
88	7.276	73.70	75.11	1.51	0.94	224.59	1.10	1.90
89	9.133	75.21	75.98	0.97	0.93	246.07	0.98	2.42
90	10.332	74.89	75.88	1.00	1.05	225.79	0.85	2.51
91	9.235	74.16	75.07	0.99	0.96	239.44	1.52	3.11
92	8.268	76.21	76.96	0.96	1.07	239.66	1.43	2.05
93	10.029	78.21	79.79	1.48	1.05	252.56	1.46	1.03
94	10.041	76.30	77.05	0.53	1.25	285.90	1.32	2.17
95	9.254	77.01	77.56	0.51	1.18	250.23	1.07	1.95
96	8.196	75.86	77.69	1.90	1.07	238.40	1.08	1.90
97	6.268	76.91	78.44	1.53	0.95	217.01	1.08	1.80
98	7.880	76.45	77.35	0.98	1.07	228.94	1.05	1.90

APPENDIX J. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT ART FARMS UNDER HIGH N

ENTRY								
99	9.960	76.81	77.64	0.98	1.11	240.78	0.94	1.95
100	9.880	75.75	76.43	0.49	1.16	259.77	1.48	2.08
101	7.606	75.47	76.06	0.51	1.12	259.50	0.91	2.05
102	12.964	74.75	75.51	0.53	1.00	257.09	1.06	2.62
103	7.516	74.04	75.55	1.49	1.04	222.70	1.45	2.01
104	8.602	76.86	78.45	1.50	1.03	244.08	0.99	2.51
105	8.336	76.93	77.94	1.02	1.00	244.94	1.07	2.48
106	9.436	77.75	78.27	0.45	1.04	237.95	1.02	3.60
107	6.694	76.02	78.06	2.03	1.02	245.95	1.11	3.05
108	9.708	76.15	76.66	0.52	1.02	236.28	1.09	3.52
109	8.608	75.90	74.83	-1.02	0.84	252.51	1.09	1.87
110	12.565	77.52	79.12	1.53	1.04	271.64	0.99	1.43
111	7.012	74.25	76.51	2.47	1.08	272.46	1.44	1.89
112	7.274	74.56	75.55	1.01	0.93	258.78	0.88	2.64
113	8.152	74.63	76.08	1.48	0.90	255.83	1.05	1.37
114	5.779	74.49	75.52	1.01	0.80	260.88	1.04	2.15
Mean	**9.10**	**74.71**	**75.88**	**1.17**	**1.04**	**245.15**	**1.21**	**2.00**
LSD	**3.41**	**1.90**	**2.46**	**1.92**	**0.24**	**25.18**	**0.78**	**0.97**
MSE	**3.07**	**0.80**	**1.44**	**0.94**	**0.02**	**134.74**	**0.15**	**0.25**
CV	**19.**	**1.**	**2.**	**83.**	**11.**	**5.**	**32.**	**24.**
P	**0.000**	**0.000**	**0.000**	**0.342**	**0.007**	**0.000**	**0.178**	**0.000**
Min	**5.20**	**69.49**	**71.21**	**-1.02**	**0.80**	**205.68**	**0.85**	**0.79**
Max	**13.68**	**79.16**	**79.88**	**4.01**	**1.28**	**285.90**	**2.10**	**3.60**

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT CIMMYT HARARE UNDER LOW N

ENTRY	GY	AD	SD	ASI	EPP	PH	SENESC	SKW	KERNELS PER EAR
1	3.488	70.62	73.58	2.96	1.00	197.10	67.09	258.07	310.49
2	1.890	75.03	76.89	1.99	0.87	191.71	71.57	233.07	247.73
3	2.175	71.48	73.63	2.44	0.82	205.58	62.04	220.28	244.85
4	2.141	77.41	78.07	0.98	0.82	197.85	61.34	270.78	226.85
5	1.267	75.29	76.58	1.52	0.50	177.31	63.79	241.15	223.49
6	1.428	77.50	79.70	1.51	0.76	181.68	60.64	233.26	229.99
7	4.118	74.78	75.20	0.93	0.96	200.48	61.90	259.36	378.71
8	3.037	70.70	73.87	3.11	0.77	182.96	60.20	257.25	258.10
9	1.492	73.46	75.43	1.44	0.60	169.32	62.66	220.47	279.96
10	3.190	74.93	74.39	-0.05	0.80	223.96	61.91	315.79	341.44
11	1.612	74.95	79.15	3.92	0.68	209.33	69.18	271.10	224.73
12	2.775	77.08	77.82	0.56	0.74	198.46	66.93	241.38	342.18
13	3.147	77.05	76.07	-0.60	0.87	181.52	62.23	249.33	330.43
14	2.064	74.75	76.71	1.54	0.76	199.03	60.35	257.72	277.04
15	2.095	73.74	75.74	1.59	0.59	211.71	60.91	287.89	252.51
16	2.537	75.57	76.65	1.50	0.80	184.98	56.30	276.47	259.47
17	2.393	75.69	75.85	0.45	0.66	189.17	61.94	256.52	337.26
18	2.821	74.14	76.75	2.51	0.85	212.08	63.61	244.64	253.51
19	1.801	72.38	74.01	1.50	0.65	244.29	68.13	247.30	271.25
20	2.196	71.02	73.50	3.06	0.92	188.21	70.65	256.11	286.18
21	1.768	75.61	78.69	3.01	0.85	209.57	63.37	223.13	222.91
22	2.465	75.79	78.13	2.03	0.73	212.34	73.74	228.85	271.88
23	1.397	74.92	76.19	1.88	0.85	197.70	66.61	244.79	158.39
24	3.060	74.96	76.62	1.99	0.85	210.76	64.99	224.81	343.81
25	2.287	77.40	79.91	2.98	0.62	212.71	63.70	252.18	292.39
26	1.964	76.80	79.89	2.56	0.60	205.83	66.18	217.47	288.01
27	1.662	76.98	79.33	2.44	0.80	192.67	59.42	271.77	170.95
28	2.254	74.42	77.06	2.48	0.53	222.79	66.69	226.19	333.21
29	1.832	76.26	78.60	2.49	0.70	190.85	72.45	198.42	412.32
30	2.836	75.67	76.27	1.50	0.73	215.06	68.92	302.34	288.63
31	2.190	73.65	76.74	2.95	0.61	195.09	68.47	227.72	284.43
32	2.187	72.92	75.83	2.65	0.46	192.97	64.53	234.75	320.06
33	3.452	76.60	79.23	2.06	0.83	193.19	58.85	248.43	408.75
34	2.634	80.27	81.30	1.15	0.62	176.15	64.24	233.27	337.44
35	2.408	73.68	74.67	1.00	0.66	194.39	66.99	260.70	291.71
36	2.930	77.62	78.27	0.97	0.92	192.29	62.87	223.86	321.50
37	3.409	74.53	75.76	1.55	0.73	209.41	58.48	287.70	399.59
38	2.010	75.32	75.74	0.47	0.73	208.51	61.56	252.25	202.72
39	2.307	75.35	78.61	3.08	0.79	187.62	65.51	241.71	278.54
40	1.906	71.69	73.63	2.51	1.00	155.35	66.73	238.96	190.62
41	3.785	78.53	81.14	2.58	0.85	195.02	66.46	216.59	479.35
42	2.720	73.75	75.45	1.10	0.88	202.86	62.44	266.49	332.54
43	2.463	76.74	79.48	2.08	0.91	182.86	57.48	221.31	278.24
44	4.231	74.25	74.87	1.35	0.81	208.90	61.92	261.92	524.40
45	1.965	71.54	73.28	1.03	0.85	175.30	65.29	241.06	243.20
46	1.550	77.91	82.95	4.09	0.68	180.17	62.81	224.49	210.56
47	2.412	74.56	75.50	1.05	0.76	186.96	61.78	259.19	267.40
48	2.789	76.21	78.47	1.55	0.97	215.35	67.36	265.79	272.41
49	2.642	75.80	78.40	2.49	1.02	217.58	73.56	238.03	230.84
50	2.096	75.49	77.37	1.52	0.77	201.69	67.90	244.36	225.88
51	2.299	76.29	77.75	1.50	0.77	194.27	70.16	249.33	218.51
52	2.607	75.02	77.40	2.41	0.66	193.79	65.75	252.41	244.68
53	3.630	73.93	78.14	4.44	0.68	212.14	65.30	244.84	477.10
54	2.239	75.70	74.56	-1.19	0.77	208.04	68.57	255.56	296.08
55	2.289	73.79	76.81	2.47	0.67	208.91	70.49	217.34	319.45
56	3.148	76.76	80.51	3.08	0.77	232.04	62.58	318.38	279.48

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT CIMMYT HARARE UNDER LOW N

ENTRY	GY	AD	SD	ASI	EPP	PH	SENESC	SKW	KERNELS PER EAR
57	2.279	75.76	77.30	1.51	0.77	207.09	59.59	260.09	301.58
58	2.669	73.66	75.49	2.00	0.95	201.31	64.08	263.30	223.49
59	2.485	79.12	82.03	2.06	0.87	202.78	60.47	253.64	359.03
60	2.118	77.98	78.71	1.01	0.66	190.35	62.24	248.15	293.16
61	2.854	75.69	77.44	1.98	0.93	183.81	65.26	224.46	305.72
62	2.190	78.83	80.65	2.55	0.73	196.80	63.78	257.42	333.47
63	3.202	77.29	79.52	2.41	0.72	213.21	61.51	275.65	417.28
64	1.798	76.42	78.03	1.51	0.75	226.04	65.99	271.01	215.30
65	2.175	77.25	78.19	0.97	0.58	198.38	68.64	222.09	296.76
66	3.174	77.35	79.62	2.46	0.60	236.51	62.81	326.54	345.79
67	3.174	72.79	76.62	3.92	0.88	239.14	70.53	284.94	265.10
68	1.792	76.45	78.24	1.51	0.64	179.33	66.97	281.61	188.13
69	2.017	77.57	79.15	1.93	0.80	199.59	67.61	260.53	258.45
70	2.551	75.34	77.94	1.97	0.94	209.24	66.82	258.76	189.49
71	2.552	78.07	80.34	1.56	0.67	201.15	59.89	289.66	290.77
72	3.207	72.68	74.87	1.51	0.70	213.34	65.59	283.66	327.08
73	2.365	78.59	79.57	1.02	0.75	211.17	63.55	251.77	231.97
74	2.133	79.97	80.83	1.11	0.93	223.27	59.92	260.12	221.44
75	1.941	78.00	80.57	2.02	0.65	203.57	59.99	295.35	203.10
76	3.674	76.54	78.93	1.52	0.92	216.91	63.25	295.08	289.80
77	2.971	78.09	81.35	3.05	0.88	206.19	68.78	274.16	278.46
78	1.662	71.53	73.51	1.96	1.25	199.16	71.56	249.69	200.13
79	2.657	73.88	76.11	2.52	0.83	199.88	68.22	253.41	305.19
80	2.215	79.09	80.24	0.99	0.87	208.63	63.71	243.76	213.00
81	3.674	77.82	78.86	1.91	0.79	199.84	64.17	249.28	362.72
82	2.938	77.49	78.82	1.03	0.68	175.26	61.00	261.26	363.30
83	1.982	73.77	76.69	2.65	0.47	181.51	56.38	281.69	267.95
84	3.120	77.98	80.20	2.48	0.79	182.60	64.39	207.28	367.33
85	3.847	77.61	79.61	2.39	0.79	221.10	60.20	273.74	471.26
86	4.129	75.69	77.08	1.08	0.74	210.95	68.59	267.45	380.59
87	2.843	73.97	73.90	1.03	0.79	190.53	67.87	248.22	276.01
88	1.652	75.77	76.48	2.03	0.50	191.08	65.60	266.01	295.90
89	2.406	79.76	81.70	2.01	0.69	194.63	57.78	243.62	321.81
90	2.789	77.80	80.79	3.01	0.93	197.63	59.86	255.40	242.11
91	3.204	75.20	76.41	1.90	0.71	198.12	64.76	232.30	364.07
92	2.393	78.95	81.49	2.48	0.98	226.13	61.92	239.75	275.45
93	3.819	76.88	79.46	2.54	0.96	213.27	61.74	304.09	310.64
94	3.142	78.86	81.30	3.43	0.77	238.78	66.32	265.23	323.83
95	0.606	73.33	75.35	2.08	0.49	155.60	52.37	223.51	97.85
96	1.659	81.02	82.10	1.48	0.82	192.23	65.02	222.31	160.93
97	2.364	75.80	78.12	1.50	0.80	182.32	63.43	256.33	229.85
98	2.662	75.93	78.29	2.46	0.63	189.56	58.43	267.47	309.27
99	2.991	73.15	77.67	3.99	0.75	199.72	62.63	227.56	346.71
100	1.999	76.89	78.78	1.94	0.77	190.31	65.05	271.85	206.38
101	1.432	74.18	76.86	3.01	0.75	194.18	65.44	304.73	139.91
102	2.817	77.15	79.29	2.07	0.88	195.49	63.53	267.87	239.58
103	3.676	77.77	78.33	0.48	1.01	242.22	64.66	284.43	288.04
104	1.801	78.72	79.87	1.94	0.55	208.57	65.93	255.36	264.71
105	2.546	74.03	76.72	2.46	0.74	190.41	63.78	261.77	313.90
106	2.580	78.01	79.83	2.48	0.85	206.95	64.66	305.79	247.79
107	3.286	78.90	80.42	1.98	0.86	216.74	62.30	289.98	264.87
108	2.398	74.83	77.74	2.61	0.69	187.83	63.17	276.86	269.30
109	2.665	77.12	77.63	1.07	1.02	196.60	64.80	270.97	215.47
110	3.326	80.21	81.34	0.99	0.92	230.39	58.18	347.26	281.44
111	2.262	78.56	80.49	1.96	0.83	205.76	68.41	265.05	259.16
112	1.179	72.88	76.22	2.50	0.77	200.01	64.47	305.40	154.61

APPENDIX K. MEAN VALUES OF GRAIN YIELD AND SECONDARY TRAITS AT CIMMYT HARARE UNDER LOW N

ENTRY	GY	AD	SD	ASI	EPP	PH	SENESC	SKW	KERNELS PER EAR
113	1.574	76.87	79.62	2.83	0.84	208.61	59.14	269.00	184.74
114	1.193	79.28	80.63	1.01	0.79	209.07	63.88	238.32	127.69
Mean	**2.49**	**75.92**	**77.86**	**1.95**	**0.78**	**201.13**	**64.19**	**257.07**	**281.34**
LSD	**1.97**	**5.33**	**4.91**	**2.33**	**0.29**	**27.58**	**7.28**	**45.33**	**204.26**
MSE	**0.84**	**6.13**	**6.48**	**1.33**	**0.02**	**587.93**	**33.07**	**462.82**	**10069**
CV	**40.**	**4.**	**3.**	**60.**	**19.**	**7.**	**6.**	**9.**	**37.**
P	**0.398**	**0.041**	**0.000**	**0.136**	**0.001**	**0.000**	**0.000**	**0.000**	**0.342**
Min	**0.61**	**70.62**	**73.28**	**-1.19**	**0.46**	**155.35**	**52.37**	**198.42**	**97.85**
Max	**4.23**	**81.02**	**82.95**	**4.44**	**1.25**	**244.29**	**73.74**	**347.26**	**524.40**

APPENDIX L. SPECIFIC COMBINING ABILITY (SCA) OF LINE X TESTER ACROSS ENVIRONMENT

		Across all sites											
Line	tester	GY	SD	AD	ASI	EPP	PH	SKW	KNEAR	SENESC	GLS	HT	RUST
1	x1	0.4**	0.2	0.0	0.2	0.0	1.6	-12.1*	5.2	-2.2	-0.4**	-0.2*	0.3
1	x3	-0.6**	0.2	0.1	-0.1	0.0	12.9**	-9.3	-1.5	4.8**	-0.1	0.0	0.3
1	x4	-0.1	0.1	1.0**	-0.7**	0.0	0.9	14.3**	13.9	-0.8	0.1	0.2*	-0.4
1	x5	0.1	1.2**	0.8*	0.8**	0.0	-2.7**	6.2	-23.0	0.9	0.0	0.0	-0.4
1	x6	0.0	0.4	0.1	0.0	0.0	-5.0**	4.9	-15.3	1.5	0.0	-0.1	0.0
1	x7	0.0	-0.7**	-0.4	-0.1	0.1**	2.9**	-1.3	6.0	-3.7**	0.3**	0.0	0.2
1	x8	0.5**	-0.8**	-1.2**	0.3	0.0	-7.4**	4.6	22.8	-1.0	0.3**	0.0	-0.9
1	x9	0.4**	-0.4	-0.2	-0.1	0.0	4.0**	-0.2	-3.9	0.0	-0.2	0.0	0.3
1	x12	-0.7**	-0.2	0.0	-0.4	0.0	-7.2**	-6.8	-4.0	0.4	0.1	0.1	0.7
2	x1	-0.1	0.2	0.6	-0.3	0.0	8.4**	5.1	-19.4	-1.0	-0.2	-0.1	-0.3
2	x3	0.3*	-0.3	-1.2**	0.9**	0.0	-8.4**	-2.6	16.3	-4.6**	0.4**	-0.2*	-0.3
2	x4	-0.4**	1.2**	0.6	0.7**	0.0	0.8	6.6	-1.5	-2.3	0.2	-0.1	0.1
2	x5	0.2	-1.3**	-0.3	-1.1**	0.0	2.4**	6.0	-5.3	3.6**	0.0	0.2*	0.8
2	x6	-0.1	-0.8**	-1.5**	0.7**	0.0	2.8**	-6.0	-57.7**	2.1	0.0	0.0	-0.3
2	x7	0.5**	1.4**	0.9**	0.5*	0.0	0.0	2.1	-2.3	3.0*	-0.3**	-0.1	-0.6
2	x8	-0.2	0.9**	1.1**	-0.1	-0.1**	4.0**	4.0	27.6*	-0.5	0.0	0.2*	0.4
2	x9	-0.3*	-0.9**	0.1	-1.1**	0.0	-7.0**	-4.5	23.2	1.7	0.2	0.1	-0.1
2	x12	0.0	-0.5	-0.4	-0.3	0.1**	-3.0**	-13.0**	11.2	-2.0	-0.3**	-0.1	0.2
4	x1	-0.1	0.2	0.2	-0.2	0.0	11.3**	-17.8**	17.2	3.7**	0.1	0.1	0.7
4	x3	-0.4**	0.7**	0.4	0.2	0.0	2.0*	12.7*	35.2**	-1.7	-0.1	0.4**	-0.3
4	x4	0.3*	-1.6**	-0.7*	-1.0**	0.0	3.8**	10.7*	-8.8	1.8	-0.1	-0.1	-0.1
4	x5	0.3*	-0.2	-0.5	0.4	0.0	-3.0**	-7.8	27.4*	-1.2	-0.1	-0.2*	-0.2
4	x6	0.7**	-0.9**	-0.1	-0.6**	0.0	-1.6	5.9	63.2**	-4.8**	0.2	0.0	-0.6
4	x7	-0.1	0.6*	0.3	-0.1	0.0	0.1	6.3	-51.4**	-2.8*	0.0	-0.2*	0.0
4	x8	0.1	-0.8**	-0.7*	-0.1	0.0	-0.8	0.5	-27.9*	0.2	-0.2	0.0	-0.4
4	x9	-0.6**	1.6**	1.4**	0.6**	0.0	-3.1**	3.9	-64.1**	0.4	-0.3**	-0.1	0.5
4	x12	-0.1	0.4	-0.2	0.8**	0.0	-8.8**	-14.2**	9.4	4.4**	0.4**	0.1	0.3
6	x1	-0.2	-0.3	0.3	-0.3	0.0	-1.6	-3.4	-23.4	7.1**	-0.6**	0.2*	-0.2
6	x3	-0.5**	-0.1	-0.2	0.2	0.0	-10.3**	10.2*	-41.0**	-5.1**	-0.2	0.0	-0.3
6	x4	0.4**	-0.3	0.0	-0.4	0.0	-0.9	-2.7	40.0**	-0.3	0.3**	0.1	0.1
6	x5	0.1	0.5*	-0.4	0.6**	0.1**	3.2**	4.3	-1.1	-5.3**	0.3**	-0.1	0.0
6	x6	-0.1	-0.2	0.5	-0.6**	0.0	8.2**	-13.7**	14.6	1.4	0.0	0.0	-0.2
6	x7	-0.1	-0.4	0.1	-0.4	0.0	-2.6**	5.2	42.9**	5.7**	0.1	-0.2*	-0.1
6	x8	-0.2	1.2**	0.4	0.8**	0.0	0.0	5.3	-11.7	0.4	0.1	-0.1	-0.3
6	x9	0.2	0.5*	0.2	0.5*	-0.1**	3.5**	0.1	-41.9**	-1.5	0.2	-0.1	0.1
6	x12	0.4**	-0.9**	-0.9**	-0.3	0.0	0.4	-5.3	21.9	-2.4	-0.2	0.1	0.9
7	x1	-0.2	0.3	0.6	-0.4	0.0	-6.3**	-15.5**	19.8	-2.9*	0.4**	-0.1	-0.3
7	x3	-0.2	-0.5*	0.4	-1.0**	0.1**	-0.5	-12.0*	25.5	2.0	0.0	-0.1	-0.4
7	x4	0.3*	0.1	-0.6	0.7**	0.0	7.1**	6.1	-30.9*	0.0	-0.2	0.0	0.0
7	x5	-0.1	-0.8**	0.0	-0.9**	0.0	7.5**	-2.2	22.1	2.0	-0.6**	0.2*	-0.2
7	x6	0.1	0.4	-0.4	0.6**	0.0	0.6	9.8*	-40.2**	0.6	-0.3**	0.2*	0.1
7	x7	0.5**	-0.5*	-0.9**	0.5*	0.0	5.7**	-6.1	26.2	-5.9**	-0.2	-0.1	0.6

7 x8	-0.1	-0.8**	0.7*	-1.1**	0.0	2.5**	-15.8**	26.7*	7.6**	0.3**	-0.2*	-0.4
7 x9	-0.4**	0.4	-0.8*	1.1**	0.0	-9.8**	12.8*	-33.0*	-1.2	0.2	-0.1	0.1
7 x12	0.0	1.2**	0.9**	0.4	0.0	-6.8**	23.0**	-15.9	-2.1	0.3**	0.1	0.6
8 x1	-0.3*	0.6*	0.5	-0.1	0.0	-8.6**	10.8*	10.7	-3.3*	-0.4**	-0.2*	0.2
8 x3	0.3*	0.0	-0.1	0.1	0.0	-2.3**	-4.5	-3.7	1.3	0.1	-0.1	0.4
8 x4	0.4**	-0.8**	-0.5	-0.3	0.0	-13.1**	-11.9*	19.2	2.1	-0.1	0.1	0.3
8 x5	0.3*	0.4	0.1	0.3	0.0	-0.5	-2.9	14.7	-1.8	0.0	-0.1	0.3
8 x6	0.0	0.7**	0.5	0.3	0.0	-3.2**	-14.8**	-14.6	0.1	0.1	0.0	0.0
8 x7	-0.4**	0.1	-0.3	0.4	0.0	9.8**	1.9	-33.5*	0.3	0.1	0.3**	-0.7
8 x8	-0.2	0.6*	0.5	0.1	0.0	4.1**	9.5	-7.3	-0.8	-0.1	-0.1	-0.1
8 x9	0.0	-1.0**	-0.3	-0.7**	0.0	8.4**	-7.3	41.5**	0.8	0.1	0.1	-0.3
8 x12	0.0	-0.6*	-0.3	0.0	0.0	5.4**	19.4**	-26.8*	1.3	0.1	0.0	-0.1
9 x1	0.4**	-0.1	-1.0**	1.0**	0.0	-7.8**	10.6*	10.5	-1.6	0.4**	0.2*	0.1
9 x3	0.2	0.2	0.7*	-0.4	0.0	-8.3**	-7.3	-14.2	0.1	-0.2	-0.1	0.0
9 x4	0.0	-0.3	-0.5	0.1	0.0	7.0**	-14.5**	1.3	-2.4	-0.1	-0.1	0.2
9 x5	-0.8**	1.3**	0.7*	0.6**	0.0	-3.2**	-1.8	-47.9**	3.1*	0.2	-0.1	0.1
9 x6	-0.2	-0.7**	-0.7*	0.1	-0.1**	4.6**	-4.1	50.2**	-1.2	-0.3**	-0.1	-0.1
9 x7	0.0	-0.3	0.4	-0.7**	0.0	-6.7**	-1.8	-16.6	-2.4	-0.2	0.1	0.2
9 x8	-0.3*	-0.3	0.2	-0.4	0.1**	4.6**	5.5	-10.3	-0.3	-0.4**	0.3**	0.4
9 x9	0.1	1.2**	0.4	0.5*	0.0	-3.3**	14.2**	-5.2	1.1	0.2	0.0	0.2
9 x12	0.5**	-0.8**	-0.2	-0.8**	0.0	13.2**	-1.6	26.5	3.6**	0.3**	-0.2*	-1.0
10 x1	0.5**	-0.1	-0.2	0.1	0.0	3.7**	19.3**	-54.7**	2.3	0.3**	0.1	0.1
10 x3	0.0	-1.0**	-1.0**	0.2	0.1**	5.1**	11.7*	-17.8	-0.4	-0.2	0.0	0.6
10 x4	-0.1	0.4	0.5	0.1	0.0	-1.4	-2.3	-16.8	1.0	-0.2	0.0	-0.2
10 x5	-0.1	0.2	0.5	-0.2	0.0	-3.2**	14.1**	-0.1	-2.6	0.0	0.1	-0.4
10 x6	-0.5**	0.5*	0.8*	-0.3	0.0	-1.3	-1.2	-15.1	1.0	0.4**	0.1	0.3
10 x7	-0.2	0.4	0.3	-0.1	0.0	-5.9**	-12.0*	26.5	4.6**	0.3**	0.0	0.3
10 x8	0.2	-0.4	-0.9**	0.4	-0.1**	-3.6**	-8.4	0.2	-2.5	-0.1	-0.1	0.7
10 x9	0.1	0.0	0.0	0.1	0.0	5.7**	-7.0	53.3**	-2.9*	-0.3**	0.0	-0.3
10 x12	0.2	0.0	0.1	-0.2	0.0	1.0	-14.1**	24.7	-0.5	-0.1	-0.1	-1.0
11 x1	-0.4**	-1.0**	-1.0	0.0	0.0	-0.6	3.2	34.5*	-2.1	0.4**	-0.1	-0.6
11 x3	1.0	0.7**	0.9**	-0.1	0.0	9.8**	1.2	-3.3	3.6**	0.3**	0.0	0.0
11 x4	-0.8**	1.2**	0.3	0.8**	-0.1**	-4.3**	-6.2	-16.0	0.9	0.0	0.1	0.1
11 x5	-0.1	-1.2**	-0.9**	-0.4	0.0	-0.5	-15.9**	13.8	1.3	0.3**	0.0	-0.1
11 x6	0.1	0.6*	0.8*	-0.3	0.1**	-5.2**	16.3**	3.9	-0.6	-0.1	-0.2*	0.9
11 x7	-0.3*	-0.5*	-0.4	0.0	0.0	-3.3**	5.9	2.6	1.2	-0.1	0.1	0.1
11 x8	0.1	0.3	0.0	0.1	0.0	-3.3**	-5.0	-19.6	-3.1*	0.0	0.0	0.7
11 x9	0.5**	-1.6**	-0.8*	-0.9**	0.1**	1.5	-11.8*	30.7*	1.6	-0.1	0.0	-0.5
11 x12	-0.2	1.4**	1.0**	0.7**	0.1**	5.8**	12.6*	-46.3**	-2.8	-0.6**	0.0	-0.6
S.E	**0.16**	**0.27**	**0.35**	**0.25**	**0.02**	**0.87**	**4.99**	**13.55**	**1.40**	**0.13**	**0.10**	**-**

APPENDIX M. SPECIFIC COMBINING ABILITY (SCA) OF LINE X TESTER UNDER LOW N

		Across Low N Sites									
line	tester	GY	AD	SD	ASI	EPP	PH	SKW	KNEAR	SENESC	HT
1	x1	0.4**	-1.0*	-0.4	0.4	0.0	-5.1	-7.4	32.6*	2.1	-0.2
1	x3	-0.2*	0.0	1.2	0.5	0.0	5.5	-28.3**	-8.9	3.6*	0.3
1	x4	0.1	1.0*	-0.2	-1.0*	0.0	5.7	23.3**	-23.4	1.5	0.0
1	x5	-0.7**	1.1**	2.0**	1.7**	-0.1**	-2.3	4.2	-27.8	0.7	-0.2
1	x6	0.0	0.1	0.5	-0.2	0.0	-8.8**	5.8	6.9	2.3	-0.3
1	x7	0.3**	0.0	-0.4	0.0	0.1**	0.3	1.0	12.2	-3.6*	0.1
1	x8	0.4**	-1.4**	-1.0	0.2	0.0	-2.6	13.4**	9.0	-4.4**	0.1
1	x9	-0.3**	0.1	-0.6	-0.6	0.0	-3.7	-2.4	-8.6	-0.2	0.0
1	x12	0.1	0.0	-1.0	-1.1*	0.1**	11.0**	-9.6*	7.9	-1.9	0.3
2	x1	0.3**	1.1**	0.3	-0.5	0.1**	-1.8	13.6**	0.7	2.1	-0.1
2	x3	0.1	-1.4**	-0.2	1.3**	0.0	9.5**	-3.9	-33.6*	0.4	0.0
2	x4	-0.2*	0.5	1.0	0.7	0.0	5.6	9.5*	15.5	-2.2	-0.3
2	x5	0.0	0.0	-1.9**	-1.9**	0.0	-5.6	-2.3	-6.6	3.2*	0.1
2	x6	-0.3**	-1.1**	0.3	1.6**	0.0	-2.5	-2.3	-33.0*	-1.4	0.2
2	x7	0.0	0.1	1.0	0.8	-0.1**	5.2	-6.8	-20.2	2.8	-0.2
2	x8	0.2*	2.1**	1.9**	-0.1	-0.1**	-0.9	-1.7	45.8**	-3.9**	0.2
2	x9	0.2*	-0.5	-1.5*	-1.6**	0.0	-1.4	15.0**	41.3**	-1.4	0.1
2	x12	-0.4**	-0.8	-1.0	-0.4	0.1**	-8.1**	-21.2**	-9.9	0.4	0.1
4	x1	-0.3**	0.4	-0.1	-0.9	-0.1**	-0.7	-14.3**	-11.7	3.5*	0.3
4	x3	-0.2*	1.3**	1.3*	0.0	0.0	-4.7	-13.7**	42.4**	-3.0*	0.4
4	x4	0.2*	-1.3**	-2.8**	-1.9**	0.1**	2.3	-0.7	13.5	0.3	0.0
4	x5	-0.2*	-1.1**	-0.5	1.1*	-0.1**	8.8**	-7.5	12.1	-2.9	0.0
4	x6	0.5**	0.1	-1.2	-1.0*	0.1**	3.3	-2.3	55.9**	-2.1	-0.2
4	x7	-0.1	0.7	1.2	-0.2	0.0	-5.7	6.2	-38.0**	-4.5**	-0.1
4	x8	0.1	-0.7	-0.2	0.6	0.1**	-1.4	6.0	-18.4	3.8*	0.0
4	x9	-0.1	1.1**	1.5*	0.9	0.0	1.7	9.0	-35.5*	0.0	-0.1
4	x12	0.0	-0.6	0.6	1.4**	0.0	-3.6	17.3**	-20.3	4.8**	-0.3
6	x1	-0.3**	0.1	-0.7	-0.4	0.0	0.4	0.0	-33.4*	1.5	0.4
6	x3	-0.1	0.6	0.7	0.4	-0.1**	-1.8	19.2**	-43.1**	-2.6	-0.2
6	x4	0.4**	0.8	0.0	-1.0*	0.0	5.5	-1.2	119.4**	-4.3**	0.2
6	x5	0.2*	-1.0*	0.4	0.8	0.1**	9.9**	16.7**	14.7	0.4	0.0
6	x6	-0.1	1.0*	-0.3	-1.0*	0.0	1.8	-14.1**	-8.1	0.4	-0.2
6	x7	0.4**	0.3	-0.7	-0.8	0.0	7.4*	3.9	46.0**	1.8	-0.2
6	x8	-0.4**	-0.3	1.2	1.2*	0.0	-7.7**	-9.1	-38.6**	0.9	-0.2
6	x9	-0.2*	0.3	1.1	1.1*	-0.1**	-3.6	-6.3	-55.1**	2.7	-0.1
6	x12	0.0	-1.9**	-1.7**	-0.3	0.0	-11.9**	-9.1	-1.8	-0.7	0.2
7	x1	0.1	0.5	0.0	-0.7	0.0	-1.1	0.6	-0.8	-4.2**	-0.2
7	x3	0.2*	0.6	-1.3*	-2.1**	0.1**	10.5**	-10.6*	64.7**	1.6	-0.1
7	x4	-0.3**	-0.3	1.1	1.4**	-0.1**	-6.0*	-3.5	-61.5**	5.5**	0.1
7	x5	-0.3**	0.7	-0.4	-1.4**	0.0	-7.2*	-8.6	-34.4*	-0.1	0.4
7	x6	0.0	-0.8	0.9	1.3**	-0.1**	-4.8	-3.6	-49.7**	-1.7	0.4
7	x7	0.3**	-1.5**	-0.4	1.4**	0.0	-0.9	-6.3	58.8**	-4.4**	-0.2

7 x8	0.0	0.8	-2.1**	-2.3**	0.0	7.8**	4.1	21.0	4.9**	-0.3
7 x9	0.0	-1.3**	0.3	1.5**	-0.1**	-2.5	-0.7	17.6	0.2	0.0
7 x12	0.2*	1.2**	1.9**	0.9	0.0	4.0	28.6**	-15.8	-1.7	0.1
8 x1	-0.1	0.6	1.0	0.0	-0.1**	0.8	-1.0	-4.5	-2.4	-0.2
8 x3	0.1	-1.1**	-0.6	0.4	0.1**	-6.5*	3.3	-7.1	-1.2	-0.3
8 x4	0.2*	-0.5	-0.5	-0.3	0.0	-5.8*	-2.0	15.8	-0.4	0.1
8 x5	0.3**	-0.5	0.3	0.7	0.1**	-2.4	-5.7	10.4	-2.6	0.0
8 x6	-0.2*	0.5	0.5	0.3	0.0	-1.3	-3.7	-35.4*	0.3	0.1
8 x7	-0.2*	-0.6	0.2	0.7	0.0	5.5	0.1	-13.3	2.3	0.6
8 x8	-0.1	1.4**	1.3*	0.0	0.0	1.5	2.0	-2.2	2.2	0.0
8 x9	0.1	-0.1	-1.6*	-1.5**	0.0	7.8**	-3.8	27.3	0.8	-0.1
8 x12	0.0	0.3	-0.6	-0.3	-0.1**	0.3	10.8*	8.9	1.2	-0.2
9 x1	0.2*	-1.0*	0.5	1.9**	0.1**	6.9*	-5.3	28.1	2.0	0.3
9 x3	-0.1	0.0	-0.8	-0.5	-0.1**	-8.4**	13.4**	-10.6	0.3	-0.1
9 x4	0.0	-0.1	0.2	0.1	0.1**	-3.2	-17.3**	-17.9	-5.3**	-0.1
9 x5	0.2*	0.9*	2.1**	0.9	-0.1**	-5.7	2.6	27.4	2.0	-0.1
9 x6	0.2*	-1.4**	-1.5*	-0.2	-0.1**	6.5*	-1.8	47.4**	2.6	0.0
9 x7	-0.4**	0.9*	-0.2	-1.2	0.0	-3.1	-2.3	-36.8*	-3.8*	-0.1
9 x8	0.1	0.1	-1.2	-1.0	0.1**	7.2*	0.8	-4.8	-0.8	0.5
9 x9	-0.2*	0.7	1.9**	0.8	-0.1**	-1.1	20.0**	-30.7*	3.1*	0.0
9 x12	0.0	-0.2	-0.9	-1.0	0.0	1.0	-10.0*	-2.2	-0.1	-0.3
10 x1	0.2*	0.5	0.8	0.4	0.0	2.4	0.5	-24.5	4.0**	0.2
10 x3	-0.2*	-0.9*	-1.0	0.1	0.1**	-6.6*	18.0**	-3.3	-2.1	-0.1
10 x4	0.0	0.0	-0.4	-0.1	0.1**	1.8	-3.7	-11.9	1.8	0.0
10 x5	0.1	1.1**	0.2	-0.9	0.1**	4.9	8.8	-14.1	-2.4	0.0
10 x6	0.1	0.7	0.1	-0.4	0.0	1.4	-2.3	-8.9	-1.9	0.1
10 x7	-0.2*	0.0	0.1	-0.3	0.0	-10.5**	3.8	2.3	5.7**	0.0
10 x8	-0.3**	-1.5**	-0.3	1.0	-0.1**	-2.3	4.4	-25.6	0.5	-0.3
10 x9	0.2*	0.2	0.3	0.2	0.0	2.8	-13.9**	44.5**	-4.0**	0.1
10 x12	0.0	0.0	0.2	0.0	0.0	6.1*	-15.5**	41.5**	-1.7	-0.1
11 x1	-0.4**	-1.1**	-1.4*	-0.2	0.0	-1.8	13.3**	13.4	-8.6**	-0.4
11 x3	0.3**	0.9*	0.7	-0.2	-0.1**	2.4	2.7	-0.4	3.2*	0.0
11 x4	-0.5**	-0.3	1.7**	1.9**	-0.1**	-5.9*	-4.5	-49.6**	3.1*	0.1
11 x5	0.4**	-1.3**	-2.2**	-1.0	0.0	-0.5	-8.3	18.2	1.7	0.0
11 x6	-0.1	0.8	0.6	-0.4	0.1**	4.4	24.4**	24.9	1.5	-0.2
11 x7	0.0	0.0	-0.8	-0.5	0.0	1.9	0.5	-11.0	3.7*	0.0
11 x8	-0.1	-0.5	0.4	0.4	0.0	-1.7	-20.0**	13.8	-3.2*	0.0
11 x9	0.4**	-0.6	-1.4	-0.8	0.1**	0.1	-16.9**	-0.9	-1.1	0.2
11 x12	-0.1	2.1**	2.4**	0.8	0.1**	1.1	8.8	-8.4	-0.4	0.2
S.E	**0.11**	**0.44**	**0.65**	**0.49**	**0.03**	**2.96**	**4.86**	**14.51**	**1.51**	**-**

APPENDIX N. SPECIFIC COMBINING ABILITY (SCA) OF LINE X TESTER UNDER HIGH N

		Across High N sites										
line	tester	GY	AD	SD	ASI	EPP	PH	SKW	KNEAR	SENESC	GLS	HT	RUST
1	x1	0.4	0.9**	0.8*	-0.1	0.0	1.6	-16.5	-20.9	-8.6**	-0.4**	-0.2**	0.3
1	x3	-1.0**	0.1	-0.7*	-0.6**	0.0	12.9**	7.8	2.1	6.7**	-0.1	-0.2**	0.3
1	x4	-0.3	0.9**	0.4	-0.4**	0.0	0.9	5.7	52.4*	-4.2	0.1	0.3**	-0.4
1	x5	0.9**	0.4	0.3	-0.1	0.0	-2.7	8.6	-17.1	1.3	0.0	0.2**	-0.4
1	x6	-0.1	0.1	0.4	0.2	0.0	-5.0*	2.7	-42.4	0.2	0.0	0.0	0.0
1	x7	-0.2	-0.9**	-1.0**	-0.2	0.0	2.9	-3.2	1.1	-3.9	0.3**	0.0	0.2
1	x8	0.6*	-1.1**	-0.6	0.3*	0.0	-7.4**	-3.7	37.7	4.2	0.3**	-0.1	-0.9
1	x9	1.2**	-0.5	-0.2	0.3*	0.0	4.0	2.3	2.1	0.4	-0.2	0.0	0.3
1	x12	-1.6**	0.1	0.6	0.4**	0.0	-7.2**	-3.6	-14.8	3.9	0.1	0.0	0.7
2	x1	-0.4	0.1	0.0	-0.1	0.0	8.4**	-4.9	-44.0	-5.7*	-0.2	-0.1	-0.3
2	x3	0.5	-1.0**	-0.4	0.4**	0.0	-8.4**	-5.2	56.6*	-12.0**	0.4**	-0.2**	-0.3
2	x4	-0.7**	0.7*	1.4**	0.7**	0.0	0.8	2.1	-23.1	-2.6	0.2	0.0	0.1
2	x5	0.4	-0.5	-0.7*	-0.2	0.0	2.4	12.7	-8.7	4.3	0.0	0.3**	0.8
2	x6	0.0	-1.8**	-1.9**	-0.2	0.0	2.8	7.0	-23.5	7.4**	0.0	-0.1	-0.3
2	x7	1.0**	1.7**	1.8**	0.1	0.0	0.0	9.4	11.1	3.3	-0.3**	0.0	-0.6
2	x8	-0.5	0.2	0.0	0.0	0.0	4.0	8.1	4.8	4.5	0.0	0.2**	0.4
2	x9	-0.8**	0.6*	-0.2	-0.5**	0.0	-7.0**	-25.6**	0.3	6.4**	0.2	0.2**	-0.1
2	x12	0.4	0.0	0.0	-0.1	0.1**	-3.0	-6.4	27.6	-5.7*	-0.3**	-0.3**	0.2
4	x1	0.1	0.0	0.5	0.5**	0.0	11.3**	-20.9**	47.4	4.0	0.1	0.0	0.7
4	x3	-0.7**	-0.5	0.1	0.5**	0.0	2.0	37.3**	24.3	0.3	-0.1	0.4**	-0.3
4	x4	0.4	-0.2	-0.4	-0.2	0.0	3.8	22.5*	-29.8	4.1	-0.1	-0.2	-0.1
4	x5	0.8**	0.2	0.0	-0.2	0.1**	-3.0	-7.6	43.9	1.3	-0.1	-0.3**	-0.2
4	x6	0.9**	-0.3	-0.7*	-0.2	0.0	-1.6	13.0	65.6**	-8.9**	0.2	0.1	-0.6
4	x7	-0.2	-0.2	-0.1	-0.1	0.0	0.1	6.8	-63.6*	-0.3	0.0	-0.2**	0.0
4	x8	0.0	-0.8**	-1.3**	-0.7**	0.0	-0.8	-4.6	-36.1	-5.2*	-0.2	0.0	-0.4
4	x9	-1.1**	1.7**	1.7**	0.3*	0.0	-3.1	-0.9	-91.6*	1.1	-0.3**	0.0	0.5
4	x12	-0.2	0.1	0.2	0.1	0.0	-8.8**	-45.3**	40.2	3.6	0.4**	0.3**	0.3
6	x1	-0.1	0.5	0.0	-0.3*	0.0	-1.6	-6.3	-12.2	15.4**	-0.6**	0.0	-0.2
6	x3	-0.9**	-0.9**	-0.9**	0.0	0.0	-10.3**	-0.7	-42.8	-8.8**	-0.2	0.2**	-0.3
6	x4	0.3	-0.9**	-0.7*	0.3*	0.0	-0.9	-3.7	-38.1	5.8*	0.3**	0.0	0.1
6	x5	0.0	0.2	0.7*	0.4**	0.0	3.2	-7.6	-15.7	-13.9**	0.3**	-0.2**	0.0
6	x6	0.0	0.0	-0.1	-0.1	0.0	8.2**	-14.5	32.3	2.9	0.0	0.2**	-0.2
6	x7	-0.5	-0.1	-0.2	-0.1	0.0	-2.6	6.9	41.1	11.4**	0.1	-0.1	-0.1
6	x8	0.0	1.0**	1.2**	0.3*	0.0	0.0	20.1*	16.3	-0.3	0.1	0.0	-0.3
6	x9	0.6*	0.1	0.0	-0.1	0.0	3.5	7.0	-27.4	-7.7**	0.2	0.0	0.1
6	x12	0.7**	0.1	-0.1	-0.3*	-0.1**	0.4	-0.9	46.8	-4.9*	-0.2	0.0	0.9
7	x1	-0.4	0.7*	0.7*	0.0	0.0	-6.3**	-31.1**	41.6	-0.9	0.4**	0.1	-0.3
7	x3	-0.6*	0.2	0.3	0.1	0.0	-0.5	-15.3	-17.6	2.7	0.0	0.0	-0.4
7	x4	1.0**	-0.9**	-0.8*	0.0	0.1**	7.1**	16.2	0.9	-8.2**	-0.2	-0.1	0.0

7 x5	0.2	-0.7*	-1.1**	-0.5**	0.0	7.5**	4.6	79.8**	5.0*	-0.6**	0.0	-0.2
7 x6	0.2	0.0	-0.1	0.0	0.1**	0.6	21.9*	-35.5	4.0	-0.3**	0.1	0.1
7 x7	0.8**	-0.4	-0.6	-0.3*	0.0	5.7*	-5.5	-5.2	-8.0**	-0.2	0.0	0.6
7 x8	-0.2	0.6*	0.5	0.1	0.0	2.5	-35.3**	33.6	11.5**	0.3**	-0.1	-0.4
7 x9	-0.8**	-0.3	0.5	0.7**	0.0	-9.8**	26.8**	-82.5**	-3.3	0.2	-0.1	0.1
7 x12	-0.1	0.7*	0.5	-0.1	-0.1**	-6.8**	17.9	-14.8	-2.8	0.3**	0.1	0.6
8 x1	-0.5	0.3	0.2	-0.2	0.1**	-8.6**	22.9*	27.2	-4.6	-0.4**	-0.1	0.2
8 x3	0.4	0.8**	0.6	-0.2	-0.1**	-2.3	-14.1	-4.3	5.1*	0.1	-0.1	0.4
8 x4	0.7**	-0.6*	-1.1**	-0.4**	0.0	-13.1**	-21.4*	23.9	5.9*	-0.1	0.0	0.3
8 x5	0.3	0.6*	0.5	-0.2	0.0	-0.5	0.4	20.3	-0.6	0.0	-0.2**	0.3
8 x6	0.3	0.5	0.8*	0.3*	-0.1**	-3.2	-27.2**	1.4	-0.2	0.1	-0.1	0.0
8 x7	-0.6*	0.0	0.0	0.1	0.1**	9.8**	4.1	-52.4*	-2.6	0.1	0.1	-0.7
8 x8	-0.3	-0.4	-0.1	0.1	0.0	4.1	17.4	-11.3	-5.3*	-0.1	-0.2**	-0.1
8 x9	-0.2	-0.5	-0.4	0.1	0.0	8.4**	-10.4	56.8*	0.7	0.1	0.2**	-0.3
8 x12	0.0	-0.8**	-0.6	0.3*	0.1**	5.4*	28.5**	-61.3*	1.5	0.1	0.2**	-0.1
9 x1	0.6*	-1.0**	-0.7*	0.2	-0.1**	-7.8**	25.2**	-12.5	-6.9**	0.4**	0.2**	0.1
9 x3	0.4	1.4**	1.1**	-0.2	0.0	-8.3**	-17.1	47.2	-0.2	-0.2	-0.1	0.0
9 x4	0.0	-0.9**	-0.8*	0.1	0.0	7.0***	-13.0	15.2	2.0	-0.1	-0.2**	0.2
9 x5	-1.7**	0.4	0.5	0.2	0.0	-3.2	-7.5	-128.6**	4.7	0.2	0.0	0.1
9 x6	-0.5	-0.1	0.1	0.3*	-0.1**	4.6	-9.3	41.5	-6.8**	-0.3**	-0.2**	-0.1
9 x7	0.4	-0.1	-0.4	-0.2	0.0	-6.7**	-2.5	-1.6	-0.4	-0.2	0.2**	0.2
9 x8	-0.6*	0.2	0.5	0.3*	0.1**	4.6	9.0	-21.1	0.3	-0.4**	0.1	0.4
9 x9	0.5	0.2	0.5	0.1	0.0	-3.3	7.2	15.0	-2.0	0.2	0.0	0.2
9 x12	0.9**	-0.1	-0.8*	-0.6**	0.0	13.2**	5.6	49.9*	9.2**	0.3**	-0.1	-1.0
10 x1	0.8**	-0.8**	-1.0**	-0.2	0.0	3.7	38.5**	-83.7**	-0.3	0.3**	0.0	0.1
10 x3	0.2	-1.0**	-0.9**	0.2	0.0	5.1*	3.5	-36.3	2.1	-0.2	0.0	0.6
10 x4	-0.3	0.9**	1.2**	0.2	0.0	-1.4	-0.4	-20.5	-0.3	-0.2	0.1	-0.2
10 x5	-0.3	-0.2	0.1	0.4**	0.0	-3.2	19.9*	15.2	-2.8	0.0	0.1	-0.4
10 x6	-1.1**	0.9**	0.8*	-0.1	0.0	-1.3	-1.3	-26.1	5.2*	0.4**	0.0	0.3
10 x7	-0.2	0.6*	0.7*	0.1	0.0	-5.9**	-27.3**	51.8	2.9	0.3**	0.0	0.3
10 x8	0.6*	-0.3	-0.5	-0.2	0.0	-3.6	-20.8*	27.3	-6.9**	-0.1	0.0	0.7
10 x9	0.0	-0.3	-0.2	-0.1	0.0	5.7*	0.4	63.2*	-1.3	-0.3**	-0.2**	-0.3
10 x12	0.3	0.2	-0.2	-0.4**	0.0	1.0	-12.2	9.1	1.4	-0.1	-0.2**	-1.0
11 x1	-0.4	-0.8**	-0.6	0.2	0.0	-0.6	-6.5	56.8*	7.6**	0.4**	0.1	-0.6
11 x3	1.7**	1.0**	0.8*	-0.1	0.1**	9.8**	-2.2	-10.2	4.1	0.3**	0.0	0.0
11 x4	-1.1**	1.0**	0.7*	-0.3*	0.0	-4.3	-7.6	18.8	-2.4	0.0	0.1	0.1
11 x5	-0.7**	-0.5	-0.3	0.2	0.0	-0.5	-23.1*	10.6	0.6	0.3**	0.0	-0.1
11 x6	0.3	0.7*	0.6	-0.1	0.0	-5.2*	6.8	-21.9	-3.8	-0.1	-0.1	0.9
11 x7	-0.5	-0.8**	-0.3	0.5**	0.0	-3.3	11.8	17.5	-2.4	-0.1	0.1	0.1
11 x8	0.4	0.6*	0.3	-0.1	0.0	-3.3	10.3	-51.8*	-2.9	0.0	0.0	0.7
11 x9	0.7**	-1.0**	-1.8**	-0.9**	0.0	1.5	-6.2	63.6**	5.6*	-0.1	-0.1	-0.5
11 x12	-0.4	-0.2	0.4	0.7**	0.0	5.8*	16.9	-83.1**	-6.3*	-0.6**	-0.1	-0.6
S.E	**0.29**	**0.32**	**0.34**	**0.16**	**0.02**	**2.30**	**9.24**	**24.56**	**2.50**	**0.13**	**0.08**	**-**

PPENDIX O. Mean values of yield and secondary traits of 81 crosses evaluted at 3 low N and 3 high N sites in Zambia and Zimbabwe (across environments)

NE	X TESTER	GY	AD	SD	ASI	EPP	PH	GLS	HT	RUST	SENESC	SKW	KNEAR
1	1	5.21	70.80	73.86	2.93	0.94	196.30	2.19	1.58	2.26	45.95	279.53	361.32
1	3	3.56	69.58	72.39	2.56	0.85	187.31	1.58	1.87	2.33	51.30	268.43	340.59
1	4	4.53	72.83	74.88	2.25	0.86	183.15	2.02	1.86	1.39	45.19	284.49	392.76
1	5	4.50	72.56	75.86	3.69	0.82	178.50	1.90	1.75	1.50	50.18	271.40	338.17
1	6	4.44	72.24	75.36	2.78	0.85	168.74	2.10	1.73	2.06	47.93	273.19	358.32
1	7	4.60	71.70	74.48	2.92	0.95	179.18	2.33	1.91	2.56	42.77	270.84	383.44
1	8	4.98	69.68	72.55	2.63	0.91	172.83	2.25	1.74	1.27	46.43	271.71	374.00
1	9	4.93	71.81	74.02	2.31	0.87	179.53	1.31	1.78	2.04	41.58	274.13	355.66
1	12	4.63	72.57	75.23	2.55	0.91	196.35	2.43	2.30	2.05	44.50	297.34	368.49
2	1	4.71	72.69	75.75	3.20	0.97	206.26	2.14	2.07	0.98	48.78	284.29	337.50
2	3	4.43	69.61	73.79	4.22	0.88	183.58	1.94	2.05	1.05	43.63	262.61	359.19
2	4	4.15	73.70	77.91	4.33	0.87	187.89	1.96	1.94	1.13	45.33	264.30	378.16
2	5	4.55	72.79	75.29	2.53	0.81	184.33	1.72	2.32	1.99	54.55	258.71	356.68
2	6	4.27	71.95	76.05	4.16	0.83	180.73	1.89	2.22	1.11	50.29	249.84	316.75
2	7	5.03	74.32	78.40	4.24	0.83	185.06	1.52	2.16	0.97	51.17	261.70	375.96
2	8	4.23	73.31	76.24	3.01	0.82	184.27	1.71	2.35	1.93	48.60	258.62	379.68
2	9	4.12	73.31	75.48	2.10	0.85	180.06	1.45	2.33	0.94	45.01	257.33	383.47
2	12	5.36	73.39	76.86	3.35	0.94	193.76	1.91	2.43	0.79	43.79	278.58	384.49
4	1	5.04	72.10	75.16	2.83	0.87	206.69	3.16	1.86	2.05	49.36	273.71	410.29
4	3	4.03	70.97	74.10	3.14	0.85	180.09	2.06	2.22	1.08	42.36	290.35	414.28
4	4	5.22	72.21	74.44	2.15	0.90	186.27	2.31	1.55	0.99	45.35	280.73	407.04
4	5	5.02	72.38	75.72	3.60	0.81	187.29	2.23	1.55	1.05	45.60	257.29	425.57
4	6	5.45	73.07	75.26	2.46	0.88	179.88	2.73	1.83	0.83	39.22	274.14	473.80
4	7	4.73	73.45	76.98	3.21	0.84	178.14	2.57	1.71	1.63	41.15	278.29	362.99
4	8	4.84	71.26	73.90	2.55	0.89	180.09	2.26	1.77	1.08	45.20	267.47	360.33
4	9	4.22	74.47	77.33	3.32	0.87	182.04	1.69	1.75	1.55	39.54	278.09	332.35
4	12	5.58	73.37	77.09	3.93	0.84	191.54	3.27	2.23	0.94	46.01	289.75	418.89
6	1	4.53	70.60	72.71	2.35	0.96	186.50	1.44	1.90	1.99	56.80	274.77	350.64
6	3	3.58	68.83	71.44	2.70	0.88	161.16	1.03	1.82	1.97	42.99	274.39	319.00
6	4	4.94	71.31	73.85	2.46	0.95	171.17	1.81	1.75	2.05	47.30	254.00	436.84
6	5	4.43	70.85	74.65	3.39	0.93	176.66	1.71	1.60	2.10	45.57	256.00	378.05
6	6	4.34	72.15	74.15	2.11	0.91	169.73	1.66	1.83	2.11	49.48	241.13	406.18
6	7	4.40	71.72	74.10	2.52	0.90	169.01	1.65	1.69	2.45	53.71	263.79	438.33
6	8	4.22	70.78	73.99	3.03	0.94	162.99	1.57	1.59	2.17	49.44	258.86	357.48
6	9	4.62	71.69	74.38	2.84	0.85	168.39	1.18	1.71	2.12	41.72	260.94	335.63
6	12	5.66	71.12	73.94	2.55	0.88	177.67	1.68	2.23	2.53	43.33	285.33	412.41
7	1	4.88	72.04	75.28	3.08	0.94	199.43	3.18	1.80	0.90	46.34	279.46	389.62
7	3	4.17	70.53	72.94	2.28	0.92	188.23	1.91	1.82	0.82	49.68	268.96	381.28
7	4	5.19	71.92	76.20	4.29	0.85	185.47	1.96	1.76	0.91	47.14	279.60	361.68
7	5	4.53	72.45	75.22	2.62	0.86	186.26	1.46	1.99	0.94	52.36	266.30	397.05
7	6	4.81	72.40	76.60	4.07	0.85	178.68	2.00	2.16	1.37	48.20	281.35	347.18
7	7	5.31	71.84	75.95	4.24	0.88	185.04	2.08	1.90	2.07	41.72	269.25	417.35
7	8	4.56	72.26	73.87	1.89	0.87	188.06	2.43	1.62	0.97	56.11	254.54	391.67
7	9	4.28	71.83	76.15	4.23	0.82	178.31	1.86	1.84	1.02	41.51	290.44	340.23
7	12	5.62	74.09	77.93	3.97	0.84	198.11	2.91	2.34	1.15	43.10	330.42	370.34
8	1	4.76	71.85	74.81	2.70	1.00	199.03	1.90	1.64	2.67	42.29	297.34	380.07
8	3	4.70	69.96	72.72	2.76	0.93	178.59	1.57	1.71	2.89	45.25	268.19	351.55
8	4	5.32	71.92	74.52	2.60	0.92	175.26	1.68	1.78	2.46	45.54	253.22	411.32
8	5	4.96	72.43	75.64	3.17	0.94	184.43	1.75	1.68	2.62	44.90	257.27	389.17
8	6	4.77	73.20	76.12	3.07	0.88	178.31	1.99	1.85	2.55	44.01	248.41	372.31
8	7	4.41	72.43	75.78	3.44	0.95	190.06	1.99	2.22	2.07	44.24	268.92	357.19
8	8	4.50	71.99	74.58	2.44	0.92	185.47	1.66	1.68	2.58	44.05	271.50	357.15
8	9	4.74	72.27	74.01	1.79	0.94	192.33	1.36	1.94	1.84	39.78	261.96	414.25
8	12	5.66	72.84	75.35	2.92	0.90	202.17	2.31	2.25	1.74	42.88	318.47	358.98
9	1	5.42	71.46	75.48	4.15	0.93	212.22	2.58	2.26	2.58	46.32	308.99	362.30
9	3	4.51	71.89	74.24	2.59	0.83	184.39	1.18	1.98	2.56	46.38	277.22	323.67
9	4	4.86	73.04	76.43	3.34	0.90	196.37	1.52	1.82	2.52	43.36	262.45	375.91
9	5	3.78	74.07	77.92	3.77	0.78	191.15	1.76	1.96	2.58	52.14	270.17	309.03
9	6	4.49	73.04	76.13	3.15	0.77	195.83	1.45	1.99	2.48	45.07	270.96	419.56
9	7	4.76	74.16	76.77	2.68	0.86	187.28	1.45	2.22	3.00	43.81	277.12	356.63
9	8	4.38	72.72	74.98	2.33	0.97	198.34	1.20	2.26	3.09	46.84	279.39	336.74
9	9	4.84	74.04	77.53	3.23	0.84	191.78	1.34	2.07	2.47	42.42	295.34	350.07
9	12	6.04	74.02	76.52	2.44	0.87	216.16	2.26	2.27	0.89	47.52	309.28	394.79
10	1	5.77	72.58	75.04	2.40	0.95	204.54	2.73	1.68	2.62	47.80	304.44	332.69
10	3	4.62	70.49	72.64	2.34	0.96	180.82	1.45	1.62	3.13	43.49	282.91	355.49
10	4	4.97	74.29	76.66	2.52	0.92	183.45	1.71	1.55	2.04	44.34	261.44	393.30
10	5	4.72	74.18	76.32	2.20	0.89	185.37	1.78	1.63	2.07	44.05	272.86	392.43
10	6	4.45	74.88	76.87	2.06	0.88	179.21	2.39	1.71	2.93	44.80	260.64	389.84
10	7	4.83	74.35	76.98	2.49	0.86	172.88	2.24	1.72	3.12	48.43	253.67	435.17
10	8	5.07	71.96	74.50	2.30	0.84	178.29	1.78	1.40	3.43	42.33	252.17	382.77
10	9	5.05	73.91	75.95	2.06	0.92	187.04	1.10	1.57	1.98	36.03	260.89	444.08
10	12	6.00	74.56	76.90	2.28	0.91	201.42	2.17	1.85	0.85	41.01	283.53	428.53
11	1	4.82	72.46	75.74	3.26	0.89	205.31	2.82	1.56	2.05	43.50	325.06	383.89
11	3	5.57	73.05	75.95	3.01	0.83	192.68	1.86	1.73	2.62	47.54	309.15	332.00
11	4	4.28	74.83	79.08	4.27	0.76	183.19	1.84	1.66	2.51	44.37	294.19	356.11
11	5	4.66	73.52	76.51	3.04	0.82	188.96	2.05	1.66	2.48	48.00	279.54	368.28
11	6	4.99	75.54	78.60	3.00	0.87	183.73	1.86	1.57	3.60	43.35	314.82	370.82
1	7	4.70	74.34	77.69	3.59	0.81	185.37	1.85	1.86	3.05	45.16	308.29	373.35
1	8	5.00	73.57	76.79	3.02	0.83	183.73	1.85	1.65	3.52	41.82	292.31	324.92
1	9	5.45	73.85	75.88	2.11	0.90	188.62	1.32	1.71	1.87	40.65	292.80	383.51
1	12	5.53	76.11	79.92	4.16	0.90	206.33	1.64	2.09	1.43	38.82	346.97	319.49
MEAN		4.78	72.54	75.49	2.96	0.88	186.18	1.92	1.87	1.95	45.54	277.07	375.45
LSD		0.87	1.46	2.09	1.40	0.12	12.96	0.65	0.46	0.98	26.62	71.71	11.33
CV		22.56	2.51	3.45	58.47	16.51	8.70	28.78	23.37	24.93	10.92	21.78	28.35

APPENDIX P. Mean values of yield and secondary traits of 81 crosses evaluted at Golden Valley, Kabwe and CIMMYT-Harare under low N

LINE	TESTER	GY	AD	SD	ASI	EPP	PH	GLS	HT	RUST	SENESCE	SKW	KNEAR
1	1	2.28	70.3	75.3	4.7	0.82	156.71	.	1.78	.	51.89	234.38	260.34
1	3	1.19	70.8	75.9	4.6	0.76	151.76	.	2.44	.	56.79	185.55	214.14
1	4	1.70	73.9	77.0	3.4	0.71	151.85	.	2.07	.	51.51	239.47	224.02
1	5	0.87	73.6	78.7	6.0	0.59	142.95	.	1.84	.	51.79	214.18	197.46
1	6	1.68	73.1	77.8	4.1	0.73	133.57	.	1.82	.	51.27	225.35	235.14
1	7	2.03	73.3	77.6	4.7	0.86	142.70	.	2.28	.	47.94	209.76	255.10
1	8	1.91	70.5	74.9	3.9	0.78	142.42	.	2.17	.	46.93	220.05	229.74
1	9	1.23	73.4	76.6	3.4	0.75	139.79	.	1.93	.	48.17	204.59	206.15
1	12	2.15	73.0	76.4	3.3	0.83	168.55	.	2.56	.	49.28	240.06	244.96
2	1	1.80	73.9	78.5	4.9	0.89	165.83	.	2.29	.	51.95	248.07	210.76
2	3	1.14	70.9	77.0	6.4	0.73	161.55	.	2.49	.	53.67	202.57	171.80
2	4	1.01	74.9	80.7	6.1	0.69	157.49	.	2.12	.	47.96	218.44	245.28
2	5	1.16	73.9	77.2	3.4	0.60	145.47	.	2.55	.	54.34	200.38	201.04
2	6	0.93	73.4	80.0	6.8	0.67	145.74	.	2.72	.	47.63	209.98	177.59
2	7	1.40	74.9	81.3	6.6	0.61	153.41	.	2.44	.	54.42	194.65	205.06
2	8	1.26	75.6	80.2	4.7	0.61	149.91	.	2.70	.	47.56	197.73	248.91
2	9	1.32	74.4	78.1	3.4	0.70	147.86	.	2.41	.	47.09	214.67	238.45
2	12	1.24	73.8	78.8	5.0	0.76	155.22	.	2.78	.	51.70	221.09	209.54
4	1	1.51	72.7	77.3	4.1	0.69	163.49	.	2.23	.	51.24	231.11	232.94
4	3	1.14	73.1	77.7	4.8	0.77	143.92	.	2.44	.	48.19	203.75	282.36
4	4	1.65	72.7	76.0	3.2	0.74	150.87	.	1.96	.	48.32	219.14	277.84
4	5	1.27	72.3	77.8	6.0	0.56	156.43	.	1.98	.	46.20	206.07	254.30
4	6	2.03	74.1	77.7	3.9	0.74	148.05	.	1.87	.	44.87	220.91	301.03
4	7	1.55	75.0	80.8	5.2	0.69	139.12	.	2.06	.	44.95	218.61	221.90
4	8	1.50	72.3	77.3	5.0	0.79	146.01	.	2.02	.	53.15	216.39	219.22
4	9	1.33	75.5	80.4	5.6	0.69	147.56	.	1.81	.	46.37	219.65	196.19
4	12	1.93	73.5	79.6	6.5	0.67	156.24	.	1.95	.	54.00	270.54	233.72
6	1	1.49	71.5	74.9	3.5	0.82	152.37	.	2.37	.	48.66	229.60	218.50
6	3	1.23	71.4	75.3	4.1	0.73	134.69	.	1.91	.	47.94	220.83	204.19
6	4	1.88	73.8	77.1	3.0	0.82	141.81	.	2.23	.	43.04	202.90	390.99
6	5	1.69	71.5	77.0	4.7	0.83	145.41	.	2.05	.	48.89	214.49	264.15
6	6	1.42	74.2	76.9	2.9	0.81	134.42	.	1.93	.	46.70	193.36	244.36
6	7	2.00	73.7	77.1	3.6	0.78	140.04	.	2.03	.	50.65	200.54	313.12
6	8	1.00	71.8	76.9	4.6	0.81	127.52	.	1.81	.	49.59	185.48	206.34
6	9	1.25	73.8	78.1	4.7	0.71	130.10	.	1.79	.	48.43	188.52	183.86
6	12	1.90	71.2	75.5	3.8	0.79	135.76	.	2.43	.	47.83	228.33	259.52
7	1	1.93	72.5	77.8	5.0	0.86	166.63	.	1.82	.	46.65	249.43	225.69
7	3	1.52	72.1	75.6	3.4	0.90	162.68	.	2.01	.	55.90	210.23	286.48
7	4	1.19	73.3	80.4	7.1	0.63	146.09	.	2.16	.	56.64	219.80	184.66
7	5	1.21	73.9	78.4	4.2	0.71	143.97	.	2.50	.	52.13	208.47	189.59
7	6	1.61	73.0	80.3	6.9	0.67	143.52	.	2.59	.	48.34	223.00	177.24
7	7	2.00	72.5	79.7	7.5	0.76	147.43	.	2.12	.	48.16	209.50	300.48
7	8	1.42	73.5	75.9	2.7	0.74	158.71	.	1.77	.	57.34	217.89	240.44
7	9	1.47	72.8	79.7	6.8	0.65	146.93	.	1.97	.	49.72	213.30	231.09
7	12	2.11	75.0	81.4	6.6	0.73	167.45	.	2.45	.	50.58	285.25	219.97
8	1	1.84	72.5	77.1	4.2	0.77	165.56	.	1.92	.	45.37	236.93	239.44
8	3	1.61	70.2	74.6	4.5	0.86	142.65	.	1.99	.	50.02	213.22	232.20
8	4	1.79	73.0	77.1	4.0	0.78	143.26	.	2.31	.	47.63	210.33	279.41
8	5	1.89	72.5	77.3	4.9	0.83	145.81	.	2.24	.	46.47	200.40	251.80
8	6	1.48	74.1	78.2	4.5	0.76	144.01	.	2.38	.	47.25	211.98	209.03
8	7	1.63	73.2	78.5	5.3	0.74	150.83	.	2.98	.	51.77	204.96	245.80
8	8	1.43	73.9	77.6	3.6	0.78	149.45	.	2.24	.	51.51	204.77	234.72
8	9	1.76	73.8	76.0	2.4	0.79	154.21	.	2.05	.	47.20	199.24	258.27
8	12	2.06	73.8	77.1	4.0	0.63	160.77	.	2.27	.	50.42	256.51	262.17
9	1	1.89	72.2	78.5	6.8	0.91	176.96	.	2.54	.	51.28	257.79	216.51
9	3	1.14	72.6	76.3	4.1	0.67	146.18	.	2.29	.	52.99	248.51	173.13
9	4	1.44	74.7	79.7	5.0	0.77	151.23	.	2.22	.	44.18	220.23	190.17
9	5	1.55	75.2	81.2	5.8	0.61	147.81	.	2.23	.	52.62	233.95	213.32
9	6	1.64	73.5	78.1	4.6	0.63	157.17	.	2.43	.	50.99	239.09	236.31
9	7	1.21	76.0	80.0	4.0	0.70	147.61	.	2.35	.	47.22	227.84	166.79
9	8	1.37	73.9	77.0	3.3	0.83	160.51	.	2.80	.	50.03	228.85	176.62
9	9	1.21	75.8	81.4	5.3	0.63	150.66	.	2.21	.	50.99	248.29	144.66
9	12	1.86	74.7	78.8	4.0	0.70	166.84	.	2.27	.	50.61	260.94	195.47
10	1	2.17	73.9	78.1	4.1	0.83	164.24	.	1.86	.	54.28	243.03	220.35
10	3	1.32	71.9	75.3	3.6	0.86	139.78	.	1.68	.	51.63	232.50	236.92
10	4	1.67	75.0	78.4	3.7	0.80	148.01	.	1.66	.	52.33	213.20	252.56
10	5	1.67	75.7	78.5	2.8	0.77	150.29	.	1.77	.	49.11	219.50	228.21
10	6	1.83	75.8	79.0	3.3	0.73	143.89	.	1.94	.	47.50	218.02	236.40
10	7	1.60	75.3	79.5	3.8	0.72	132.06	.	1.94	.	57.66	213.25	262.33
10	8	1.26	72.6	77.2	4.1	0.64	142.77	.	1.37	.	52.29	211.80	212.25
10	9	1.79	75.6	79.1	3.6	0.78	146.35	.	1.77	.	44.86	193.82	276.37
10	12	2.08	75.1	79.1	3.8	0.74	163.70	.	1.91	.	49.96	234.82	295.70
11	1	1.37	73.5	78.6	5.3	0.73	163.32	.	1.54	.	41.54	295.02	207.28
11	3	1.63	74.9	79.8	5.1	0.63	152.01	.	2.05	.	56.75	256.48	188.80
11	4	0.96	75.9	83.3	7.5	0.53	143.61	.	2.06	.	53.48	251.69	163.90
11	5	1.83	74.4	78.9	4.6	0.66	148.11	.	2.01	.	53.13	241.70	209.54
11	6	1.45	77.1	82.2	5.1	0.73	150.12	.	1.91	.	50.81	284.00	219.19
11	7	1.58	76.5	81.5	5.5	0.64	147.70	.	2.18	.	55.48	249.24	198.08
11	8	1.28	74.7	80.6	5.4	0.68	146.60	.	1.98	.	48.49	226.73	200.67
11	9	1.77	76.0	80.1	4.4	0.83	146.94	.	2.05	.	47.63	230.02	179.93
11	12	1.79	78.4	84.1	6.4	0.79	161.97	.	2.47	.	51.11	298.41	194.81
MEAN		1.56	73.67	78.29	4.65	0.73	149.91	.	2.14	.	50.03	244.75	227.71
LSD		1.30	4.73	6.98	4.63	0.36	38.94	.	1.00	.	21.07	49.67	169.54
CV		72.93	5.62	7.80	86.86	22.72	42.85	.	33.29	.	36.83	19.33	65.13

APPENDIX Q. Mean values of yield and secondary traits of 81 crosses evaluted at Golden Valley, Mount Makulu and ART Farms under high N

LINE	TESTER	GY	AD	SD	ASI	EPP	PH	GLS	HT	RUST	SKW	KNEAR
1	1	8.14	71.28	72.44	1.14	1.07	235.88	2.19	1.44	2.26	324.67	462.30
1	3	5.93	68.40	68.84	0.50	0.93	222.85	1.58	1.49	2.33	351.30	467.03
1	4	7.37	71.78	72.76	1.10	1.01	214.44	2.02	1.73	1.39	329.51	561.50
1	5	8.13	71.57	72.98	1.42	1.04	214.05	1.90	1.69	1.50	328.63	478.88
1	6	7.20	71.38	72.92	1.50	0.97	203.90	2.10	1.68	2.06	321.04	481.49
1	7	7.16	70.16	71.39	1.16	1.04	215.66	2.33	1.66	2.56	331.93	511.77
1	8	8.05	68.84	70.24	1.32	1.03	203.24	2.25	1.46	1.27	323.37	518.25
1	9	8.63	70.23	71.42	1.25	0.99	219.27	1.31	1.67	2.04	343.66	505.17
1	12	7.11	72.15	74.08	1.83	0.99	224.14	2.43	2.13	2.05	354.62	492.02
2	1	7.62	71.47	73.05	1.52	1.05	246.69	2.14	1.93	0.98	320.51	464.24
2	3	7.71	68.36	70.55	2.00	1.02	205.61	1.94	1.76	1.05	322.65	546.57
2	4	7.30	72.54	75.15	2.55	1.05	218.28	1.96	1.82	1.13	310.16	511.04
2	5	7.93	71.68	73.40	1.67	1.02	223.18	1.72	2.17	1.99	317.04	512.32
2	6	7.61	70.45	72.04	1.49	0.99	215.73	1.89	1.89	1.11	309.63	525.51
2	7	8.66	73.74	75.51	1.89	1.06	216.70	1.52	1.97	0.97	328.75	546.86
2	8	7.20	71.03	72.25	1.35	1.02	218.62	1.71	2.11	1.93	319.50	510.44
2	9	6.91	72.26	72.86	0.79	0.99	212.26	1.45	2.27	0.94	299.99	528.49
2	12	9.47	73.01	74.93	1.70	1.11	232.30	1.91	2.20	0.79	336.06	559.43
4	1	8.56	71.45	73.05	1.54	1.05	249.90	3.16	1.62	2.05	316.31	587.63
4	3	6.91	68.87	70.49	1.47	0.94	216.26	2.06	2.08	1.08	376.95	546.19
4	4	8.79	71.76	72.84	1.14	1.05	221.68	2.31	1.28	0.99	342.32	536.24
4	5	8.77	72.41	73.59	1.17	1.07	218.15	2.23	1.27	1.05	308.51	596.83
4	6	8.88	72.05	72.77	0.96	1.02	211.71	2.73	1.81	0.83	327.37	646.57
4	7	7.90	71.92	73.16	1.16	0.99	217.15	2.57	1.47	1.63	337.98	504.08
4	8	8.18	70.18	70.48	0.11	0.99	214.17	2.26	1.61	1.08	318.56	501.43
4	9	7.11	73.47	74.29	1.06	1.06	216.52	1.69	1.71	1.55	336.53	468.50
4	12	9.23	73.23	74.62	1.38	1.01	226.83	3.27	2.41	0.94	308.95	604.05
6	1	7.57	69.69	70.57	1.16	1.10	220.63	1.44	1.58	1.99	319.94	482.78
6	3	5.92	66.22	67.55	1.32	1.02	187.62	1.03	1.75	1.97	327.94	433.81
6	4	8.00	68.81	70.64	1.94	1.09	200.53	1.81	1.43	2.05	305.10	482.68
6	5	7.18	70.16	72.30	2.06	1.04	207.90	1.71	1.30	2.10	297.51	491.95
6	6	7.25	70.13	71.46	1.35	1.01	205.04	1.66	1.76	2.11	288.89	567.99
6	7	6.79	69.74	71.15	1.46	1.02	197.99	1.65	1.47	2.45	327.03	563.54
6	8	7.43	69.73	71.07	1.44	1.07	198.47	1.57	1.45	2.17	332.25	508.62
6	9	7.98	69.62	70.65	1.00	1.00	206.67	1.18	1.65	2.12	333.36	487.40
6	12	9.42	70.99	72.40	1.32	0.98	219.58	1.68	2.09	2.53	342.33	565.30
7	1	7.83	71.53	72.75	1.15	1.02	232.23	3.18	1.79	0.90	309.48	553.55
7	3	6.82	68.99	70.28	1.21	0.95	213.78	1.91	1.69	0.82	327.69	476.08
7	4	9.19	70.51	71.98	1.50	1.08	224.85	1.96	1.49	0.91	339.40	538.71
7	5	7.85	71.00	72.04	1.02	1.00	228.55	1.46	1.65	0.94	324.12	604.50
7	6	8.01	71.85	72.87	1.20	1.03	213.83	2.00	1.88	1.37	339.70	517.12
7	7	8.62	71.16	72.22	1.02	1.00	222.65	2.08	1.76	2.07	329.01	534.21
7	8	7.69	71.02	71.82	1.04	0.99	217.41	2.43	1.52	0.97	291.20	542.91
7	9	7.09	70.91	72.63	1.63	0.98	209.70	1.86	1.75	1.02	367.58	449.37
7	12	9.13	73.23	74.50	1.30	0.95	228.77	2.91	2.27	1.15	375.58	520.70
8	1	7.68	71.21	72.56	1.18	1.22	232.51	1.90	1.46	2.67	357.76	520.70
8	3	7.78	69.75	70.86	1.06	1.00	214.54	1.57	1.53	2.89	323.16	470.90
8	4	8.85	70.89	71.98	1.18	1.07	207.25	1.68	1.42	2.46	296.11	543.23
8	5	8.02	72.37	73.94	1.45	1.05	223.04	1.75	1.31	2.62	314.15	526.54
8	6	8.05	72.35	74.07	1.68	0.99	212.61	1.99	1.49	2.55	284.84	535.58
8	7	7.19	71.61	73.05	1.55	1.16	229.28	1.99	1.71	2.07	332.87	468.57
8	8	7.57	70.10	71.55	1.24	1.07	221.49	1.66	1.31	2.58	338.22	479.57
8	9	7.71	70.77	72.00	1.17	1.09	230.45	1.36	1.87	1.84	324.68	570.22
8	12	9.26	71.84	73.61	1.84	1.17	243.57	2.31	2.23	1.74	380.44	455.80
9	1	8.95	70.74	72.46	1.54	0.94	247.48	2.58	2.07	2.58	360.18	508.09
9	3	7.88	71.16	72.18	1.04	0.99	222.60	1.18	1.77	2.56	320.28	549.47
9	4	8.28	71.42	73.11	1.66	1.04	241.51	1.52	1.56	2.52	304.66	561.66
9	5	6.02	72.96	74.68	1.79	0.96	234.50	1.76	1.78	2.58	306.40	404.73
9	6	7.34	72.62	74.18	1.68	0.91	234.49	1.45	1.70	2.48	302.84	602.80
9	7	8.30	72.32	73.52	1.31	1.01	226.95	1.45	2.14	3.00	326.39	546.47
9	8	7.40	71.51	72.92	1.38	1.12	236.17	1.20	1.91	3.09	329.92	496.86
9	9	8.47	72.28	73.65	1.15	1.04	232.89	1.34	1.98	2.47	342.39	555.48
9	12	10.21	73.37	74.26	0.92	1.03	265.47	2.26	2.27	0.89	357.61	594.10
10	1	9.37	71.29	71.96	0.70	1.08	244.84	2.73	1.56	2.62	365.86	445.03
10	3	7.92	69.09	69.99	1.04	1.05	221.86	1.45	1.58	3.13	333.31	474.07
10	4	8.26	73.59	74.94	1.35	1.04	218.89	1.71	1.47	2.04	309.68	534.04
10	5	7.77	72.71	74.15	1.64	1.01	220.44	1.78	1.55	2.07	326.21	556.64
10	6	7.07	73.99	74.76	0.84	1.02	214.52	2.39	1.56	2.93	303.26	543.27
10	7	8.06	73.41	74.42	1.16	1.00	213.70	2.24	1.57	3.12	294.09	608.00
10	8	8.87	71.35	71.79	0.47	1.03	213.82	1.78	1.43	3.43	292.53	553.30
10	9	8.32	72.23	72.83	0.50	1.05	227.73	1.10	1.44	1.98	327.96	611.78
10	12	9.91	74.03	74.70	0.74	1.07	239.13	2.17	1.81	0.85	332.24	561.35
11	1	8.26	71.47	72.83	1.21	1.06	247.31	2.82	1.58	2.05	355.09	560.49
11	3	9.50	71.24	72.09	0.87	1.03	233.34	1.86	1.52	2.62	361.82	475.19
11	4	7.59	73.78	74.89	1.00	0.99	222.77	1.84	1.39	2.51	336.69	548.31
11	5	7.50	72.60	74.18	1.52	0.98	229.82	2.05	1.44	2.48	317.38	527.02
11	6	8.54	73.96	74.97	0.95	1.01	217.34	1.86	1.35	3.60	345.64	522.45
11	7	7.82	72.21	73.90	1.68	0.99	223.03	1.85	1.64	3.05	367.34	548.62
11	8	8.72	72.40	73.01	0.68	0.97	220.86	1.85	1.43	3.52	357.89	449.18
11	9	9.12	71.70	71.65	-0.18	0.97	230.30	1.32	1.49	1.87	355.57	587.09
11	12	9.28	73.84	75.77	1.88	1.01	250.70	1.64	1.84	1.43	395.53	444.17
MEAN		8.01	71.42	72.69	1.27	1.02	222.45	1.92	1.7	1.95	329.82	523.8
LSD		2.73	1.91	2.14	1.65	0.18	23.22	1.08	1.07	1.00	22.72	20.45
CV		29.88	2.34	2.58	11.56	15.67	1971.78	40.27	44.97	25.57	22.72	20.45