CHARACTERIZATION OF MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

A Dissertation

by

FRANCIS MAIDENI

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2006

Major Subject: Plant Breeding

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Approved by:

Chair of Committee,	Javier F. Betrán
Committee Members,	William L. Rooney
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ABSTRACT

Characterization of Maize Testing Locations in Eastern and Southern Africa. (May 2006)

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Chair of Advisory Committee: Dr. Javier F. Betrán

The region of eastern and southern Africa is very diverse in environments and agronomic practices. The region has one of the highest per capita consumption of maize (*Zea mays.* L), which is predominantly produced by smallholder farmers. Some important constraints facing these farmers include drought and low fertility. For decades, the International Center for Wheat and Maize Improvement (CIMMYT) has been involved in developing maize genotypes that have high grain yields and are tolerant to drought, low fertility and other important constraints. This germplasm is developed for wide adaptation. However, the development of superior germplasm is significantly affected by interaction between genotypes and the environment (i.e., genotype by environment interaction, GEI). To estimate and understand GEI maize genotypes are evaluated in a range of environments representing as much variability of the target growing areas as possible. Because of dwindling resources needed to conduct testing in the region, it may not be possible to test in all potential target areas. Therefore, a careful process of site selection for testing is essential to improve efficiencies in cultivar testing and deployment.

The objective of this research was to characterize the maize testing locations of the eastern and southern Africa region. Historical data from CIMMYT Regional Trials from 1999 to 2003 was used to characterize the environments and estimate genetic parameters.

Environmnent and GEI showed consistently high contributions to the total variation observed among genotypes for grain yield. Environment contributed over 60% and sometimes up to 85% of total variation observed. Sequential retrospective pattern analysis (Seqret) was conducted on the adjusted standardized grain yield.

A total of 7 groups of environments were identified. Repeatabilites, a measure of the proportion of phenotypic variation that is due to genetic differences, was reduced under stress conditions. The relationship among traits showed that anthesis-silking interval (ASI) is an important selective trait, which can improve selection efficiency for grain yield under stress conditions. Stability analysis provided an opportunity to observe the response and adaptation of genotypes to a wide range of environments. Variety ZM621 was a stable and high yielding genotype.

DEDICATION

I would like to dedicate this work to my brother-in-law the late Mr. Frank Tony Chamanga.

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TABLE OF CONTENTS

LIST OF TABLES

TABLE Page

TABLE | Page

TABLE Page

LIST OF FIGURES

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

FIGURE Page

CHAPTER I

INTRODUCTION

Sustained and improved food production has a vital role to play in enhancing food security, social and economic development, peace and democracy in Africa. This remains a practical and direct option for fighting malnutrition and general poverty in the continent. This is rational because the bulk of the population in Africa lives in the rural areas and largely depends on rain fed agriculture. Positive changes in household agricultural productivity, which may result in increased household incomes, would generate further rounds of spending that stimulate economic growth by increasing demand for rural nonfarm and urban industrial products and services. Increased crop productivity could be achieved by increasing area of production or/and increasing production per unit area. Increasing agricultural production by increasing hectarage is becoming more and more difficult in most parts of Africa because of high population growth. The current focus for crop improvement is therefore to increase production per unit area. This is achieved through use better crop management and protection techniques and use of improved germplasm. Maize, with its high yield potential and ease of processing and marketing in urban consumers, has considerable potential to help reverse the downward spiral of food production in Africa (Blackie, 1994). In most countries in Africa use of improved germplasm is relatively low. Table 1.1 shows the estimate of extent of hybrid use in selected countries of the World. For eastern and southern Africa, Zimbabwe, South Africa, Lesotho, Kenya and Zambia show high percentage use of hybrids at 100%, 94%, 80%, 74% and 65% respectively. In other parts, there is still a long way to go, for example in Rwanda, where there is no yet use of hybrid maize.

Maize is the staple food for more than 250 million people in eastern and southern Africa, who gets their income and subsistence directly from agriculture. Maize therefore has a unique strategic importance for food security and socio-economic stability of the region. In most countries of the region, the major objective of households' decision making is to produce or access enough maize to satisfy annual needs (Smale and Heisy, 1997). Consumption of maize is high throughout the region and accounts for over 50% of the total calories and per capita annual consumption averages more 100Kg in several countries (Table 1.2). The region has also the greatest maize grain yield variability in the developing world due to high variability in

This dissertation follows the style and format of Crop Science.

environmental, edaphic and management factors. This has a direct significance in germplasm development because the materials are developed to suit in a wide range of environments.

Table 1.1. Estimated area planted to maize hybrids as a percentage of total maize area in selected African countries in 1993.

Country	Percent	Country	Percent	Country	Percent
Egypt	28	Kenya	74	Zambia	65
Benin	0	Rwanda	0	Guatemala	12
Ghana	0	Mozambique	4	Honduras	12
Nigeria	3	Tanzania	6	Mexico	29
Togo	1	Uganda	5	Nicaragua	3
Cameroon	5	Lesotho	80	Venezuela	95
Ethiopia	4	Zimbabwe	100	United States	100
Malawi	24	El Salvador	34	South Africa	94

Source: CIMMYT, 1994.

CIMMYT maize germplasm development and deployment activities in eastern and southern Africa are aimed at helping the poor in developing countries by increasing the productivity of resources committed to maize while preserving the natural resources (water, nutrients and land) (CIMMYT, 1996). The germplasm development activities are directed towards tropical maize growing areas at elevations ranging from 800 to 1800 above sea level, and comprise approximately 6.5 million hectares in eastern and southern Africa with a regional maize yield average of 1.2 Mg ha^{-1}, with the majority of smallholder farmers obtaining yields of less than a ton per hectare. Important maize production constraints include poor quality germplasm, drought, low and declining soil fertility, maize streak virus and grey leaf spot (produced by *Cercospora zeae maydis*). Specifically, CIMMYT maize breeding research in sub-Saharan Africa is addressing these constraints by making available to the region, materials with increased yields and adaptability and which perform better under drought, low nitrogen and specific disease presence. Those conditions are typical to most smallholder farmers in the region.

Table 1.2. Average maize production and per capita consumption for eastern and southern Africa, Mexico and the USA for years 1999 to 2002.

Country	Production (000 Metric tons)	Per capita Consumption (Kg/year)
Angola	419	37.8
Botswana	8	42.3
Congo, Dem Republic of	1177	22.3
Ethiopia	2945	42
Kenya	2400	84.7
Lesotho	124	149.1
Madagascar	174	9.4
Malawi	2032	181.3
Mozambique	1149	60.2
Namibia	26	41.3
Rwanda	73	10.1
South Africa	9294	107.3
Swaziland	91	64.2
Tanzania, United Rep of	2601	72.2
Uganda	1135	30.6
Zambia	727	125.7
Zimbabwe	1398	107.1
Mexico	18674	127.8
United States of America	240423	13.4

Source: FAOSTAT, 2005

Conventionally, germplasm development activities are conducted in research institutions where growing conditions are optimum for the maize and therefore gains in selection and heritabilities/repeatabilities are easily evaluated, attainable and usually higher compared to the random stress conditions of the farmers fields. The unprecedented combination of climatic risk, extreme poverty, and the production constraints cited earlier have resulted with smallholder farmers in the region producing maize in extremely low-input low risk systems which result in very low yields (less than 500 Mg/ha). Genotype-by-environment interactions in southern African maize-growing environments result from factors related to maximum temperature, seasonal rainfall, season length, within season drought, subsoil pH and socio-economic factors that result in sub-optimal input application (Banziger et.al, 2004). For effective deployment and use, maize germplasm had to be developed while taking into account the farmers maize growing conditions. To assess the differences in performance of maize varieties under agronomically well managed conditions, as conventionally used by breeders, and the type of conditions most farmers face, a maize regional testing network was established among countries with stress screening sites. This network was further consolidated with other regional testing efforts so that maize cultivars at pre-release and release stages from the germplasm developing community in the SADC region; vis: public and private seed sector (IARCs, NARS, private seed companies) are now routinely evaluated for drought and low N stress tolerance, responsiveness to optimal conditions and resistance to important diseases. Elite maize (open pollinated and hybrids) germplasm are currently being evaluated through a network encompassing more than 50 collaborators and 30 institutions in eastern and southern Africa. Testing germplasm in multiple locations through out the region results in differences in the ranking order of germplasm among in the various locations. In this dissertation, results from these regional trials from 1999 to 2003 were used to characterize the maize testing locations in eastern and southern Africa. We analyzed the environmental (location) relationships, conducted genetic studies on variance components of mean yields, studied relationships among important maize traits, varietal performance and stability and identified high predictive locations for selection for four maize types and maturity groups; the early to intermediate hybrids (EIHYB), intermediate to late (ILHYB), early populations (EPOP) and intermediate to late populations (ILPOP). The trials were conducted under optimum, controlled drought, low pH and low nitrogen conditions.

CHAPTER II

RELATIONSHIPS AMONG MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

INTRODUCTION

Maize (*Zea mays* L.) is the most important cereal crop in eastern and southern Africa. It accounts for over 50% of total calories consumed by about 250 million people, and over 70% of them live in the rural areas. Because of continued population growth and eating habits in the region, maize production has to experience corresponding improvements in productivity to satisfy the annual requirements. The International Maize and Wheat Improvement Center (CIMMYT) hold an international mandate to increase maize production and improve the productivity of maize-based cropping systems in developing countries including those of eastern and southern Africa. In implementing this mandate CIMMYT collaborates with National Agricultural Research Systems (NARS), private and non-governmental organizations that are involved in germplasm improvement and diffusion activities. This involves among others activities, multilocational testing of advanced lines. The evaluation usually requires a large number of test locations to cover the wide range of regional climatic and edaphic characteristics. However, it has been difficult to cover as much variation as possible while at the same time testing in as few locations as possible in light of shrinking resources and a growing demand for improving the quality of cultivar testing (Yang et al, 2005). The difficulty arises largely because of inconsistent performance of genotypes that are grown and evaluated in different locations. Differential genotypic responses to variable environmental conditions limit the identification of superior and stable hybrids, especially when associated with changes in genotypic ranking. This slows down the process of germplasm development, release and distribution. It is largely a manifestation of genotype-environment interaction. Genotype by environment interaction is the difference between the phenotypic value and the value expected from the corresponding genotypic and environmental values (Baker, 1988b). When responses of two genotypes to different growing locations are compared, an interaction is described statistically as the failure of two response curves to be parallel. This is the variation caused by joint effects of genotypes and the locations. Crossover interaction results in changes in ranking of genotypes and this has significant implications for plant breeding. The main feature of crossover interaction is the intersecting lines in a graphical representation. If the lines do not intersect, there is no crossover interaction (Kang, 1998). In non crossover interaction, the superior genotypes maintain their superiority in various locations, but in varying magnitudes. This may mean that the genotypes are heterogeneous while the test locations are more or less homogeneous.

An understanding of GEI is the main feature in understanding the relationships among maize testing locations, particularly in eastern and southern Africa which has wide variation among the various maize growing areas. However, it is important to note that genotype by environment interaction also provides opportunities for germplasm development. Exploring positive interaction of locations and genotypes while avoiding its negative effects could provide real opportunity for further improvement maize production. Determining the relationship among diverse maize testing locations and their degree of association is valuable in helping plant breeders to more efficiently target the germplasm to the region for broad and specific adaptation. CIMMYT has developed an extensive network of collaborators and testing locations in eastern and southern Africa for evaluation of materials for performance, suitability and adaptation. This cooperative multilocation international testing program which is planned and organized by CIMMYT and implemented in collaboration with the national agricultural research systems (NARS), seed companies and the non-governmental organizations, provides valuable information on yield performance, stability, adaptation, disease tolerance and resistance of newly developed maize hybrids, lines and open pollinated cultivars. In addition to obtaining biological information, the multilocation sites serve as an effective tool for germplasm dissemination. There is no limitation to the number of locations or trial sets sent out each year other than seed availability and cooperator's requests. Maize testing locations should be representative to all the growing areas, but that does not necessarily mean the highest number of locations. The major testing locations are shown in figure 2.1. At each location, the conditions could be optimum, under random drought, low nitrogen and/or low pH.

Fig. 2.1. Map of Africa, showing major maize testing locations in eastern and southern Africa.

Most Consultative Group of International Agricultural Research (CGIAR) centers, including CIMMYT and the national programs, are faced with diminishing resources, and it is not viable to have a non-limited number of test locations. There is a real need to test more efficiently than testing quite extensively. One way is to limit the number of testing sites needed to generate information. Thus, to increase efficiency and to maximize selection gains, identification of key locations for multilocation testing is becoming increasingly important (Abdalla et al., 1996). An understanding of the relationships among international maize testing locations and growing environments in the region is quite valuable for effectively targeting and dissemination of germplasm. This, to some extent acknowledges and appreciates the involvement of the users; the farmers and seed companies, in the development of improved maize hybrids and open pollinated cultivars. In light of these developments in international agricultural research, the challenge is to understand the relationship among the various testing sites and identify groupings of locations that present similar selection environments. The objective of this research was to determine the relationships among the maize testing locations in eastern and southern Africa and identify locations that represent similar selection conditions, which would be the basis for effective limitation of number of testing locations, thereby increasing efficiency in germplasm development and increasing gains in selection.

REVIEW OF LITERATURE

Multilocation testing is important in germplasm development. It not only provides information on genotype performance, but it offers valuable feedback to plant breeders, as it provides opportunities for exchange of information, especially when testing is done in representative locations, to the target growing conditions. Allen et al., (1978) stated that success in breeding programs requires evaluation environments that are representative of the target population of environments. This is relevant even when testing is done under stress conditions. Van Oosterom et al. (1993) and Ceccarelli and Grando (1996) contended that breeding for stress should be performed under conditions that are representative of the target environment. Maize in eastern and southern Africa is grown by largely smallholder farmers and they normally do not apply nitrogen fertilizer, and face random and recurring drought conditions; and these conditions were replicated in the CIMMYT maize regional trials for eastern and southern Africa. In multilocation testing program, genotypes do not perform the same in all locations all the time. They are changes in ranks in time and space. This is of interest to plant breeders because development of cultivars for specific purposes is determined by an understanding of the interaction with repeatable environmental factors (Fehr, 1987).

Variance components of genotype by environment interaction have been used to analyze the relationships among test locations (Horner and Frey, 1957; McCain and Schultz, 1959; Liang et al., 1966; and Schultz and Benard, 1967) and correlations of cultivar yields among test locations had been used to describe their relationships (Guitard, 1960; Hamblin et al., 1980). Peterson (1992) averaged the correlations of 30 years of cultivar yields among locations, and used principal factor analysis to describe similarities among locations.

Peterson and Pfeifer (1989) examined 17 years of yield data from International Winter Wheat Performance Nursery (IWWPN) to characterize international test locations based on cultivar yield responses. They used factor analysis, a multivariate technique for reducing a large number of correlated variables to small number of hypothetical main factors (Cooper, 1983; Cattel, 1965). It was used effectively to understand the underlying structure and relationships among yield components, and using correlations of yield among test locations, principal factor analysis provided an effective means for understanding and describing location relationships and they were able to identify seven regions of similarities of test locations based on yield. He elucidated intraregional production zones which were basis for facilitating precise targeting of wheat breeding and evaluation.

However, the most widely technique for studying relationships among test locations had been cluster analysis based on cultivar differential yield response (Fox et al., 1990; Yau et al., 1991) and pattern analysis, a combination of classification and ordination (Mirzawan et al., 1994; DeLacy et al., 1994).

Relationships among testing environments had been investigated by DeLacy et al, 1994. They reported on long-term association of locations for testing spring bread wheat, in which they looked at results of International Spring Wheat Yield Nursery (ISWYN) which examined the adaptability of spring wheat in many parts of the World. Ordination and clustering of locations was conducted using data collected from ISWYN from 1964 to 1990. A long term squared Euclidean distances (SEDs) among locations, across years was constructed by averaging over the 26 ISWYNs, and the matrix was used to classify the 74 locations from 45 countries using the incremental sum of squares procedure (Ward, 1963; Burr, 1968, 1970; Wishart, 1969) as recommended by DeLacy and Cooper (1990). Ordination of the same matrix was conducted using Principal Coordinate Analysis (Gower, 1966, 1967). They identified two major spring wheat environments, typified as Asian and European and suggested that the mega-environmental classification did not explain all significant associations among locations and that location groupings based on discrimination of germplasm should be considered parallel to mega-environments on regular basis.

Abdalla et al.(1996) reported on relationships among international testing sites of spring durum wheat in which the used the five year data, 1987 to 1991 of Elite durum wheat trail which was planned and distributed by CIMMYT. Over the five year period, yield was reported from 213 trials grown in 41 countries. To describe over-years relationships among sites only locations that reported data for three or more years were used and it resulted in a working data set of 132 trials from 32 locations in 22 countries. They used pattern analysis on standardized grain yield and constructed the final long term SED matrix which was used to classify the 32 locations, with the agglomerative hierarchical clustering procedure with SED as the dissimilarity measure and incremental sum of squares as the grouping strategy as recommended by DeLacy and Cooper (1990). Association among locations identified by PCA was portrayed as proximity plots and the first three vectors of PCA were evaluated by correlation analysis with latitude and precipitation to determine their role in ordination. For spring durum wheat, cluster analysis across years of pooled SEDs among locations indicated that there were two major environments, “European” and “Asian”, and these results parallel the findings of DeLacy et al.,(1994) with 26 year data of spring bread wheat. Both DeLacy et al. (1994) and Abdalla et al. (1996) showed that pattern analysis was an effective technique for describing the relationships among test locations. Grouping of international test locations resulted in clusters containing geographically dispersed locations which suggested the existence transcontinental agroecological zones.

A study conducted by Trethowan et al. (2003) looked at the relationships among bread wheat international trials in dry and semi-arid areas conducted during the period 1992 to 1997. This work was different technically from DeLacy et al., (1994) in that he was looking at wheat bread lines bred specifically for tolerance to moisture stress. They paid particular attention to the reaction of the advanced lines in the various test locations in reaction to drought which is one of the most important abiotic stress condition affecting yields of cereals in the developing nations; who produces the crop virtually exclusively under rain fed conditions. The shifted multiplicative model (SHMM) was used to group locations within each year and pattern analysis was employed to group those sites across years.

Two types of multiplicative models have been used for studying genotype x environment interaction (GEI) and for developing methods for clustering sites or cultivars into groups without crossover interaction (COI) (Cornelius et al., 1992, 1993; Crossa and Cornelius, 1993, 1997; Osman et al., 1997). These are the shifted multiplicative model (SHMM) in which $\bar{y}_{ij.} = ß + \sum^{t}_{k=1} \lambda_k \alpha_{ik} \gamma_{jk} + \bar{\epsilon}_{ij.}$ (Seyedsadr and Cornelius, 1992) and the site regression model (SREG) in which $\bar{y}_{ij.} = \mu_j + \sum^{t}_{k=1} \lambda_k \alpha_{ik} \gamma_{jk} + \bar{\epsilon}_{ij.}$ (Cornelius et al., 1992). The variable $\bar{y}_{ij.}$ is the mean of the i^{th} cultivar (i = 1,2, ..., g) in the j^{th} environment (j = 1,2, ..., e); ß is the shift parameter; μ_j is the site mean; λ_k ($\lambda_1 \geq \lambda_2 \geq ... \geq \lambda_t$) are singular values that allow the imposition of orthonormality constraints on the singular vectors for cultivars, $\alpha_{ik} = (\alpha_{1k}, ... \alpha_{gk})$ and sites, $\gamma_{jk} = (\gamma_{1k} ..., \gamma_{ek})$, such that $\sum_i \alpha^2_{ik} = \sum_j \gamma^2_{jk} = 1$ and $\sum_i \alpha_{ik}\alpha_{ik'} = \sum_j \gamma_{jk}\gamma_{jk'} = 0$ for $k \neq k'$; $\bar{\epsilon}_{ij.}$ is the residual error.

If SHMM and SREG models with one multiplicative component ($SHMM_1$ and $SREG_1$) are adequate for fitting the data and primary effects of the sites, $\hat{\gamma}_{j1}$, all of like sign, then $SHMM_1$ and $SREG_1$ predict non-COI. Thus all cultivars should have consistent patterns of response across all locations included in the analysis (Crossa and Cornelius, 1997). On the contrary, if $\hat{\gamma}_{j1}$ are of different signs, then $SHMM_1$ and $SREG_1$ models predict COI, that is, cultivar ranking in the sites with negative $\hat{\gamma}_{j1}$ are the reverse of the cultivar ranking in the sites with positive $\hat{\gamma}_{j1}$ Multiplicative models are used to determine environmental relationships for a large number of sites which have the same type of entries (cultivars) (Fox et al., 1985, 1990), and that was why they used these models only for within a year analysis and used the pattern analysis for the across years analysis.

Trials conducted in different years contain unbalanced set of cultivars, because breeders are always changing lines, due to non performance or as part of the selection process. In this case pattern analysis had been used successfully to analyze the relationships among test locations (DeLacy and Lawrence, 1988). Pattern analysis as applied to international multienvionmental trials involves the combined use of cluster and ordination techniques to explain genotype by environment interaction. It was first used by Abou-El-Fittouh et al. (1969) when they analyzed the environmental relationships in cotton and further developed by Byth et al. (1976). A two-way hierarchical, agglomerative clustering is performed; and it uses Ward's method of minimum incremental sum of squares and principal components analysis (PCA) on the environment standardized genotype x environment (GXE) matrix (DeLacy and Cooper, 1990). The GXE matrix is the rectangular array of genotype responses in each location. Location standardization involves subtracting the location mean for each entry (genotype) response in a given location and dividing by the standard deviation of the resulting centered responses in that location (Fox and Rosielle, 1982; DeLacy et al., 1990; Cooper, 1983, Cooper et al. 1997). Ward's method of hierarchical classification is based on the squared Euclidean distances between locations and between genotypes calculated from the location standardized matrix. In this method the cluster membership is assessed by calculating the total sum of squared deviations from the mean of a cluster. The criterion for fusion is that it should produce the smallest possible increase in the error sum of squares. Euclidean distances are greatly influenced by larger values and hence the need for standardization. Once these distances are computed for all possible pairs of sites, a dendogram is constructed by a linkage method; furthest or nearest neighbor (Crossa and Cornelius, 1997). The dendogram provides a sequential dichotomous splitting of the data into subsets.

Alagarswamy and Chandra (1998) of International Crop Research Institute for Semi-arid Tropics (ICRISAT) used pattern analysis to investigate the locations relationships and grain yield adaptation for international sorghum multienvironmental trials. They evaluated 12 sorghum genotypes in 25 locations in 1991. After standardization of grain yield data, they conducted the pattern analysis to classify the locations into relevant homogeneous groups and assess the relationships among locations and genotypes. For purposes of classification, an agglomerative hierarchical procedure with an incremental sum of squares grouping strategy; Ward's method

(Ward, 1963) was used, with the squared Euclidean distance as a dissimilarity measure. They used a profile plot of performance of different genotype groups to assess specific and broad adaptation of genotypes and a biplot was used to further assess the patterns of relationships among genotypes and environments and the interrelations among them. They reported that the pattern analysis permitted the sensible and useful summarization of the genotype by environment data set and assisted in examining the natural relationships and variations in the various environments. They were able to structure the sorghum testing locations which led to identification of the two mega-environment groups, Asian and African types. CIMMYT defined a mega-environment as "a broad not necessarily contiguous area, occurring in more than one country and frequently transcontinental, defined by similar biotic and abiotic stresses, cropping system requirements, consumer preference, and for volume of production" (Braun, 1996). Within the mega-environments, sub environment groups were also identified. The environments within the Asian mega-environment tended to be closer in the biplot, indicating that they tend to discriminate among sorghum genotypes similarly. This suggested that it may be possible to reduce the number of testing environments and thereby economizing on the conduct of international sorghum trials. In contrast, the environments in Africa group were widely separated on the graphical display in the biplot which suggested the need to use more testing environments to evaluate genotype adaptation.

Mirzawan et al., (1994) reported on retrospective analysis of the relationships among test environments of the southern Queensland sugarcane breeding program. In instances where a crop breeding program is conducted routinely over a number of years, the data collected from the multi-environmental trials over time provided a large sample of the target environments over years. The common standards that are maintained in the trials over the years allow linking the data sets across the years (Fox and Rosielle, 1982; Eisemann et al., 1990; Cooper et al., 1997). That characteristic had resulted in the increase in the usefulness and value of multi-environmental trials as a unique data set that could be utilized and developed into a historical data base, which then allowed retrospective analysis of repeatable elements of genotype by environment interaction. The pattern analysis was done sequentially according to the accumulated data sets over the years, from 1986 to 1989 and graphical display revealed the relationships among the test location. The different positions of environments shown by the proximity plots indicated differences among locations in the way they discriminated among clones. This indicated the importance of sampling a number of locations for selection among clones for tones of sugar yield per hectare (TSH). The analysis showed that some location discriminated similarly, and that meant that it was possible to reduce the number of test locations.

Sequential retrospective (SeqRet) pattern analysis was used to stratify pearl millet testing sites according to their similarity of line-yield differentiation using grain yield data from 90 multi-environment trials (METs) conducted in the eastern and southern Africa (Mgonja et al. 2002). The trials were conducted in 25 locations and the historical data set comprised of introductory and advanced genetic materials which span 9 years; from 1990 to 1999. The objective of the research was to stratify the pearl millet testing sites in the eastern and southern Africa region based on available historical grain yield data from regional trials to facilitate identification of key benchmark testing sites representative of the underlying production zones in the region. SeqRet pattern analysis was applied on mean data y_{ijk} derived as above from the 67 unique site–year environments for line k=1,…, δij at site i=1,…, nl in year j=1,…, γi, where δ_{ij} is the number of lines tested in (i, j)th site–year environment, n_l the number of sites, and γ_i the number of years in which site i was present. The set of δ_{ij} lines grown in the (i, j) th site–year environment was assumed as a random (representative) sample of all test-lines. For each (i, j)th site–year environment, the y_{ijk} value was transformed to an environment-standardized (ES) value $w_{ijk}=(y_{ijk}-m_{ij})/v_{ij}$, where m_{ij} is the average yield and v_{ij}^2 the phenotypic variance of δ_{ij} line mean yields in (i, j)th site–year environment. The sites that cluster together in classification or occur together in ordination were expected to be similar with respect to discrimination among lines. It was concluded from this study that using the long-term historical data for pearl millet line testing in eastern and southern Africa, enabled an objective assessment of similarities among the sites for the way they discriminated among lines, and thus provided a basis to facilitate selection of few representative sites for future testing of lines.

According to Bradu and Gabriel (1978), biplots had been used increasingly in the analysis of multienvironmental trials. Biplots were an effective tool in visual analysis of two way data. The genotype by environment biplot addressed many questions with regard to cultivar and test environment (location) evaluation. With a biplot display, cultivars could be evaluated for their performance in individual and across locations. Simultaneously, locations could be evaluated and grouped on the basis of their ability to discriminate among genotypes and their representativeness of other test locations. Redundant environments, as well as those that are appropriate for selecting superior genotypes can visually be identified (Yan et al, 2000). They could also reveal the “which won where” pattern of the multienvironmental data which is important for mega-environment identification and cultivar recommendation specific to each mega-environment (Yan and Tinker, 2005). Yan and Tinker (2005) reported on the use of an integrated biplot analysis system for displaying, interpreting and exploring genotype by environment interaction. They looked at GGE and GE patterns where they said that GGE biplots allows for visualizing both mean and stability of genotypes and although G and GE are confounded in GGE biplot it is possible to distinguish patterns due to G from those due to GE. In general the GE biplot is more powerful in environmental classification than the GGE biplot because it displays more GE although the GGE biplot is the single most informative biplot for both genotype and environment evaluation (Yan and Kang 2003, Yan and Tinker, 2005).

MATERIALS AND METHODS

The data sets and maize germplasm

The data sets are from the CIMMYT maize regional trials, which had been conducted routinely and annually to test suitability and adaptation of maize germplasm in the region. These trials facilitate germplasm dissemination and exchange in eastern and southern Africa. The data was collected from 1999 to 2003. These trials evaluated elite pre-released and released maize germplasm supplied by CIMMYT, National Agricultural Research Programs and private seed companies from eastern and southern Africa. The materials are divided into hybrids and open pollinated varieties (OPVs), and according to maturity groups, which formed four distinct replicated trials. Thus, the trials consider were: early to intermediate maturing open-pollinated varieties (EPOP)(anthesis date (AD) between 58 and 68 days), intermediate to late maturing open-pollinated varieties(ILPOP) (AD between 68 and 74 days), early to intermediate maturing hybrids (EIHYB)(AD between 61 and 69 days), and intermediate to late maturing hybrids (ILHYB) (AD between 69 and 74 days).

Trial management

The trials were planned and facilitated by CIMMYT and were managed by various collaborators who included national programs and seed companies in eastern and southern Africa. Each trial is established as an alpha (0,1) lattice design with three replicates. The collaborators were encouraged to plant the trials under the following conditions:

Optimum: the trials were adequately fertilized and grown under rain fed conditions, using optimal site specific agronomic practices.

Managed nitrogen stress: trials were grown in fields that had been depleted of nitrogen by growing unfertilized and non-leguminous crops for several seasons, and removing the biomass after each season. Nitrogen fertilization to maize trials was designed so that yields under managed nitrogen stress averaged 20-35% of the yield of a well fertilized maize crop at the location.

Managed drought stress: trials were grown during the rain-free period, with irrigation applied at the beginning of the season to establish the stand. Afterwards irrigation was withheld and the crop suffered from lack of water during flowering and grain filling.

Managed low pH stress: trials were grown in fields with high aluminum saturation (desirably 60%) and/or low amounts of plant available phosphorus (desirably 3-4 ppm P; i.e. 20-25% of the recommended levels). The objective was to achieve maize yields that were 50-65% below the optimal maize yields at the same location.

Artificial inoculations/infestation of biotic stress factors: trials were grown under artificial inoculations/inoculation of leaf diseases, stem borers and maize grain weevils.

Locations

Trials were planted in various locations in Angola, Botswana, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, South Africa, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe. At each location, the collaborators could plant trials under any of the condition/s and/or a combination of trial management conditions described earlier. Table 2.1 shows major maize testing locations in eastern and southern Africa and Table 2.2 shows all the combinations. Not all tests were carried out in all locations, location management types, all years from 1999 to 2005. A total of 701 tests throughout the five year period were conducted with 386 genotypes hybrids and populations evaluated. The program involved over 50 collaborators from seed companies, national programs, and other non-governmental organizations.

Table 2.1. Major maize testing locations in eastern and southern Africa.

COUNTRY	LOCATION	ELEVATION	LATITUDE	LONGITUDE	MEAN T§	PRE‡
Angola	Cabinda	0	-5.57	12.20	27.34	578
Angola	Chianga	1736	-12.73	15.83	19.52	1049
Angola	Humpata	1468	-15.03	13.43	19.69	619
Angola	Kilombo	432	-8.91	14.73	25.09	794
Angola	Malange	0	-9.53	16.33	22.00	720
Angola	Mazozo	50	-9.10	13.72	26.57	467
Angola	Poligno	1178	-9.52	16.32	21.43	723
Botswana	Goodhope	1231	-25.48	25.47	22.43	365
Botswana	Sebele	972	-24.57	25.95	24.75	383
Ethiopia	Bako	1650	9.10	37.15	18.18	1030
Ethiopia	Melkasa	1550	8.40	39.33	22.18	580
Ethiopia	Pawe	1100	11.23	38.00	20.27	987
Kenya	Bungoma	1386	0.57	34.57	21.06	804
Kenya	Embu	1540	-0.50	37.45	20.35	617
Kenya	Kakamega	1585	0.27	34.74	20.88	806
Kenya	Kiboko	960	-2.25	37.73	23.88	434
Kenya	Kitale	1860	1.01	35.00	17.92	709
Kenya	Sigor	981	1.48	35.47	20.42	533
Lesotho	Leribe	1699	-28.88	28.05	18.13	515
Lesotho	Machache	2273	-29.37	27.92	15.46	516
Lesotho	Maseru	1635	-29.28	27.50	18.72	459
Lesotho	Mokotlong	2359	-29.28	29.08	14.27	510
Lesotho	Teyateyaneng	1596	-29.15	27.75	18.86	468
Malawi	Bembeke	1170	-14.17	34.43	21.24	846
Malawi	Bolero	1177	-10.98	33.75	22.72	740
Malawi	Bvumbwe	889	-15.92	35.07	22.40	936
Malawi	Chitala	733	-13.13	34.07	23.94	1046
Malawi	Chitedze	1097	-13.98	33.63	22.42	794
Malawi	Lunyangwa	0	-11.45	33.92	19.71	874
Malawi	Ngabu	108	-16.47	34.92	27.70	649
Mozambique	Chokwe	33	-24.53	33.00	26.48	481
Mozambique	Lichinga	1305	-13.30	35.23	20.52	1060
Mozambique	Morrumbala	386	-17.28	35.58	25.46	887
Mozambique	Mutarara	41	-17.45	35.07	27.86	682
Mozambique	Nampula	329	-15.10	39.28	26.03	906
Mozambique	Sussundenga	787	-19.33	33.22	23.31	890
Mozambique	Tete	102	-16.17	33.58	28.68	573
Mozambique	Umbeluzzi	23	-26.58	32.38	24.54	440
South Africa	Lwamongo	0	-23.03	30.33	22.54	555
South Africa	Nelspruit	747	-25.47	30.97	23.29	601
South Africa	Potchefstroom	1354	-26.67	27.07	21.75	464

Table 2.1 continued

COUNTRY	LOCATION	ELEVATION	LATITUDE	LONGITUDE	MEAN T§	PRE‡
South Africa	Viljenskroen	1347	-27.17	26.92	20.87	408
South Africa	Betlehem	0	-28.25	28.33	18.56	507
South Africa	Ezolimo	0	-25.20	31.20	22.69	643
South Africa	Greytown	1314	-29.02	30.60	18.01	617
Swaziland	Big Bend	126	-26.86	31.93	24.79	413
Swaziland	Hebron	1348	-26.28	31.01	17.89	729
Swaziland	Malkerns	752	-26.55	31.17	22.15	643
Swaziland	Nhlangano	1076	-27.11	31.22	20.09	608
Tanzania	Arusha	0	-3.18	36.70	15.22	656
Tanzania	Ilonga	550	-6.77	37.03	23.69	768
Tanzania	Ilonga	914	-6.77	37.03	23.69	768
Tanzania	Inyala	1586	-8.87	33.63	20.57	1043
Tanzania	Katrin	0	-8.13	36.68	25.75	1107
Tanzania	Lambo/	1020	-3.23	37.88	24.02	459
Tanzania	Mbimba	1200	-10.00	35.50	23.25	1162
Tanzania	Mbulumbulu	0	-3.25	35.80	19.10	659
Tanzania	Milingano	200	-5.07	38.92	25.72	608
Tanzania	Selian	1287	-3.22	36.37	20.32	601
Tanzania	Ukiriguru	1236	-2.72	33.02	22.52	634
Tanzania	WeruWeru	0	-3.32	37.25	22.63	700
Uganda	Kamayanmiggo	1120	-0.25	31.25	19.38	415
Uganda	Namulonge	1150	0.53	32.58	21.77	520
Uganda	Serere	1067	1.52	33.45	22.79	734
Zambia	Chilanga	1213	-12.30	31.50	23.11	1000
Zambia	Golden Valley	1170	-14.17	28.37	22.38	950
Zambia	Kasama	1384	-10.10	31.10	21.06	1172
Zambia	Livingstone	986	-17.49	25.49	24.40	650
Zambia	Magoye	1049	-15.53	27.45	24.18	749
Zambia	Nanga	1182	-11.12	28.53	23.15	1011
Zambia	Mount-Makulu	1281	-15.53	28.25	21.84	775
Zambia	Msekera	1100	-13.38	32.39	23.84	909
Zimbabwe	Arcturus	1385	-17.78	31.32	21.11	832
Zimbabwe	Chiredzi	433	-21.02	31.58	25.52	498
Zimbabwe	Glendale	1250	-17.08	31.03	21.54	804
Zimbabwe	Harare	1468	-17.80	31.05	20.59	742
Zimbabwe	Kadoma	1309	-18.32	30.90	21.63	664
Zimbabwe	Makoholi	1111	-19.83	30.78	22.22	561
Zimbabwe	Matopos	1457	-20.38	28.50	20.77	526
Zimbabwe	Mazowe	1232	-17.51	30.91	21.43	777
Zimbabwe	Rattray-Arnold	1452	-17.67	31.17	20.60	793
Zimbabwe	Save Valley	446	-20.35	32.33	25.46	388

† At each location, the conditions could be optimum, under random drought, low nitrogen and/or low pH
‡ Pre – total precipitation for 5 months (mm) during the growing season
§ Mean T – mean temperature for 5 months (ºC) during the growing season

Table 2.2. Maize testing locations, management type and test from 1999 to 2003 for eastern and southern Africa.

Table 2.2a. Maize testing locations, management type, and test from 1999 to 2003 for eastern and southern Africa.

ALL (All)	Env. Type†	1999 ILHYB‡	2000 ILHYB	2001 ILHYB	2002 ILHYB	2003 ILHYB	1999 EIHYB	2000 EIHYB	2001 EIHYB	2002 EIHYB	2003 EIHYB	1999 ILPOP	2000 ILPOP	2001 ILPOP	2002 ILPOP	2003 ILPOP	1999 EPOP	2000 EPOP	2001 EPOP	2002 EPOP	2003 EPOP
AFSFTan	OPT							EH00AFT										EP00AFT			
AFSFTanLN	LN							EH00AFTLN													
AFSFTanDrt	DRT												IP00AFTDrt								
AluKenDr	DRT							EH00AluKDrt													
AngMoz	OPT															IP03AngM					
ArcZim	OPT		IH00ArcZ					EH00ArcZ					IP00ArcZ		IP02ArcZ			EP00ArcZ			
ARTZim	OPT	IH99ARTZ	IH00ARTZ	IH01ARTZ	IH02ARTZ	IH03ARTZ	EH99ARTZ	EH00ARTZ	EH01ARTZ	EH02ARTZ	EH03ARTZ	IP99ARTZ	IP00ARTZ	IP01ARTZ	IP02ARTZ	IP03ARTZ	EP99ARTZ		EP01ARTZ	EP02ARTZ	EP03ARTZ
AruTaDrt	DRT		IH00AruTDrt	IH01AruTDrt			EH99AruTDrt	EH00AruTDrt	EH01AruTDrt	EH02AruTDrt				IP01AruTDrt			EP99AruTDrt			EP02AruTDrt	
AruTaLN	LN				IH02AruTLN									IP01AruTLN	IP02AruTLN			EP00AruTLN		EP02AruTLN	EP03AruTLN
AruTan	OPT		IH00AruT	IH01AruT	IH02AruT	IH03AruT				EH02AruT	EH03AruT	IP99AruT		IP01AruT	IP02AruT	IP03AruT		EP00AruT	EP01AruT	EP02AruT	EP03AruT
AruTanDr	DRT								EH01AruTDrt												
AruTanLN	LN					IH03AruTLN			EH01AruTLN				IP00AruTLN						EP01AruTLN		
BakEth	OPT	IH99BakE	IH00BakE	IH01BakE	IH02BakE	IH03BakE	EH99BakE	EH00BakE			EH03BakE	IP99BakE	IP00BakE	IP01BakE		IP03BakE		EP00BakE	EP01BakE		
BakMal	OPT							EH00BakM	EH01BakM	EH02BakM	EH03BakM						EP99BakM	EP00BakM	EP01BakM	EP02BakM	EP03BakM
BemMal	OPT		IH00BemM		IH02BemM										IP02BemM						
BetRSA	OPT																		EP01BetR		
BigSwa	OPT									EH00BigS											
BolMal	OPT							EH00BolM													
BulUga	OPT					IH03BulU										IP03BulU					
BunKen	OPT		IH00BunK		IH02BunK								IP00BunK						EP01BunK		
BvuMal	OPT				IH02BvuM	IH03BvuM							IP00BvuM			IP03BvuM					
BvuMaLpH	LpH			IH02BvuMLpH										IP01BvuMLpH							
BwaMal	OPT							EH00BwaM													
CabAng	OPT					IH03CabA	EH99CabA	EH00CabA	EH01CabA	EH02CabA	EH03CabA									EP02CabA	EP03CabA
CabAnLpH	LpH															IP03CabALpH					EP03CabALpH
CelAng	OPT														IP02CelA						
ChiAng	OPT				IH02ChiA				EH01ChiA	EH02ChiA				IP01ChiA	IP02ChiA				EP01ChiA	EP02ChiA	
ChiAngLN	LN								EH01ChiALN										EP01ChiALN	EP02ChiALN	
ChiAngLpH	LpH								EH01ChiALpH												
ChiAnLN	LN													IP01ChiALN							
ChiAnLpH	LpH													IP01ChiALpH					EP01ChiALp	EP02ChiALpH	
ChiMal	OPT						EH99ChiM	EH00ChiM		EH02ChiM	EH03ChiM										
ChiMalDr	DRT																				
ChiZam	OPT					IH03ChiZ					EH03ChiZ					IP03ChiZ					EP03ChiZ
ChiZiDrt	DRT	IH99ChiZDrt		IH01ChiZDrt								IP99ChiZDrt	IP00ChiZDrt		IP02ChiZDrt			EP00ChiZDrt			
ChiZiLN	LN					IH03ChiZiLN										IP03ChiZLN					EP03ChiZLN
ChiZim	OPT		IH00ChiZi				EH99ChiZi			EH02ChiZi	EH03ChiZi						EP99ChiZi				
ChiZimDr	DRT							EH00ChiZDrt												EP02ChiZDrt	
ChoMoz	OPT									EH02ChoM	EH03ChoM								EP01ChoM	EP02ChoM	
ChrZiDrt	DRT				IH02ChrZDrt																
ChtMaDrt	DRT			IH01ChtMDrt										IP01ChzMDrt	IP02ChzMDrt						
ChtMal	OPT		IH00ChtM			IH03ChtM						IP99ChtM	IP00ChtM				EP99ChtM	EP00ChtM	EP01ChtM	EP02ChtM	EP03ChtM
ChtMalDrt	DRT				IH02ChtMDrt				EH01ChtMDrt										EP01ChtMDr	EP02ChtMDrt	
ChtMaLN	LN												IP00ChtMLN		IP02ChtMLN						
ChzMal	OPT	IH99ChzM	IH00ChzM	IH01ChzMLN	IH02ChzMLN									IP01ChzMLN	IP02ChzMLN	IP03ChzMLN					
ChzMaLN	LN			IH01ChzMLN	IH02ChzMLN											IP03ChzMLN					EP03ChzMLN
DakTan	OPT									EH02DakT										EP02DakT	
EmbKen	OPT	IH99EmbK	IH00EmbK		IH02EmbK			EH00EmbK						IP01EmbK				EP00EmbK			
EzoRSA	OPT																	EP00EzoR	EP01EzoR		
EzoRSLN	LN																		EP01EzoRL	EP02EzoRLN	
FreRSLN	LN																			EP02FreRLN	
FriRSA	OPT													IP01FriR					EP01FriR		
FriRSLN	LN																		EP01FriRLN		
GleZim	OPT	IH99GleZ										IP99GleZ					EP99GleZ				
GolZaLN	LN									EH02GolZLN											
GolZam	OPT								EH01GolZ		EH03GolZ										EP03GolZ
GolZamLN	LN						EH99GolZLN		EH01GolZLN	EH02GolZLN											

† OPT,LN,LpH,DRT = Optimum, low nitrogen, low pH and random drought respectively

‡ ILHYB,EIHYB,ILPOP,EPOP = Intermediate to late population, early to intermediate population, intermediate late population and early population

Table 2.2. continued.

Table 2.2b. Maize testing locations, management type, and test from 1999 to 2003 for eastern and southern Africa.

		1999	2000	2001	2002	2003	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
ALL (All)	Env. Type†	ILHYB‡	ILHYB	ILHYB	ILHYB	ILHYB	EIHYB	EIHYB	EIHYB	EIHYB	EIHYB	ILPOP	ILPOP	ILPOP	ILPOP	ILPOP	EPOP	EPOP	EPOP	EPOP	EPOP
GooBoLN	LN																				EP03GooBLN
GooBot	OPT		IH00GooB	IH01GooB	IH02GooB	IH03GooB		EH00GooB	EH01GooB	EH02GooB	EH03GooB	IP99GooB	IP00GooB	IP01GooB	IP02GooB	IP03GooB	EP99GooB	EP00GooB	EP01GooB	EP02GooB	EP03GooB
GreRSA	OPT	IH99GreR	IH00GreR	IH01GreR	IH02GreR	IH03GreR	EH99GreR		EH01GreR	EH02GreR	EH03GreR							EP00GreR			EP03GreR
HarZiCLN	LN	IH99HarZLN	IH00HarZLN	IH01HarZLN	IH02HarZLN	IH03HarZLN												EP00HarZLN		EP02HarZLN	
HarZim	OPT			IH01HarZ				EH00HarZ	EH01HarZ	EH02HarZ	EH03HarZ			IP01HarZ	IP02HarZ				EP01HarZ		
HarZiMSV	MSV	IH99HarZMS	IH00HarZMSV						EH01HarZMSV				IP00HarZMS	IP01HarZMSV		IP03HarZMSV		EP00HarZMS	EP01HarZMSV		EP03HarZMSV
HukBot	OPT																		EP01HukB		
HumAng	OPT				IH02HumA	IH03HumA				EH02HumA	EH03HumA		IP00HumA	IP01HumA	IP02HumA	IH03HumA		EP00HumA		EP02HumA	EH03HumA
IloTaLN	LN				IH02IloTLN									IP01IloTLN	IP02IloTLN				EP01IloTLN	EP02IloTLN	
IloTan	OPT		IH00IloT			IH03IloT	EH00IloT			EH02IloT	EH03IloT			IP01IloT	IP02IloT		EP99IloT		EP01IloT	EP02IloT	
KadZim	OPT		IH00KadZ	IH01KadZ	IH02KadZ	IH03KadZ		EH00KadZ	EH01KadZ	EH02KadZ	EH03KadZ			IP01KadZ		IP03KadZ		EP00KadZ			EP03KadZ
KakKen	OPT		IH00KakK		IH02KakK								IP00KakK								
KamUga	OPT			IH01KamU				EH00KamU					IP00KamU								
KasZaLpH	LpH												IP00KasZLpH								
KatTan	OPT	IH99KatT			IH02KatT									IP01KatT	IP02KatT		EP99KatT			EP02KatT	
KibKen	OPT																	EP00KibK			
KilAng	OPT												IP00KilA	IP01KilA	IP02KilA	IP03KilA				EP02KilA	EP03KilA
KitKen	OPT	IH99KitK	IH00KitK	IH01KitK	IH02KitK			EH00KitK					IP00KitK	IP01KitK				EP00KitK			
KitKenLN	LN							EH00KitKLN													
LamTan	OPT							EH00LamT					IP00LamT								
LerLeLpH	LpH																		EP01LerLLpH		
LicMoLN	LN														IP02LicMLN						
LicMoz	OPT				IH02LicM	IH03LicM									IP02LicM	IP03LicM					
LikTan	OPT						EH99LikT														
LunMal	OPT								EH01LunM	EH02LunM	EH03LunM										
LunMaLpH	LpH			IH01LunMLpH	IH02LunMLpH	IH03LunMLpH								IP01LunMLpH	IP02LunMLpH	IP03LunMLpH					EP03LunMLpH
LuvSwa	OPT																			EP02LuvS	
LwRSA	OPT								EH01LwR												
MacLes	OPT																	EP00MacLes	EP01MacLes		
MagZam	OPT	IH99MagZ		IH01MagZ			EH99MagZ		EH01MagZ			IP99MagZ		IP01MagZ			EP99MagZ		EP01MagZ	EP02MagZ	
MahLes	OPT									EH00MahL									EP01MahL		EP03MahL
MakMal	OPT													IP01MakM	IP02MakM	IP03MakM					
MakZiLN	LN			IH01MakZLN	IH02MakZLN													EP00MakZLN		EP02MakZLN	
MakZim	OPT				IH02MakZ	IH03MakZ		EH00MakZ	EH01MakZ	EH02MakZ	EH03MakZ	IP99MakZ	IP00MakZ	IP01MakZ		IP03MakZ			EP01MakZ	EP02MakZ	EP03MakZ
MalAng	OPT				IH02MalA					EH02MalA					IP02MalA				EP01MalA		
MalSwa	OPT														IP02MalS	IP03MalS				EP02MalS	EP03MalS
MarZim	OPT					IH03MarZ													EP01MarZ		EP03MarZ
MarZiLpH	LpH					IH03MarZLpH									IP02MarZLpH				EP01MarZLpH		EP03MarZLpH
MasLes	OPT								EH01MasL	EH02MasL	EH03MasL								EP01MasL		EP03MasL
MasNam	OPT														IP02MasN					EP02MasN	
MasZam	OPT											IP99MasZ		IP01MasZ							
MazAnDrt	DRT																				
MazAng	OPT				IH02MazA	IH03MazA		EH00MazA	EH01MazA	EH02MazA	EH03MazA		IP00MazA	IP01MazA	IP02MazA	IP03MazA		EP00MazA	EP01MazA	EP02MazA	EP03MazA
MazAnLN	LN				IH02MazALN			EH00MazAL	EH01MazALN			IP99MazALN		IP01MazALN	IP02MazALN	IP03MazALN	EP99MazALN		EP01MazAL	EP02MazALN	
MazZim	OPT		IH00MazZ					EH00MazZ										EP00MazZ	EP01MazZ		
MBaMal	OPT		IH00MbaM	IH01MbaM						EH02MbaM			IP00MbaM	IP01MbaM							
MbuTan	OPT		IH00MbuT	IH01MbuT	IH02MbuT	IH03MbuT				EH02MbuT	EH03MbuT			IP01MbuT	IP02MbuT	IP03MbuT					
MelEth	OPT									EH02MelE									EP01MelE		
MisKZam	OPT														IP02MisZ						
MisZaLpH	LpH		IH00MisZLpH	IH01MisZLpH	IH02MisZLpH	IH03MisZLpH								IP01MisZLpH		IP03MisZLpH			EP01MisZLpH		
MisZam	OPT										EH00MisZ										
MitNam	OPT																	EP00MitN			
MliTan	OPT																EP99MliT				
MonTan	OPT				IH02MonT													EP00MonT			
MorMoz	OPT	IH00MorM					EH99MorM					IP99MorM					EP99MorM				
MorTan	OPT							EH00MorT							IP02MorT	IP03MorT					

† OPT,LN,LpH,DRT = Optimum, low nitrogen, low pH and random drought respectively

‡ ILHYB,EIHYB,ILPOP,EPOP = Intermediate to late population, early to intermediate population, intermediate late population and early population

Table 2.2. continued.

Table 2.2c. Maize testing locations, management type, and test from 1999 to 2003 for eastern and southern Africa.

		1999	2000	2001	2002	2003	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003	1999	2000	2001	2002	2003
ALL (All)	**Env. Type†**	**ILHYB‡**	**ILHYB**	**ILHYB**	**ILHYB**	**ILHYB**	**EIHYB**	**EIHYB**	**EIHYB**	**EIHYB**	**EIHYB**	**ILPOP**	**ILPOP**	**ILPOP**	**ILPOP**	**ILPOP**	**EPOP**	**EPOP**	**EPOP**	**EPOP**	**EPOP**
MoTanDrt	DRT												IP00MorTDrt								
MphMalLN	LN													IP01MphMLN							
MpuRSA	OPT																EP99MpuR		EP01MpuR		
MseZam	OPT		IH00MseZ	IH01MseZ				EH00MseZ	EH01MseZ	EH02MseZ			IP00MseZ			IP03MseZ	EP99MseZ	EP00MseZ	EP01MseZ	EP02MseZ	EP03MseZ
Mt.Zam	OPT				IH02MtZ	IH03MtZ			EH01MtZ		EH03MtZ	IP99MtZ		IP01MtZ	IP02MtZ	IP03MtZ					
MtwKen	OPT											IP99MtwK					EP99MtwK				
Mt-Zam	OPT			IH01Mt-Z						IH02Mt-Z				IP01Mt-Z	IP02Mt-Z	IP03Mt-Z		EP00Mt-Z	EP01Mt-Z	EP02Mt-Z	EP03Mt-Z
MusZaLpH	LpH								EH01MusZLpH												
MutMoz	OPT																EP99MutM				
NaaUga	OPT							EH00NaaU											EP01NaaU		
NamMoz	OPT				IH02NamM	IH03NamM			EH01NamM	EH02NamM	EH03NamM		IP00NamM		IP02NamM	IP03NamM		EP00NamM		EP02NamM	EP03NamM
NamUga	OPT			IH01NamU	IH02NamU	IH03NamU					EH03NamU	IP99NamU		IP01NamU	IP02NamU	IP03NamU	EP99NamU	EP00NamU	EP01NamU		
NanZam	OPT					IH03NanZ			EH01NanZ		EH03NanZ			IP01NanZam		IP03NanZ		EP00NanZ	EP01NanZ	EP02NanZ	EP03NanZ
NanZaLN	LN																	EP00NanZLN			
NaUga	OPT		IH00NaaU										IP00NaaU		IP02NaaU			EP00NaU			
NelRSA	OPT																	EP00NelR			
NgaMal	OPT								EH00NgaM									EP00NgaM	EP01NgaM		
NgaTan	OPT				IH02NgaT					EH02NgaT											
NhlSwa	OPT				IH02NhlS											IP03NhlS					
NyaLes	OPT									EH02NyaL										EP02NyaL	EP03NyaL
PanBot	OPT											IP99PanB					EP99PanB				
PanZim	OPT																EP99PanZ				
PelBot	OPT				IH02PelB	IH03PelB				EH02PelB	EH03PelB		IP00PelB		IP02PelB	IP03PelB		EP00PelB		EP02PelB	EP03PelB
PioZim	OPT												IP00PioZ					EP00PioZ			
PolAng	OPT													IP01PolA							
PotRSA	OPT									EH02PotR					IP02PotR	IP03PotR				EP02PotR	EP03PotR
PotRSALpH	LpH								EHPotRLpH										EP01PotRLpH		
RatZim	OPT	IH99RatZ	IH00RatZ	IH01RatZ		IH03RatZ		EH00RatZ	EH01RatZ		EH03RatZ					IP03RatZ					EP03RatZ
RuwZim	OPT	IH99RuwZ					EH99RuwZ														
SalMal	OPT															IP03SalM					
SaUga	OPT																	EP00SaU			
SavZim	OPT					IH03SavZ			EH01SavZ	EH02SavZ	EH03SavZ			IP01SavZ		IP03SavZ			EP01SavZ		
SavZimDrt	DRT			IH01SavZDrt			EH99SavZDrt														
SebBoDrt	DRT				IH01SebBDrt										IP01SebBDrt					EP02SebBDrt	
SebBoLN	LN																		EP01SebBLN		
SebBot	OPT		IH00SebB			IH03SebB		EH00SebB		EH02SebB	EH03SebB		IP00SebB				EP99SebB	EP00SebB			EP03SebB
SebBotLN	LN																EP99SebBLN	EP00SebBLN		EP02SebBLN	
SelTan	OPT			IH01SelT			EH99SelT		EH01SelT					IP01SelT					EP01SelT		
SemMoz	OPT																EP99SemM				
SerUga	OPT										EH03SerU							EP00SerU	EP01SerU		
SetRSA	OPT													IP01SetR							
SigKen	OPT							EH00SigK										EP00SigK			
SusMoLN	LN			IH01SusMLN	IH02SusMLN										IP02SusMLN						
SusMoz	OPT		IH00SusM		IH02SusM	IH03SusM		EH00SusM			EH03SusM	IP99SusM	IP00SusM	IP01SusM		IP03SusM	EP99SusM	EP00SusM			
SVicAng	OPT								EH00SViA					IP01SViA							
SweSwa	OPT																				EP03SweS
TabTan	OPT															IP03TaT					
TetMoz	OPT														IP02TetM		EP99TetM				
TeyLes	OPT																	EP00TeyL			
TshDRC	OPT																		EP01TshD		
TshRSA	OPT													IP01TshR							
TumTan	OPT									EH02TumT					IP02TumT					EP02TumT	EP03TumT
UkiTan	OPT										EH03UkiT			IP01UkiT	IP02UkiT					EP02UkiT	EP03UkiT
UmbMoz	OPT	IH99UmbM								EH02UmbM		IP99UmbM			IP02UmbM		EP99UmbM	EP00UmbM	EP01UmbM	EP02UmbM	EP03UmbM
VilRSA	OPT								EH01VilR												
WerTan	OPT			IH01WerT	IH02WerT	IH03WerT			IH01WerT					IP01WerT	IP02WerT					EP02WerT	
ZamZam	OPT			IH01ZamZ	IH02ZamZ	IH03ZamZ			EH01ZamZ	EH02ZamZ	EH03ZamZ			IP01ZamZ	IP02ZamZ	IP03ZamZ			EP01ZamZ	EP02ZamZ	EP03ZamZ

† OPT,LN,LpH,DRT = Optimum, low nitrogen, low pH and random drought respectively

‡ ILHYB,EIHYB,ILPOP,EPOP = Intermediate to late population, early to intermediate population, intermediate late population and early population

Data analysis

At CIMMYT the data for each trial x year x location is presented in an excel file, which is generically divided into three worksheets. The fieldbook sheet contains pedigrees and variable traits (anthesis dates for both male and female flowers, plant height, ear height, root lodging, shoot lodging, number of ears, field weight, grain weight, grain moisture, husk cover and shelling percentage). It also shows the location, planting and harvesting dates and plot area. The results sheet displays the entries, all the variables tested and the mean for all the entries for those variables. It also shows the results of analysis of variance for each variable analyzed including overall means and least significant differences (LSD). Finally, the master sheet contains the raw data with variable records for all entries by experimental units or plots.

Analysis of variance

The relative values of the different sources of variation (environment, replication (env), block (rep*env), entry, and entry*environment) were determined using general linear models in Statistical Analysis System (SAS) (1997), considering all the sources as random effects. The data set analized per trial was extracted from the master sheet. The analysis across environments was conducted across all locations, and separately for environments under optimal, low nitrogen, drought and low pH conditions.

Yield adjustment, standardization and pattern analysis

The input data set for pattern analysis was composed by entry means for grain yield. Before the pattern analysis was conducted, the data was adjusted for anthesis date and standardized. The yield was adjusted in Excel by a regression slope = INDEX (LINEST (P2:P51, T2:T51), 1); and intercept INDEX (LINEST (P2:P51, T2:T51), 2); P and T were yield and anthesis date columns, respectively. Predicted grain yield was calculated in Excel as W = T2*U2+V2 where T, U and V were anthesis date, slope and intercept. The adjusted grain yield was calculated in Excel as Y = P2-(W2-X2) where P, W and X were grain yield for the entry, its predicted yield and mean of the trial, respectively. This adjustment was necessary to remove the effect of flowering on grain yield. After adjustment, values for grain yield were standardized to balance the pair wise analysis and comparisons during calculation of Euclidean distances in pattern analysis. This yield adjustment and standardization was conducted for the 701 trial x year x environment combinations.

The Harare maize streak virus location is an artificial environment for virus screening and was not included in the analysis.

The pattern analysis across location for each trial within a year was conducted using routines in IRRISTAT (IRRI, 2002). Pattern analysis was conducted for all trials, early to intermediate hybrids (EIHYB), intermediate to late hybrids (ILHYB), early population (EPOP) and intermediate to late population (ILPOP) starting from 1999 to 2003; 5 growing seasons, and hence generated a cluster dendrogram for each test at each year. There were a total of 20 cluster dendograms produced. There were fewer locations per test in 1999 than they were in 2000 to 2003. The program was still under development and collaborators from various countries in the region were still being exposed to the idea. Number of locations increased from 25 per test in 1999 to 102 per test in 2003.

At each test locations collaborators were encouraged to grow under optimum conditions and also under some predefined stress conditions. The predefined conditions were random drought, low nitrogen and low pH. It may be possible that some locations which managed more that a single scenario in a single season. This resulted in an increase in the number of test locations/management trials, thus locations were not considered as locations per se; but rather as environments with specific management conditions. The identification of environments in the pattern analysis is based on the country, location and management condition. Under optimal conditions, there was no extension on the name. For example; Harare, Zimbabwe, optimum conditions is identified in the cluster dendrogram as HarZim while the same test conducted under low N in Zimbabwe was identified as HarZimLN.

Sequential Retrospective (SeqRet) pattern analysis (Mirzawan et al., 1994; DeLacy et al., 1996) was used to stratify the testing sites according to their similarity of entry-yield-differentiation patterns. SeqRet pattern analysis was applied on mean grain yield data derived from the location x environment combinations which were used for two years or more. The environmental standardization (ES) transformation was adopted because ES-data-based pattern analysis relates the sites by their similarity of discrimination among entries (Fox and Rosielle, 1982; DeLacy et al., 1994).

The reduced D matrix was used to classify the sites represented in it using the incremental-sum-of-squares (ISS) clustering algorithm (Ward, 1963). Site-proximity plots were constructed from a principal coordinate analysis (PCoA) of the corresponding reduced similarity matrix A. The first two principal coordinate axes were used to graphically depict the sequential change in, and convergence of, site relationships as more years' data were sequentially added to the analysis. The sites that cluster together in classification or occur together in ordination are expected to be similar with respect to discrimination among entries.

The methodology was implemented using the SEQRET package Version 1.1 (DeLacy et al., 1996). The SEQRET package and its manual are available at the web-site http://pig.ag.uq.edu.au/qgpb. Tests which were conducted in two or more years were used in the pattern analysis (Trethowan et al., 2003). Table 2.3 shows the programs which were run in SeQret pattern analysis to produce the dendograms. The PCL output was used to construct the dendogram in Excel.

Biplot analysis

The use of biplot in interpreting genotype by environment interaction has been advocated and effectively used by numerous investigators including Kempton (1984), but the generic proposal was done by Gabriel (1971).

To generate an AMMI (additive main effect multiplicative interaction) GE biplot (Crossa et al. 2002), the genotype x environment two-way table of yield was first environment-standardized; the environment-standardized table was then decomposed into principal components (PC) via singular value decomposition (SVD). In this analysis an AMMI biplot was generated using an excel add-in. Biplot v1.1 (Smith, 2004). http://www.stat.vt.edu/facstaff/epsmith.html).

Table 2.3 Programs in sequential retrospective pattern analysis.

Programs	Input Files	Output Files		
			Results	
		Intermediate[1]	Interpretation[2]	Plotting[3]
PRESEQ	*.NAQ *.TXT	*.SEQ		
SEQANL	*.NAQ *.SEQ	*.PRX	*.OCC	
SEQELM	*.NAQ *.PRX	*.EMA *.MAE	*.ELM	
SEQCLU	*.NAQ *.EMA	*.CLS	*.SCL	*.PCL
SEQORD	*.NAQ *.EMA	*.ORS	*.SOR	*.POR *.ORP
SEQCOR	*.NAQ *.SEQ *.CLS	*.COS(n) *.ALC(n)	*.SCO(n)	
SEQSUM	*.NAQ *.CLS *.ORS *.AL1 *.ALC		*.SUM	*.DER

[1] Intermediate files required as input for further programs.
[2] Interpretation files contain summaries of analyses to be used for interpretation.
[3] Plotting files contain summary output in a format suitable to be imported into the worksheets of charting packages for producing dendrograms or discrimination plots as required.

RESULTS

Analysis of variance

A combined analysis of variance (Tables 2.4 to 2.23) for all sites and across optimum sites indicated that the interaction, Entry*E (genotype x location), entry and all other sources of variation were highly significant. However, at low N, low pH and drought conditions entry (genotype) and genotype x location (g x e) interaction were not significant. The variation due to genotype x environment interaction was larger than the variation due to genotypes or entries.

There was significant reduction in yield under stress conditions, which were drought, low nitrogen and low pH. For example; in Table 2.7 which shows the Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 2002, the mean grain yield for the optimum locations was 4.50 Mg/ha, while the mean grain yield across stress locations were 1.92 Mg/ha, 2.26 Mg/ha, and 1.69 Mg/ha across drought, low nitrogen, and low pH locations respectively. For Table 2.11which sowed the Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 2001, the mean grain yield was 5.85Mg/ha and mean grain yield across stress locations were 2.99Mg/ha, 2.26Mg/ha and 1.69Mg/ha across drought, low nitrogen, and low pH locations respectively. The acidic (low pH) condition resulted in the highest reduction in yield.

These results clearly suggest real presence of location by genotype interaction, and that its effect could have been sufficient to affect selection and identification of superior genotypes as genotypes performance varied from one location to the other. The characterization of maize testing locations in eastern and southern Africa is therefore fully justified.

Table 2.4. Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 1999.

	Across optimum env.			Across drought env.			Across low N env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	11	789.24***	79.54	2	32.92***	14.75	1	47.62***	18.05	16	680.06***	79.21
Rep (E)	23	10.55***	2.22	6	2.91***	3.92	4	4.56***	6.92	33	8.44***	2.03
Block (Rep*E)	315	1.77***	5.11	81	1.92***	34.98	54	1.72***	35.25	450	1.79***	5.88
Entry	48	5.93***	2.61	48	2.23	24.01	48	1.06	19.46	48	6.67***	2.33
Entry*E	528	2.17***	10.52	96	1.03***	22.33	48	1.12***	20.33	768	1.88***	10.55
Error	785	0.96		207	0.61		138	0.82		1130	0.88	
Mean		**4.45**			**2.16**			**2.82**			**3.83**	
Minimum		**3.58**			**1.04**			**1.64**			**2.87**	
Maxaximum		**5.35**			**3.40**			**3.70**			**4.59**	
Coefficient of variation		**22.09**			**32.14**			**35.16**			**24.40**	
LSD (0.05)		**1.96**			**0.72**			**1.03**			**0.41**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.5. Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 2000.

	Across optimum env.			Across drought env.			Across low N env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	26	322.02***	72.09	2	80.04***	47.27	2	45.45***	18.05	33	328.19***	70.39
Rep (E)	54	6.29***	2.92	6	2.85***	5.06	6	3.91***	6.92	67	5.68***	2.47
Block (Rep*E)	567	1.49***	7.28	63	1.08***	20.11	63	2.53***	35.25	707	1.54***	7.10
Entry	29	8.14***	2.03	29	0.77	6.67	29	2.00*	19.46	29	10.94***	2.06
Entry*E	754	1.47***	9.61	58	0.48	8.31	58	1.22	20.33	957	1.97***	12.27
Error	981	0.71		111	0.38		111	1.07		1218	0.72	
Mean		**4.05**			**1.68**			**2.35**			**3.73**	
Minimum		**2.99**			**1.12**			**1.37**			**2.69**	
Maximum		**4.69**			**2.51**			**3.38**			**4.41**	
Coefficient of variation		**22.75**			**21.08**			**42.69**			**35.00**	
LSD (0.05)		**0.26**			**0.57**			**0.96**			**0.23**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.6. Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 2001.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	24	418.95***	62.89	4	44.75***	17.73	7	132.07***	65.73	42	57.25***	76.10	42	590.84***	76.10
Rep (E)	49	5.09***	1.56	10	8.10***	8.02	14	1.26***	1.25	82	3.98***	1.16	82	4.51***	2.47
Block (Rep*E)	444	1.74***	4.83	90	1.70***	15.20	126	1.00***	8.95	744	42.34***	3.56	744	1.52***	26.29
Entry	41	33.49***	8.59	41	2.76**	11.20	41	1.03**	3.01	39	16.26**	3.81	39	31.11***	10.09
Entry*E	978	2.19***	13.39	164	1.51***	24.56	246	0.59***	10.39	1593	17.23***	9.99	1593	1.99***	10.70
Error	1502	0.92		311	0.75		443	0.34		2379	23.89		2379	0.71	
Mean		**5.33**			**2.93**			**1.63**			**0.79**			**4.04**	
Minimum		**1.06**			**0.89**			**1.41**			**0.17**			**2.69**	
Maximum		**5.93**			**3.69**			**2.31**			**1.27**			**5.00**	
Coefficient of variation		**18.06**			**29.70**			**38.69**			**32.45**			**20.98**	
LSD (0.05)		**0.30**			**0.62**			**0.33**			**0.33**			**0.20**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.7. Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 2002.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	39	455.28***	75.19	4	150.19***	72.60	7	153.97***	65.73	1	7.83***	5.54	54	432.90***	78.80
Rep (E)	80	4.16***	1.41	10	3.27***	3.95	14	3.88***	1.25	4	37.87***	26.78	109	3.66***	1.34
Block (Rep*E)	840	1.20***	4.26	105	0.49***	6.23	126	0.71***	8.95	42	24.40**	17.26	1146	1.03***	3.97
Entry	31	42.76***	5.61	31	1.52**	5.69	41	3.24**	3.01	31	28.94	20.47	29	44.73***	4.37
Entry*E	1208	1.74***	8.91	121	0.50***	7.37	246	0.67***	10.39	31	18.62**	13.17	1561	1.47***	7.76
Error	1641	0.67		168	0.20		443	0.30		77	23.70		1946	0.57	
Mean		**4.50**			**1.92**			**2.26**			**1.69**			**3.94**	
Minimum		**1.46**			**0.33**			**0.88**			**0.45**			**1.30**	
Maximum		**5.56**			**2.47**			**2.79**			**2.42**			**4.80**	
Coefficient of variation		**18.29**			**23.41**			**24.02**			**32.68**			**19.11**	
LSD (0.05)		**0.10**			**0.05**			**0.05**			**0.20**			**0.16**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.8. Analysis of variance across environments for grain yield of early to intermediate hybrids (EIHYB) in CIMMYT maize regional trials during 2003.

	Across optimum env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	38	628.28***	86.19	4	74.23***	45.74	1	66.00***	18.05	46	581.45***	86.04
Rep (E)	78	1.27***	1.41	10	2.70***	4.17	4	2.14***	6.92	93	3.94***	1.18
Block (Rep*E)	584	2.34***	4.26	75	0.77***	8.93	30	0.77***	35.25	699	1.05***	2.35
Entry	35	6.71***	0.84	35	1.48**	7.98	35	0.45*	19.46	33	8.08***	0.86
Entry*E	1330	1.07***	5.14	140	0.53	11.62	35	0.22	20.33	1518	1.05***	5.18
Error	2109	0.53		273	0.51		108	0.20		2326	0.53	
Mean		**3.74**			**2.94**			**1.01**			**3.57**	
Minimum		**3.29**			**1.62**			**0.45**			**1.04**	
Maximum		**4.40**			**2.94**			**1.58**			**4.40**	
Coefficient of variation		**19.61**			**29.49**			**43.96**			**20.42**	
LSD (0.05)		**0.17**			**0.51**			**0.50**			**0.17**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.9. Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 1999.

	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	12	862.24***	60.03	1	96.48***	24.13	1	1.01	0.13	16	956.66***	65.05
Rep (E)	25	17.61***	2.55	4	4.13***	4.13	4	2.41	1.27	33	14.20***	1.99
Block (Rep*E)	400	2.16	5.01	64	0.94***	15.01	60	2.15***	17.01	528	1.90*	4.26
Entry	64	12.17***	4.52	64	1.76**	28.22	64	4.15***	34.91	63	13.68***	3.66
Entry*E	767	2.91***	12.97	64	0.69**	11.19	64	3.12***	27.95	1007	3.04***	13.02
Error	1365	1.88		196	0.35		160	0.89		1723	1.64	
Mean		**5.50**			**2.09**			**3.05**			**5.02**	
Minimum		**4.16**			**0.62**			**0.84**			**3.42**	
Maximum		**6.89**			**3.42**			**4.83**			**6.04**	
Coefficient of variation		**24.92**			**28.40**			**30.88**			**25.51**	
LSD (0.05)		**0.59**			**0.51**			**1.06**			**0.17**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.10. Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 2000.

	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	28	591.99***	63.68	1	96.48***	24.13	1	1.01	0.13	32	601.16***	66.42
Rep (E)	58	19.31***	4.30	4	4.13***	4.13	4	2.41	1.27	65	18.85***	4.23
Block (Rep*E)	754	2.78***	8.06	64	0.94***	15.01	60	2.15***	17.01	849	2.54***	7.45
Entry	46	15.40***	2.72	64	1.76**	28.22	64	4.15***	34.91	43	16.03***	2.38
Entry*E	1288	2.28***	11.27	64	0.69**	11.19	64	3.12***	27.95	1376	2.29***	10.90
Error	1965	1.32		196	0.35		160	0.89		2004	1.24	
Mean		**5.75**			**2.09**			**3.05**			**5.53**	
Minimum		**3.80**			**0.62**			**0.84**			**3.72**	
Maximum		**6.58**			**3.42**			**4.83**			**6.58**	
Coefficient of variation		**19.98**			**28.40**			**30.88**			**20.14**	
LSD (0.05)		**0.34**			**0.51**			**1.06**			**0.31**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.11. Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 2001.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	21	753.51***	71.69	4	128.60***	72.60	7	153.97***	65.73	1	7.83***	5.54	35	809.87***	77.29
Rep (E)	43	10.71***	2.08	10	6.39***	3.95	14	3.88***	1.25	4	37.87***	26.78	70	8.94***	1.70
Block (Rep*E)	641	1.65***	4.78	105	1.61***	6.23	126	0.71***	8.95	42	24.40**	17.26	1050	1.43***	4.09
Entry	43	29.35***	5.72	43	3.39**	5.69	41	3.24**	3.01	31	28.94	20.47	41	33.34***	3.72
Entry*E	903	2.58***	10.55	172	0.93***	7.37	246	0.67***	10.39	31	18.62**	13.17	1435	2.41***	9.42
Error	1156	0.99		273	0.62		443	0.30		77	23.70		1763	0.78	
Mean		**5.85**			**2.99**			**2.26**			**1.69**			**4.66**	
Minimum		**4.30**			**1.71**			**0.88**			**0.45**			**3.27**	
Maximum		**6.99**			**4.39**			**2.79**			**2.42**			**5.77**	
Coefficient of variation		**16.97**			**26.34**			**28.44**			**30.74**			**18.96**	
LSD (0.05)		**0.34**			**0.34**			**0.05**			**0.20**			**0.23**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.12. Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 2002.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	29	626.04***	74.27	4	151.22***	55.35	7	172.76***	61.33	2	94.14***	29.99	45	670.88***	78.07
Rep (E)	59	11.52***	2.78	10	5.70***	5.21	14	8.98***	7.28	4	7.42***	4.73	91	11.50***	2.71
Block (Rep*E)	619	2.32***	5.87	105	1.30***	12.46	126	1.00***	8.58	42	6.30***	42.17	959	2.26***	5.61
Entry	39	16.37***	2.61	39	1.62***	5.80	41	2.17**	4.31	39	0.95	5.92	37	17.82***	1.70
Entry*E	1131	1.67***	7.74	156	0.69**	9.86	246	0.68***	9.42	39	0.84	5.21	1665	1.53***	6.61
Error	1650	0.99		284	0.20		443	0.39		111	0.67		1641	0.85	
Mean		**5.33**			**2.29**			**2.32**			**2.33**			**4.40**	
Minimum		**4.28**			**1.38**			**1.33**			**1.46**			**3.40**	
Maximum		**6.04**			**2.88**			**2.64**			**3.03**			**5.02**	
Coefficient of variation		**18.02**			**28.72**			**26.94**			**35.38**			**21.03**	
LSD (0.05)		**0.29**			**0.47**			**0.35**			**0.76**			**0.22**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.13. Analysis of variance across environments for grain yield of intermediate to late hybrids (ILHYB) in CIMMYT maize regional trials during 2003.

Source of variation	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	34	1128.51***	85.39	4	151.22***	55.35	4	28.86***	17.40	2	71.04***	33.04	43	1017.73***	84.69
Rep (E)	70	7.20***	1.12	10	5.70***	5.21	10	3.56***	5.36	6	6.29***	8.78	87	6.62***	1.11
Block (Rep*E)	735	1.56***	2.55	105	1.30***	12.46	105	1.47***	23.21	63	1.80***	26.39	917	1.57***	2.79
Entry	47	14.59***	1.52	39	1.62***	5.80	47	2.42**	17.14	47	0.56	6.14	45	18.02***	1.56
Entry*E	1595	1.45***	5.16	156	0.69**	9.86	188	0.63***	17.73	94	0.40	8.82	1933	1.58***	5.93
Error	2495	0.76		284	0.20		365	0.35		218	0.33		2942	0.68	
Mean		**4.02**			**2.29**			**2.26**			**1.62**			**3.76**	
Minimum		**2.74**			**1.38**			**1.23**			**1.12**			**2.66**	
Maximum		**4.46**			**2.88**			**2.37**			**3.03**			**4.40**	
Coefficient of variation		**21.72**			**28.72**			**35.36**			**35.38**			**22.05**	
LSD (0.05)		**0.24**			**0.47**			**0.53**			**0.76**			**0.20**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.14. Analysis of variance across environments for grain yield of early populations (EPOP) in CIMMYT maize regional trials during 1999.

	Across optimum env.			Across low N env.			Across drought env			Across all env		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	28	120.04***	64.79	1	96.48***	24.13	1	1.01	0.13	32	104.45***	65.01
Rep (E)	58	5.89***	6.59	4	4.13***	4.13	4	2.41	1.27	65	5.49***	7.06
Block (Rep*E)	435	1.37***	9.53	64	0.94***	15.01	60	2.15***	17.01	849	1.01***	9.80
Entry	23	5.27***	2.34	64	1.76**	28.22	64	4.15***	34.91	43	5.42***	2.88
Entry*E	644	0.86***	10.73	64	0.69**	11.19	64	3.12***	27.95	1376	0.75***	9.74
Error	885	0.35		196	0.35		160	0.89		2004	0.36	
Mean		**3.20**			**2.09**			**3.05**			**3.14**	
Minimum		**2.83**			**0.62**			**0.84**			**2.77**	
Maximum		**3.94**			**3.42**			**4.83**			**3.84**	
Coefficient of variation		**18.95**			**28.40**			**30.88**			**18.98**	
LSD (0.05)		**0.18**			**0.51**			**1.06**			**0.29**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.15. Analysis of variance across environments for grain yield of early populations (EPOP) in CIMMYT maize regional trials during 2000.

	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	38	243.16***	66.11	3	108.18***	70.13	1	117.67***	38.28	44	212.11***	66.09
Rep (E)	76	5.27***	2.87	8	1.73***	3.00	4	6.51***	8.47	89	4.52***	2.85
Block (Rep*E)	684	1.04***	5.08	72	0.72***	11.15	36	1.76***	20.57	804	0.98***	5.57
Entry	27	38.35***	7.41	27	0.80**	4.68	27	0.74	6.54	25	41.40***	7.33
Entry*E	998	1.59***	11.40	81	0.29*	5.07	27	1.67***	14.74	1100	1.46***	11.36
Error	1358	0.73		140	0.20		72	0.49		1415	0.67	
Mean		**3.89**			**1.48**			**2.52**			**3.15**	
Minimum		**1.43**			**0.77**			**1.74**			**1.38**	
Maximum		**4.46**			**2.06**			**2.94**			**4.25**	
Coefficient of variation		**25.29**			**29.84**			**27.65**			**26.07**	
LSD (0.05)		**0.22**			**0.36**			**0.80**			**0.20**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.16. Analysis of variance across environments for grain yield of early populations (EPOP) in CIMMYT maize regional trials during 2001.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	31	191.24***	70.11	6	69.09***	53.17	6	63.69***	65.15	6	167.50***	74.83	53	200.69***	78.11
Rep (E)	64	2.91***	2.21	14	1.19*	2.13	14	0.66**	1.58	14	4.76***	4.96	107	2.27***	1.78
Block (Rep*E)	480	1.07***	6.10	101	1.22***	15.84	105	0.69***	12.42	104	0.89***	6.94	800	0.94***	5.55
Entry	23	16.53***	4.50	23	1.15**	3.40	23	1.21***	4.76	23	0.72	1.23	21	17.93***	2.76
Entry*E	712	1.26***	10.58	137	0.57	10.09	137	0.34*	7.91	138	0.56*	5.74	1113	0.86***	6.99
Error	984	0.56		198	0.60		214	0.22		209	0.40		1412	0.46	
Mean		**4.22**			**2.68**			**1.68**			**1.83**			**3.38**	
Minimum		**3.54**			**2.22**			**1.32**			**1.52**			**2.72**	
Maximum		**5.12**			**3.14**			**2.12**			**2.16**			**4.06**	
Coefficient of variation		**17.72**			**28.95**			**29.24**			**34.57**			**20.11**	
LSD (0.05)		**0.05**			**0.47**			**0.29**			**0.39**			**0.15**	

*, **,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.17. Analysis of variance across environments for grain yield of early populations (EPOP) in CIMMYT maize regional trials during 2002.

	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	36	236.82***	79.37	8	77.81***	77.72	4	105.15***	78.69	50	220.09***	82.60
Rep (E)	74	2.99***	2.06	18	2.68***	6.04	10	2.32***	4.34	102	2.68***	2.06
Block (Rep*E)	442	0.94**	3.90	107	0.33**	4.41	60	0.58***	6.59	609	0.79***	3.62
Entry	19	10.59***	1.87	19	0.58**	1.38	19	0.67***	2.37	18	10.31***	1.39
Entry*E	684	0.90**	5.74	152	0.26	4.93	76	0.19	2.72	900	0.67*	4.54
Error	1058	0.72		215	0.20		129	0.22		1298	0.59	
Mean		**4.02**			**1.84**			**2.28**			**3.49**	
Minimum		**3.56**			**1.49**			**1.73**			**3.05**	
Maximum		**4.90**			**2.13**			**2.61**			**4.17**	
Coefficient of variation		**21.03**			**24.62**			**20.44**			**21.99**	
LSD (0.05)		**0.22**			**0.04**			**0.06**			**0.17**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.18. Analysis of variance across environments for grain yield of early populations (EPOP) in CIMMYT maize regional trials during 2003.

Source of variation	Across optimum env.			Across low N env.			Across low pH env.			Across all env.		
	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	46	449.48***	86.30	9	46.13***	50.15	4	8.30***	29.17	62	367.54***	85.86
Rep (E)	94	3.51***	1.38	20	1.34***	3.24	10	0.76***	6.68	125	2.74***	1.29
Block (Rep*E)	705	0.81***	2.38	150	0.63***	11.35	75	0.23**	15.49	940	0.70***	2.48
Entry	29	12.29***	1.49	29	1.89***	6.63	29	0.29*	7.38	27	16.62***	1.69
Entry*E	1332	0.93***	5.21	261	0.35*	11.11	116	0.17*	17.61	1673	0.85***	5.41
Error	1967	0.40		518	0.28		214	0.13		2469	0.35	
Mean		**2.97**			**1.99**			**0.83**			**2.69**	
Minimum		**2.01**			**1.54**			**0.74**			**1.79**	
Maximum		**3.62**			**2.44**			**1.10**			**2.97**	
Coefficient of variation		**21.13**			**26.55**			**42.41**			**22.05**	
LSD (0.05)		**0.15**			**0.49**			**0.25**			**0.12**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.19 Analysis of variance across environments for grain yield of intermediate late populations (ILPOP) in CIMMYT maize regional trials during 1999.

	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	18	361.14***	85.81	2	20.07***	27.48	1	45.14***	29.70	23	285.02***	85.24
Rep (E)	38	3.37***	1.69	6	4.80***	19.72	4	1.36**	3.57	48	3.07***	1.92
Block (Rep*E)	285	1.02***	3.86	45	0.56**	17.39	30	1.59***	31.45	360	0.94***	4.42
Entry	23	4.76***	1.44	23	0.52	8.07	23	1.09*	16.52	21	5.43***	1.48
Entry*E	414	0.80***	4.37	46	0.32	10.33	23	0.48*	7.29	483	0.65***	4.13
Error	589	0.36		518	0.28		62	0.28		645	0.33	
Mean		**3.75**			**1.98**			**2.52**			**3.44**	
Minimum		**3.05**			**1.49**			**2.09**			**2.80**	
Maximum		**4.50**			**2.81**			**3.52**			**4.23**	
Coefficient of variation		**16.09**			**26.52**			**21.00**			**16.73**	
LSD (0.05)		**0.22**			**0.49**			**0.61**			**0.19**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.20. Analysis of variance across environments for grain yield of intermediate late populations (ILPOP) in CIMMYT maize regional trials during 2000.

Source of variation	Across optimum env.			Across low N env.			Across drought env.			Across all env.		
	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			Mg ha^{-1}			Mg ha^{-1}			Mg ha^{-1}	
Env (E)	25	285.23***	72.11	2	38.71***	36.76	2	141.56***	46.82	33	309.44***	76.13
Rep (E)	52	6.24***	3.28	6	4.67***	13.30	6	10.32***	10.23	67	5.99***	2.99
Block (Rep*E)	468	1.67***	5.53	54	0.67**	17.09	54	3.27***	29.18	606	1.32***	5.98
Entry	27	8.19***	2.37	27	0.48	6.26	27	0.64	2.86	26	9.48***	1.83
Entry*E	674	1.50***	10.28	54	0.44*	11.34	54	0.48	4.25	857	1.24***	7.94
Error	931	0.69		108	0.30		107	0.38		1131	0.61	
Mean		**4.36**			**2.00**			**1.53**			**4.08**	
Minimum		**4.10**			**1.57**			**0.94**			**3.67**	
Maximum		**5.50**			**2.50**			**2.34**			**4.91**	
Coefficient of variation		**18.27**			**27.20**			**39.97**			**19.10**	
LSD (0.05)		**0.26**			**0.51**			**0.57**			**0.21**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Table 2.21. Analysis of variance across environments for grain yield of intermediate late populations (ILPOP) in CIMMYT maize regional trials during 2001.

	Across optimum env.			Across drought env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha-1			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**			**Mg ha-1**	
Env (E)	29	205.85***	69.47	6	54.74***	43.40	6	23.38***	45.72	3	198.08***	67.31	48	206.07***	75.37
Rep (E)	60	7.89***	5.51	14	9.49***	17.56	14	3.11**	14.18	8	3.27***	6.97	97	6.32***	4.67
Block (Rep*E)	450	1.21***	6.38	105	1.07***	14.96	102	0.32**	10.56	59	2.27***	15.14	726	1.15***	6.35
Entry	23	9.75***	2.61	23	1.09**	3.24	23	0.76**	5.72	23	0.97	2.53	21	10.59***	1.69
Entry*E	666	1.26***	9.78	137	0.50	9.03	137	0.28**	12.45	69	0.65	5.10	1004	0.94***	7.19
Error	903	0.59		212	0.42		184	0.19		120	0.51		1252	0.49	
Mean		**4.10**			**2.73**			**1.41**			**1.40**			**3.34**	
Minimum		**3.71**			**2.41**			**0.85**			**1.52**			**2.68**	
Maximum		**4.86**			**3.11**			**2.38**			**2.16**			**3.95**	
Coefficient of variation		**18.75**			**23.63**			**50.88**			**34.57**			**21.00**	
LSD (0.05)		**0.22**			**0.28**			**0.57**			**0.39**			**0.16**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.22. Analysis of variance across environments for grain yield of intermediate late populations (ILPOP) in CIMMYT maize regional trials during 2002.

Source of variation	Across optimum env.			Across site low N env.			Across drought env.			Across all env.		
	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	38	232.24***	82.08	8	77.61***	79.38	4	105.18***	78.82	52	158.05***	83.90
Rep (E)	76	2.93***	2.07	18	1.97***	4.54	10	2.34***	4.38	104	1.89***	2.04
Block (Rep*E)	456	0.93***	3.96	107	0.33***	4.53	60	0.58***	6.54	620	0.74***	4.81
Entry	19	10.53***	1.86	19	0.54**	1.32	19	0.64***	2.28	14	9.28***	1.35
Entry*E	703	0.89***	5.88	152	0.24	4.82	76	0.19	2.83	714	0.60***	4.48
Error	972	0.46		212	0.20		128	0.21		807	0.40	
Mean		**4.02**			**1.83**			**2.28**			**3.49**	
Minimum		**3.50**			**1.54**			**2.04**			**3.11**	
Maximum		**4.81**			**2.13**			**2.61**			**4.14**	
Coefficient of variation		**16.84**			**24.34**			**20.24**			**18.17**	
LSD (0.05)		**0.08**			**0.24**			**0.33**			**0.14**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.

†MS mean squares

‡SS % total sums of squares

Table 2.23. Analysis of variance across environments for grain yield of intermediate late populations (ILPOP) in CIMMYT maize regional trials during 2003.

	Across optimum env.			Across low N env.			Across low pH env.			Across all env.		
Source of variation	df	MS†	SS‡	df	MS	SS	df	MS	SS	df	MS	SS
		Mg ha^{-1}			**Mg ha^{-1}**			**Mg ha^{-1}**			**Mg ha^{-1}**	
Env (E)	36	261.97***	84.51	6	15.08***	25.95	2	25.13***	55.61	47	222.83***	84.65
Rep (E)	74	2.91***	1.93	14	5.32***	21.38	6	2.30***	15.31	95	2.81***	2.15
Block (Rep*E)	443	0.77***	3.04	84	0.63***	15.27	36	0.25***	10.28	571	0.70***	3.27
Entry	19	8.29***	1.41	19	1.45***	7.93	19	0.23	4.77	17	10.51***	1.44
Entry*E	684	0.81***	4.96	114	0.42*	14.00	38	0.15*	6.24	799	0.75***	4.88
Error	955	0.48		181	0.29		77	0.09		1037	0.42	
Mean		**3.34**			**2.32**			**0.72**			**3.12**	
Minimum		**2.81**			**1.92**			**0.53**			**2.72**	
Maximum		**3.87**			**2.94**			**1.10**			**3.66**	
Coefficient of variation		**20.79**			**23.45**			**41.49**			**20.94**	
LSD (0.05)		**0.18**			**0.33**			**0.28**			**0.15**	

*,**,*** Indicates significance at 0.05, 0.01, 0.001 probability levels, respectively.
†MS mean squares
‡SS % total sums of squares

Pattern analysis within seasons

Pattern analysis, which is the combined and complimentary use of clustering and ordination methodologies, is an exploratory data analysis technique. It is mostly a hypothesis-generating technique (Williams, 1976; Byth, 1981 and Byth and Delacy, 1989), and does not necessarily test the hypothesis. The real focus of the analysis was to explore, identify, extract and display pattern in the multilocational data sets from CIMMTY maize regional trials. The essential part of the analysis therefore was the graphical output the dendograms.

Figures 2.2 through 2.21 are dendograms showing realationships among locations in each season for each each test from 1999 to 2003. All the dendrograms from all tests indicated that locations were not grouped according to countries. Perceived similarities or differences among testing locations cut across political and geographical boundaries. There were instances where different organizations (collaborators) managed similar trials under exact conditions at a location. In that case, dendrograms showed that there were almost always together in the dendrogram in Figure 2.15. This was the case at Embu in Kenya and Harare in Zimbabwe. In Zimbabwe CIMMYT and the Department of Research and Extension (AREX) may conduct trials under similar conditions in Harare. The results from the dendogram were able to capture this similarity. This also served as a tests and control for the clustering procedure, as similar tests carried out under similar conditions may not be expected to be too far apart in the dendrogram.

There was no specific trend in the manner in which four tests classified the maize testing locations. There were more genotypes tested for hybrids, up to 63, and fewer open pollinated entries, 23 per growing season. Standardization of yield for anthesis date (AD) meant that the effect of maturity on quantifying and qualifying the extent of genotype by environment interaction and further ordination and clustering was minimized. The four tests classified the locations in a consistent manner. Ordinarily there are many physical and biological factors that influence location clustering. This study looked deliberately at some major constraints for maize production in the region, which are water availability, plant nutrition, and low pH. Most locations in the region have acidic soils which adversely affect growth of maize. In central and northern Malawi, this condition is worsened by long term and persistent use of sulphate of ammonia fertilizer as a source of nitrogen by some farmers.

The cluster dendograms showed that stress, in general, was the primary influence on how the locations were grouped. Figure 2.13 illustrates that the low N site of Sussundenga in Mozambique and a low N site in Harare Zimbabwe were similar in the way they discriminated among intermediate to late hybrids in 2001. Figure 2.12 illustrates that low pH sites of Lunyangwa in Malawi, low pH sites of Potchefstroom in South Africa, low N sites of Chianga in Angola and Arusha in Tanzania were also similar in the manner they discriminated among early populations in 2001.

For early intermediate hybrids in 2001, as shown in Figure 2.10, low pH locations of Kasama in Zambia and Lunyangwa in Malawi, drought location of Arusha in Tanzania and a low N location in Chianga in Angola, were grouped together. Figure 2.6 illustrates that low N sites of Mazozo in Angola, Harare in Zimbabwe and Arusha in Tanzania revealed similar discrimination of early to intermediate hybrids in 2000. In the same dendrogram, drought sites of Chitedze in Malawi and Alupe in Kenya showed non significant genotype by environment interaction. Amount of available moisture has been a primary factor on location clustering in other studies (Nachit et.al., 1992; Peterson and Pfeiffer, 1989; Trethowan et al., 2003). In this study drought conditions discriminated genotypes in a similar manner at different locations. Trethowan et al (2003) planted the elite spring wheat yield trials (ESWYT) across a wide range of soil moisture conditions, and cropping season water availability was clearly a primary differentiating factor. Hierarchical classification of the maize testing location indicated that stress in general and water availability, low nitrogen and low pH in particular were influential in determining potential for discrimination among genotypes of the testing locations.

Pattern analysis across seasons

The reduced matrices returned 63 locations as shown in dendrograms in Figures 2.22 and 2.23. The cluster dendrogram in Figure 2.22 is based on standardized and adjusted grain yield of maize trials and Figure 2.23 is based on standardized yield (unadjusted for anthesis date). Both dendrograms retained 63 test locations. Out of the 63 sites retained only 15 were under stress conditions (Table 2.4). The use of the locations for maize evaluation especially for stress is hence validated by this research work. The remaining 48 locations had trials conducted under optimum conditions. The across season pattern analysis revealed stress testing locations in Angola, Lesotho, Malawi, Tanzania, Zambia and Zimbabwe as shown in Table 2.24.

Table 2.24. Major maize stress testing locations in eastern and southern Africa based on pattern analysis.

COUNTRY	LOCATION	STRESS	ELEVATION masl	MEAN T§	PRE‡
Angola	Chianga	Low Nitrogen	1736	19.52	1049
Angola	Mazozo	Low Nitrogen	50	26.57	467
Lesotho	Mokotlong	Low pH	2359	14.27	510
Malawi	Chitala	Drought	733	23.94	1046
Malawi	Chitedze	Low Nitrogen	1097	22.42	794
Malawi	Lunyangwa	Low pH	0	19.71	874
Tanzania†	Arusha	Low nitrogen	0	15.22	656
Tanzania	Arusha	Drought	0	15.22	656
Zambia	Kasama	Low pH	1384	21.06	1172
Zambia	Nanga	Drought	1182	23.15	1011
Zimbabwe	Chiredzi	Drought	433	25.52	498
Zimbabwe	Harare	Low nitrogen	1468	20.59	742
Zimbabwe	Makoholi	Low Nitrogen	1111	22.22	561
Zimbabwe	Marondera	Low pH	1457	20.77	526

† Location with drought and low N testing
‡ Pre – total precipitation for 5 months (mm) during the growing season
§ Mean T – mean temperature for 5 months (ºC) during the growing season

Table 2.25. Location groupings identified with sequential retrospective pattern analysis for maize regional trial in eastern and southern Africa based on standardized adjusted grain yield.

1	2	3	4	5	6
TanAru	ZimMak	UgaNam	EthMel	LesMas	MozNam
ZimRat	TanAruDr	MozUmb	ZamZam	MalBak	ZamGol
ZimSav	ZimMakLN	ZimHar	AngMaz	BotSeb	BotGoo
MozSus	TanIlo	AngMal	ZamNan	ZimKad	TanUki
ZamKasLp	ZimMarLp	ZamMse	RSAGre	RSAPot	MalChzLN
TanAruLN	LesNya	AngMazLN	ZimHarLN	ZimHarMS	TanKat
ZimMar	LesMahLp	TanWer	EthBak	ZimART	KenKak
MalLunLp	MalChiDr	AngCab	AngHum	ZimChiDr	MalBvu
TanMbu		AngChiLN	ZamMt_		MozCho
KenKit		KenBun			TanTum
MalChi		ZamNanDr			KenEmb
		BotPel			MalChz
		AngChi			TanIloLN
		ZimArc			

Location groupings identified with sequential retrospective pattern analysis for maize regional trial in eastern and southern Africa based on grain yield are presented in Tables 2.25 and 2.26. Although the adjusted yield for anthesis date produced 6 groupings and the unadjusted yield produced 9 grouping, they generally show similar location associations. The cumulative analysis across the years did not retain a high proportion of stress locations which indicated that in terms of discrimination among genotypes optimum locations were much more influential than the stress locations, as 28 percent of the locations retained in the analysis were from stressed locations. The results were similar to those obtained in within season analysis in IRRISTAT. Locations were not grouped according to geographical locations or country. For example, group 1 comprises locations from Tanzania, Zimbabwe, Malawi, Kenya, Mozambique and Zambia. These results are consistent with the findings of Mgonja et al. (2002), working on pearl millet testing sites in eastern and southern Africa. They showed that locations clustered together based on their growth cycles. Short season (3 months) locations clustered together and long growth cycle (>4 months) sites also clustered together. There were 6 locations groupings (clusters) identified by pattern analysis based on standardized adjusted yield. The clustering did not look to be influenced significantly to the five month temperature and rainfall location averages. Cluster 1 in Figure 2.13 comprised Kitale, Kenya which had average 5 month temperature of 17.9ºC and Chitala, Malawi, which had the had average 5 month temperature of 23.9ºC. The same cluster also included Save Valley, Zimbabwe which had the 5 month average rainfall of 388 mm and Kasama in Zambia with a 5 month average rainfall of 1172 mm. Mirzawan et al. (1994) conducted retrospective pattern analysis among the test environments of the Southern Queensland sugarcane breeding program and they also found that the available meteorological information did not provide an obvious explanation for the grouping of locations. Lillemo et al. (2004) who looked at relationships among international wheat testing locations found that their study did not provide evidence of any direct relationship between temperature profile and the locations' ability to predict global wheat performance. They theorized, however, that generally there were many external or environmental factors that affect yield ranking of cultivars from location to location. The most common were latitude, altitude, cultural practices (planting time, pest and disease control and fertilizer application), day length, temperature, water availability and pH. Specifically, temperature towards maturity was a common environmental feature of sites with good predictability of wheat yield performance. Abdalla et al. (1996) however showed that grouping of wheat international testing locations was mainly associated with latitude and moisture supply and further delineation of clusters was influence by biotic and abiotic stresses. Those findings are consistent with the findings of this study where pattern analyses within and across the seasons are considered as complimentary. It was clear from the within year analysis that stress conditions were influential in determining association among locations. To some extent temperature was also important factor for in the pattern analysis as some locations with similar temperature clustered together and the across year clustering revealed important maize testing locations in eastern and southern Africa, for optimum conditions, as well as for specific stress factors.

Biplot analysis

The AMMI biplot analysis was also conducted to further evaluate the relationships among maize testing locations in eastern and southern Africa. The biplots were generated by singular value decomposition on two way data table for locations and genotypes (entries). These are trial and year biplots and others comprised only stress locations. The biplots are presented from Fig 2.24 to Fig. 2.45. It is noted that the biplot results for the trials in a season are closely related to the results of the pattern analysis in the cluster dendrograms. The results indicate that the stress locations are grouped together and the optimum locations are also grouped together. It did nor really matter what type of a stress factor. For instance, EIHYB01, had a grouping of MalLunLpH, ZimHarLN, TanAruLN, AngChiLN, RSAPotLpH and ZamGolLpH. The optimum locations of TanWer, ZamGol, RSAGre and Bot Goo also formed their own distinct grouping. The principle components 1 and 2 comprised of 30.4% and 17.4% respectively explaining a total of 47.8% of the variation. Yan and Tinker (2005) also found that the biplot explined only 31% of the total variation and they contended that the genotype by interaction for yield in the data set was complex. For EPOP01, there was a grouping of HarZimLN, ChiAngLpH, ChtMalDrt, LerLesLpH, AruTanDrt and PotRSALpH, and a different grouping for optimum locations of BakEth, PawEth, ChtMal, ARTZim, BunKen and NamUga. When stress locations were analyzed independenlty, they showed high genotype by environment interaction (Fig. 2.44 and Fig. 2.45). This result then urges caution in considerations for testing in stress locations, in that although they may look similar when conducting an overall analysis, stress locations should be looked at carefully as separate locations from optimal conditions. This may be expected because eastern and southern Africa is a place of unique and abundant diversity in terms of maize growing conditions.

SUMMARY

The historic data set of CIMMYT maize regional trials in eastern and southern Africa for five seasons (1999-2003) presented an opportunity for investigating the relationships among the testing locations, although size of the data set may have had presented its own unique challenges. This is the first time that a data set of this magnitude had been used for investigating relationships among locations in public maize breeding in Africa. This is particularly important when most of investigators have recommended an extensive data set to substantiate some notable findings in relationships of international crop testing sites (Abdalla et. al., 1996).

From the analysis of variance it is noted that most of the variation in the international multilocation trials was due to the location and the interaction between the location and the genotype. Pattern analysis was an adequate and effective technique for exploring and understanding the relationships among the test locations. Within year pattern analysis revealed the importance of stress conditions and their influence on grouping of environments. For the across season sequential retrospective pattern analysis which was accomplished by SEQRET, it was possible to identify groupings of environments with non-crossover genotype by environment interaction. This would facilitate the selection of testing locations and effective reduction of maize testing sites, which may result in increased and better efficiency in testing. Important stress testing locations for maize in eastern and southern Africa were also identified.

The biplot analysis was also very effective in displaying the location and genotype relationships. The biplot analysis complimented the pattern analysis and confirmed the importance of associations that existed among stress locations. Stress locations, however should not be managed as particularly similar, as revealed by substantial genotype by environment interaction when only stress environments are considered in the analysis. We also know from the proportion of variation (<50%) explained by the principle components 1 and 2 that the locations relationships are much more complex.

Findings from this study are clear although further investigations needs to look at the influence of meteorological data in determining relationships among the testing locations. The use of findings should be complimented by experience of individual scientists working in the various locations. That is why the quality of collaboration is crucial for the success of maize testing in the region.

The fact that the locations did not cluster according to countries, validates the regional CIMMYT approach of testing and dissemination.

Table 2.26 Location groupings identified with sequential retrospective pattern analysis for maize regional trial in eastern and southern Africa based on standardized grain yield.

1	2	3	4	5	6	7	8	9
TanAru	AngMal	TanIlo	LesMas	MozCho	TanAruLN	AngMazLN	BotPel	KenKak
ZimRat	ZamMse	ZimMarLp	MalBak	TanTum	ZimMar	TanWer	KenBun	MalBvu
ZimSav	ZamNanDr	LesNya	RSAGre	MalChzLN	MalLunLp	AngCab	ZimArc	EthBak
MozSus	UgaNam	LesMahLp	ZimHarLN	TanKat	TanMbu	AngChi	EthMel	AngHum
ZamKasLp	MozUmb	MalChiDr	BotSeb		KenKit	MozNam	ZamZam	ZamMt_
	ZimHar	ZimChiDr	ZimART		MalChi	ZamGol		
	ZimMak	RSAPot	KenEmb		AngMaz	ZimKad		
	TanAruDr	ZimHarMS	MalChz		ZamNan	AngChiLN		
	ZimMakLN		TanIloLN			BotGoo		
						TanUki		

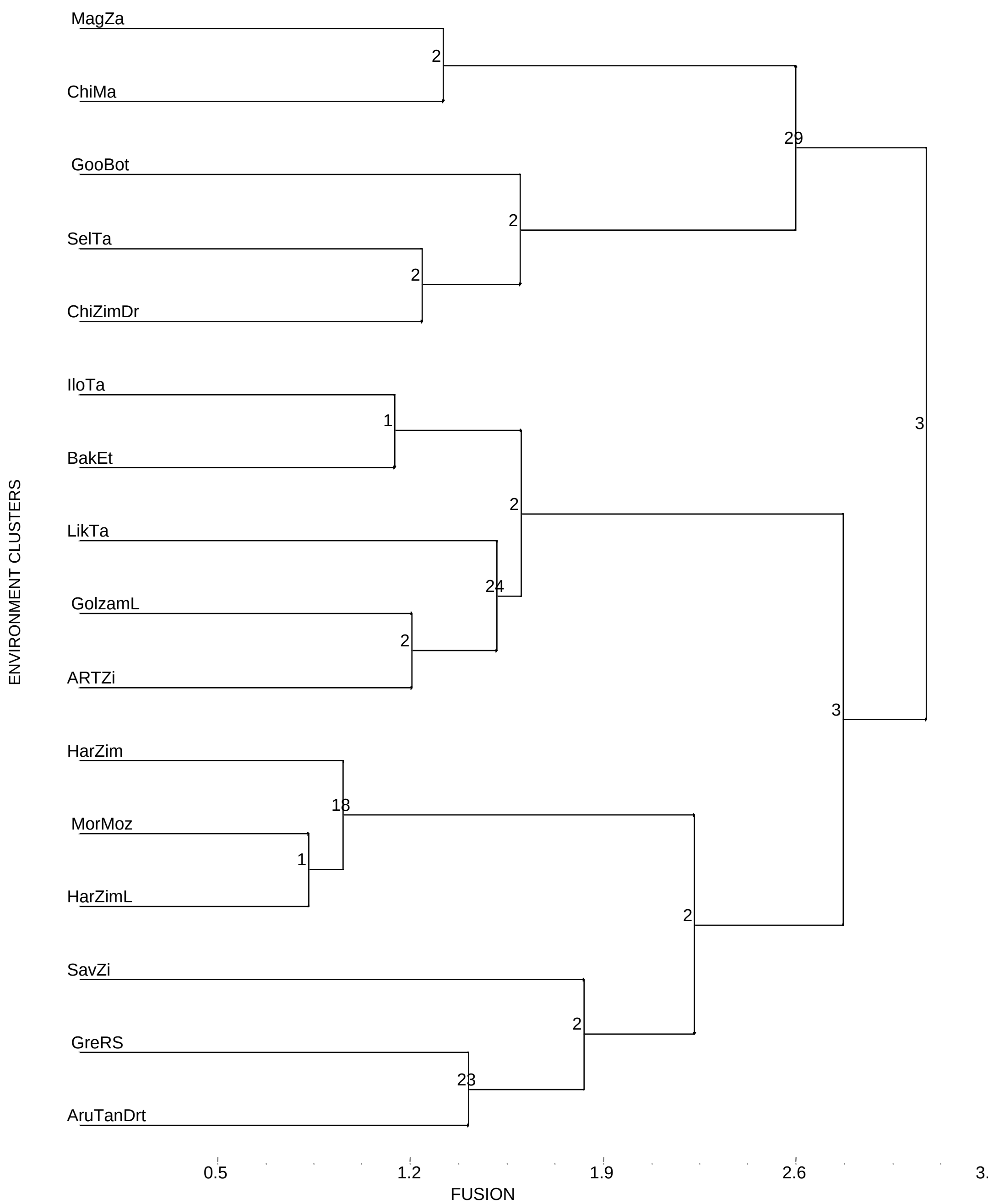

Fig. 2.2. Cluster dendrogram for maize testing locations in eastern and southern Africa for EIHYB99.

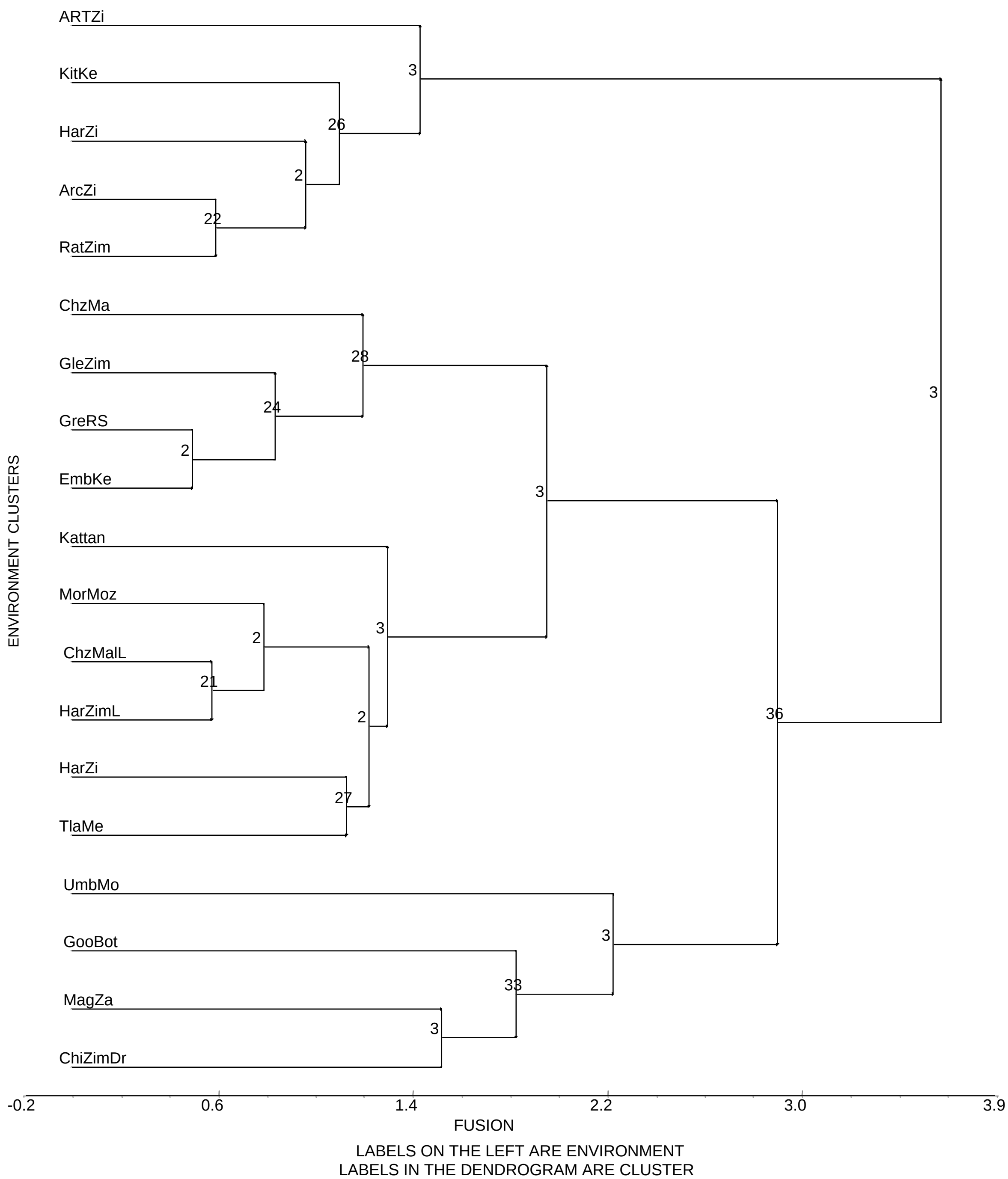

Fig.2.3. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILHYB99.

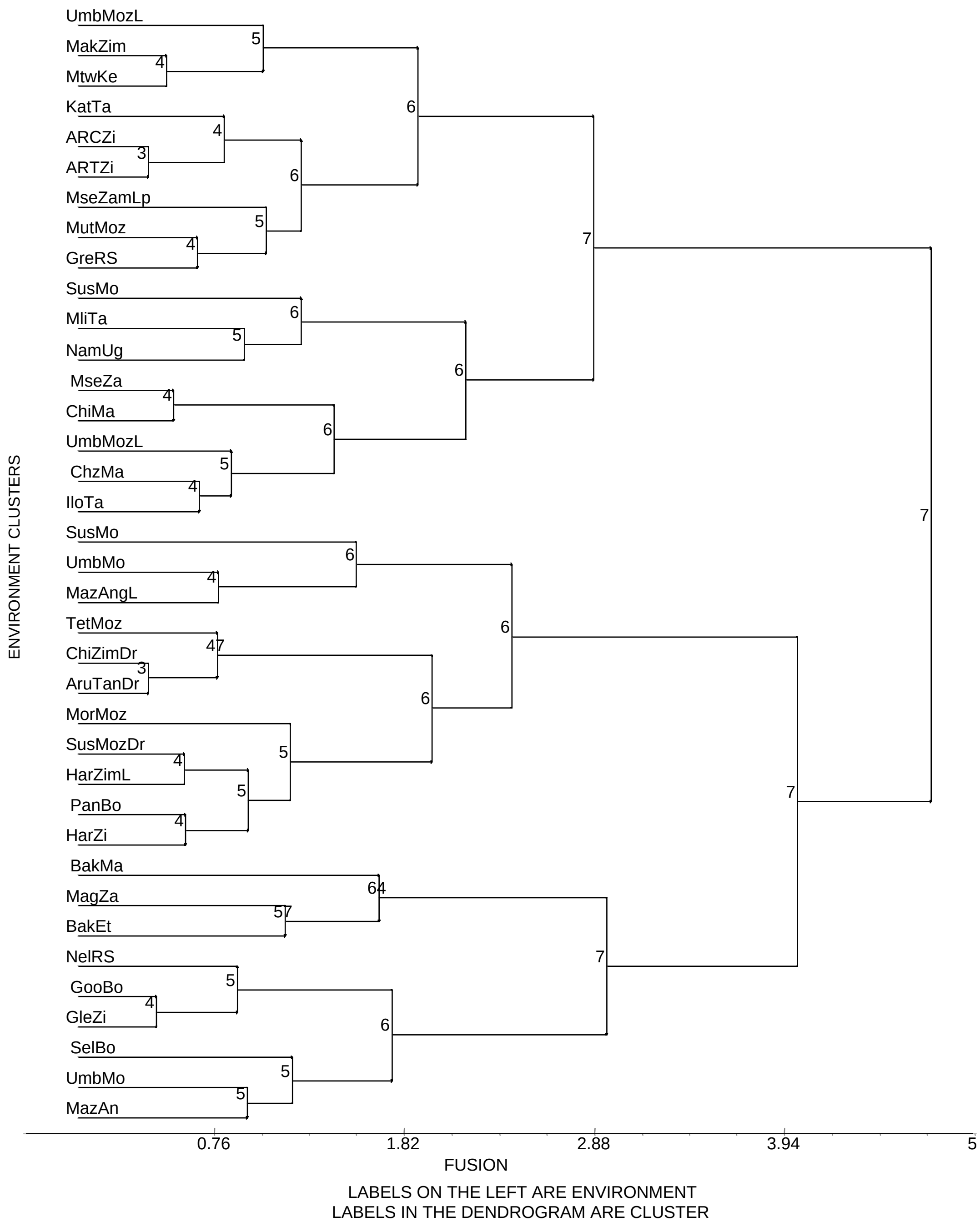

Fig.2.4. Cluster dendrogram for maize testing locations in eastern and southern Africa for EPOP99.

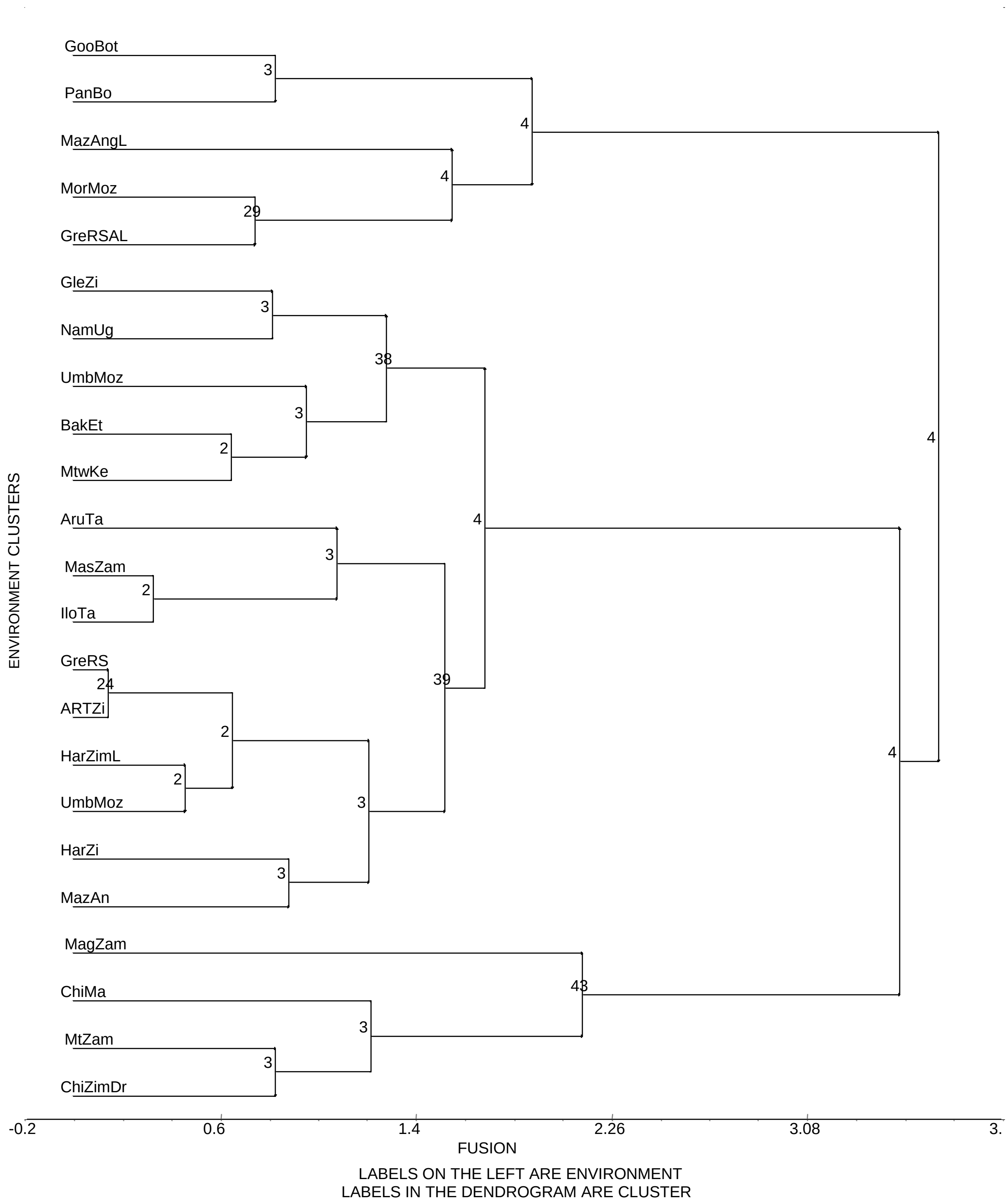

Fig. 2.5. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILPOP99.

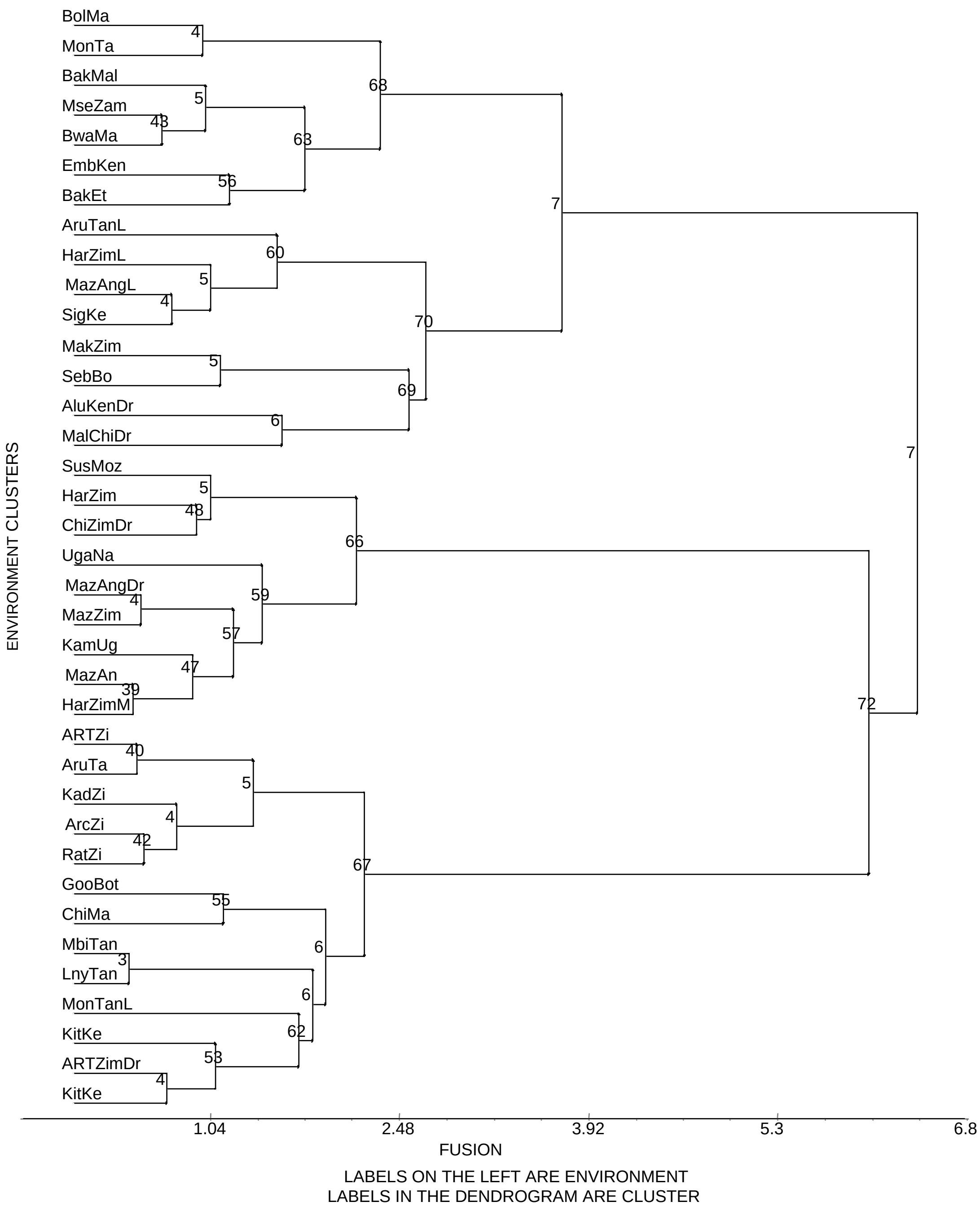

Fig.2.6. Cluster dendrogram for maize testing locations in eastern and southern Africa for EIHYB00.

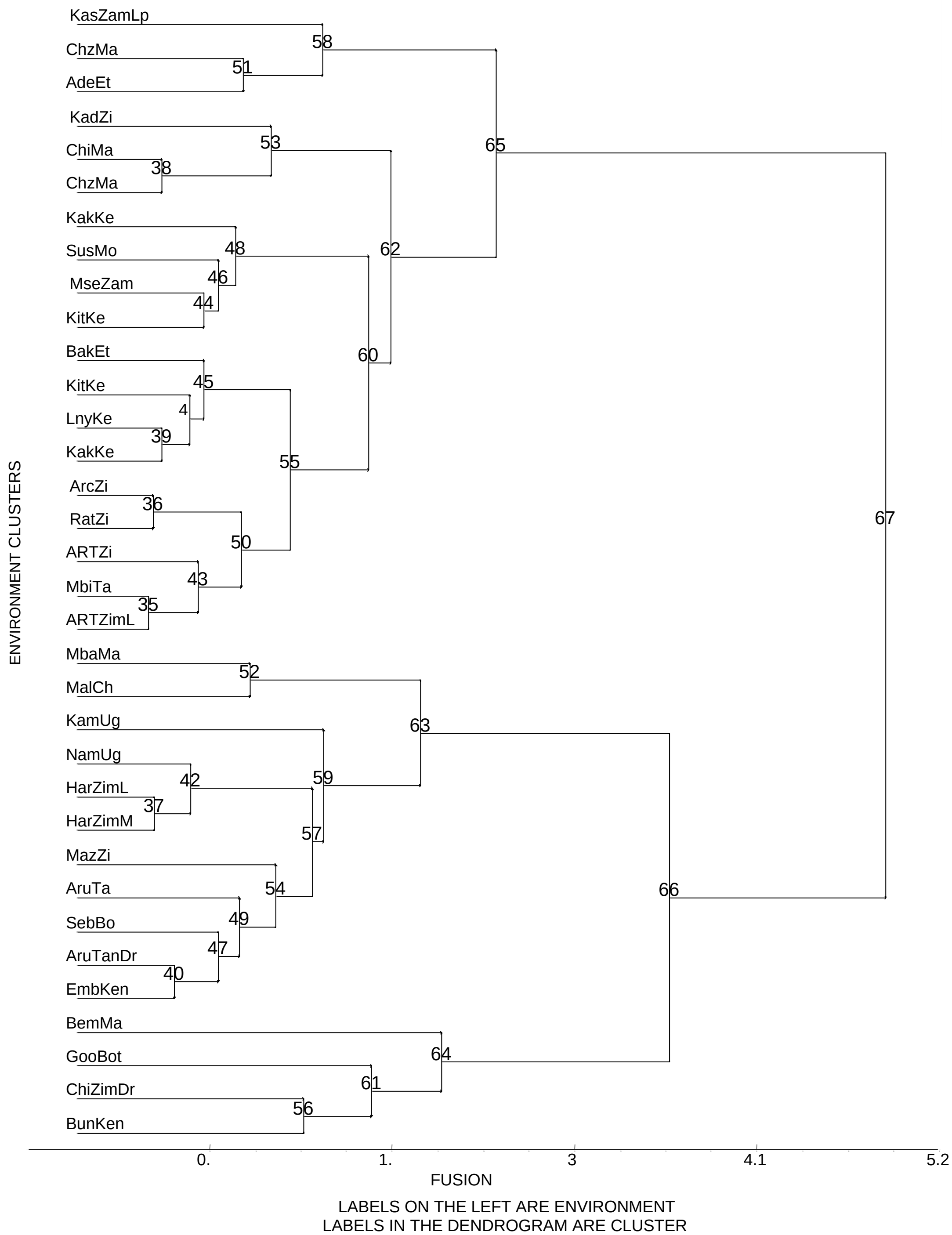

Fig. 2.7. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILHYB00.

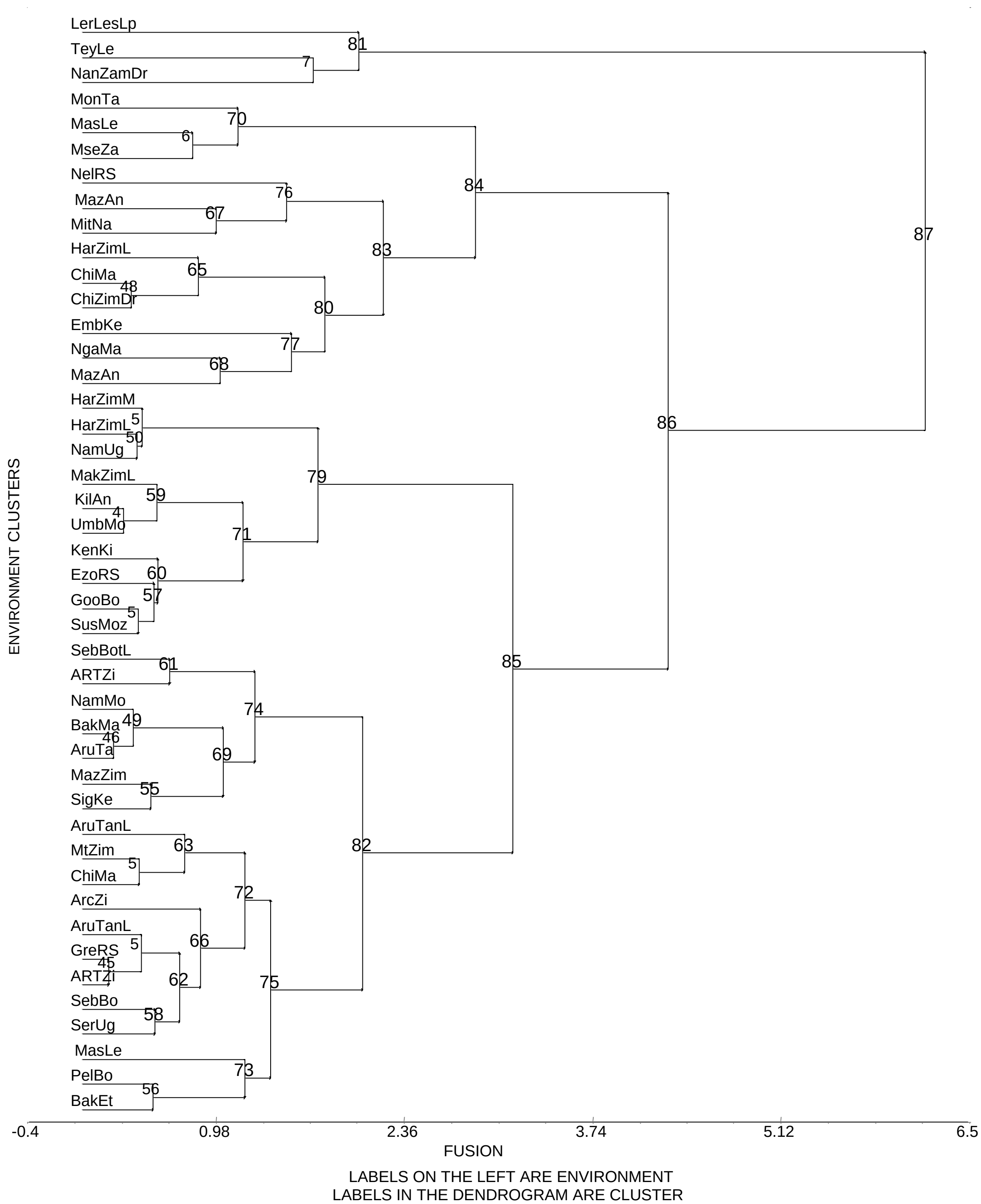

Fig.2.8. Cluster dendrogram for maize testing locations in eastern and southern Africa for EPOP00.

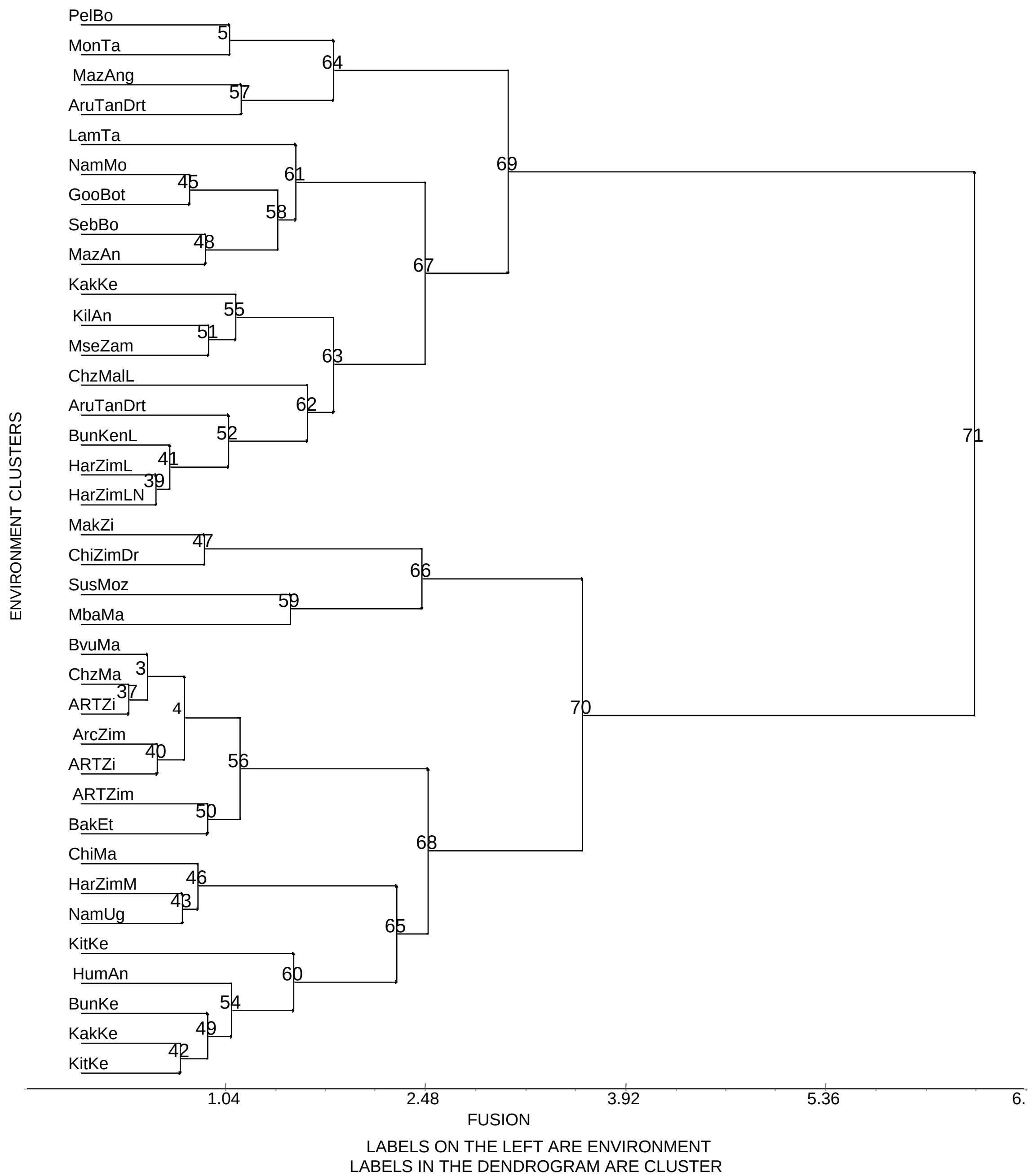

Fig. 2.9. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILPOP00.

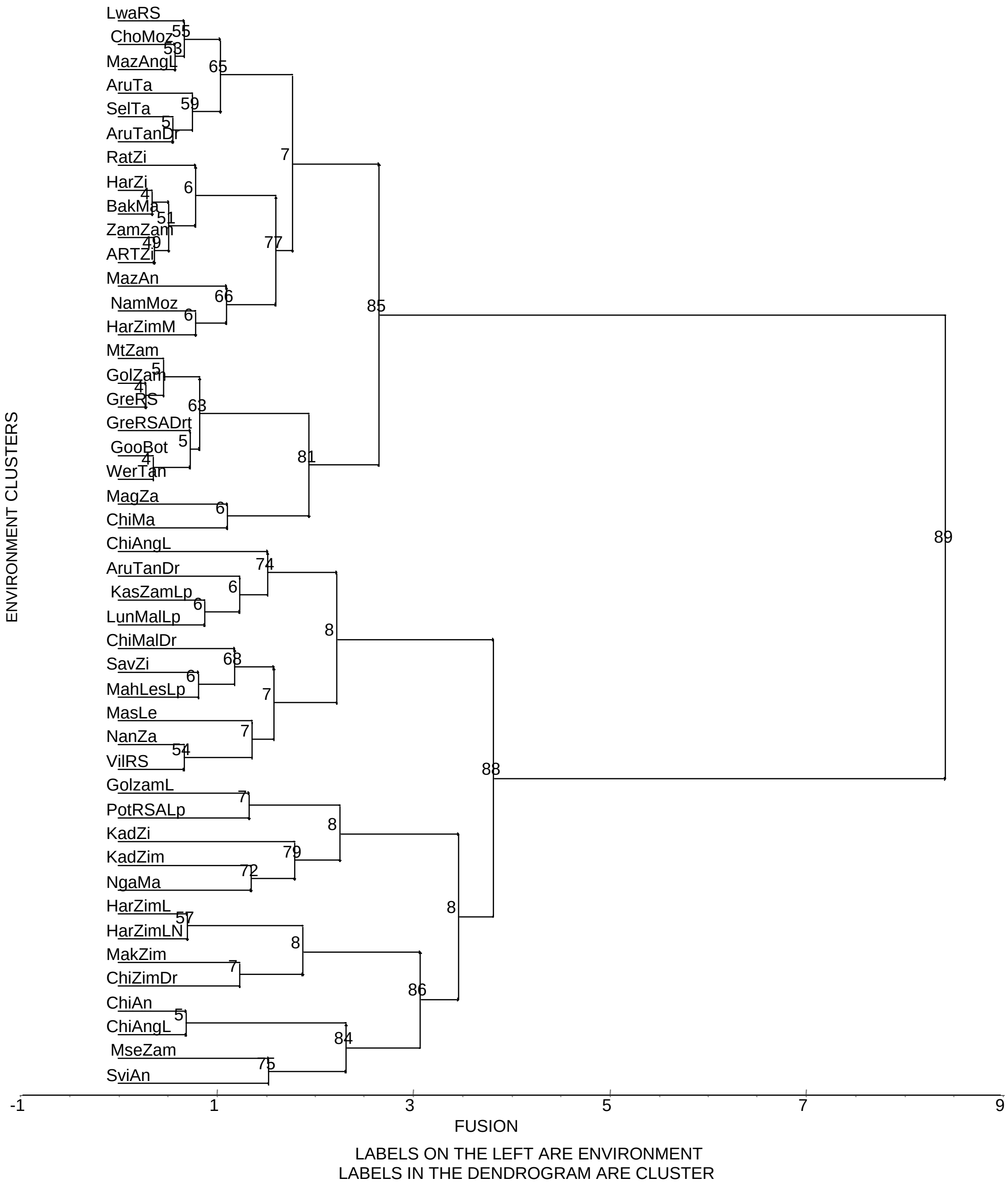

Fig. 2.10. Cluster dendrogram for maize testing locations in eastern and southern Africa for EIHYB01.

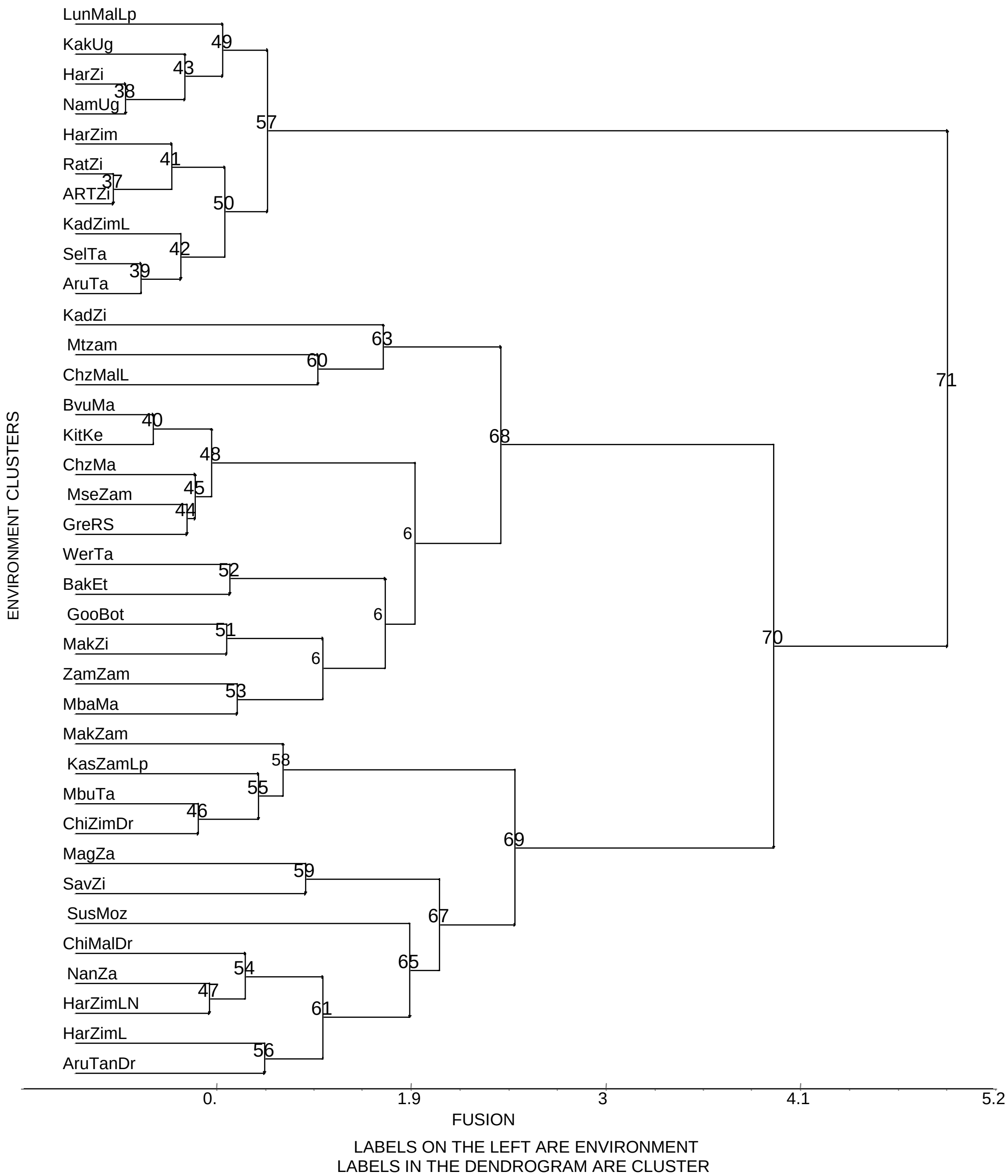

Fig. 2.11. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILHYB01.

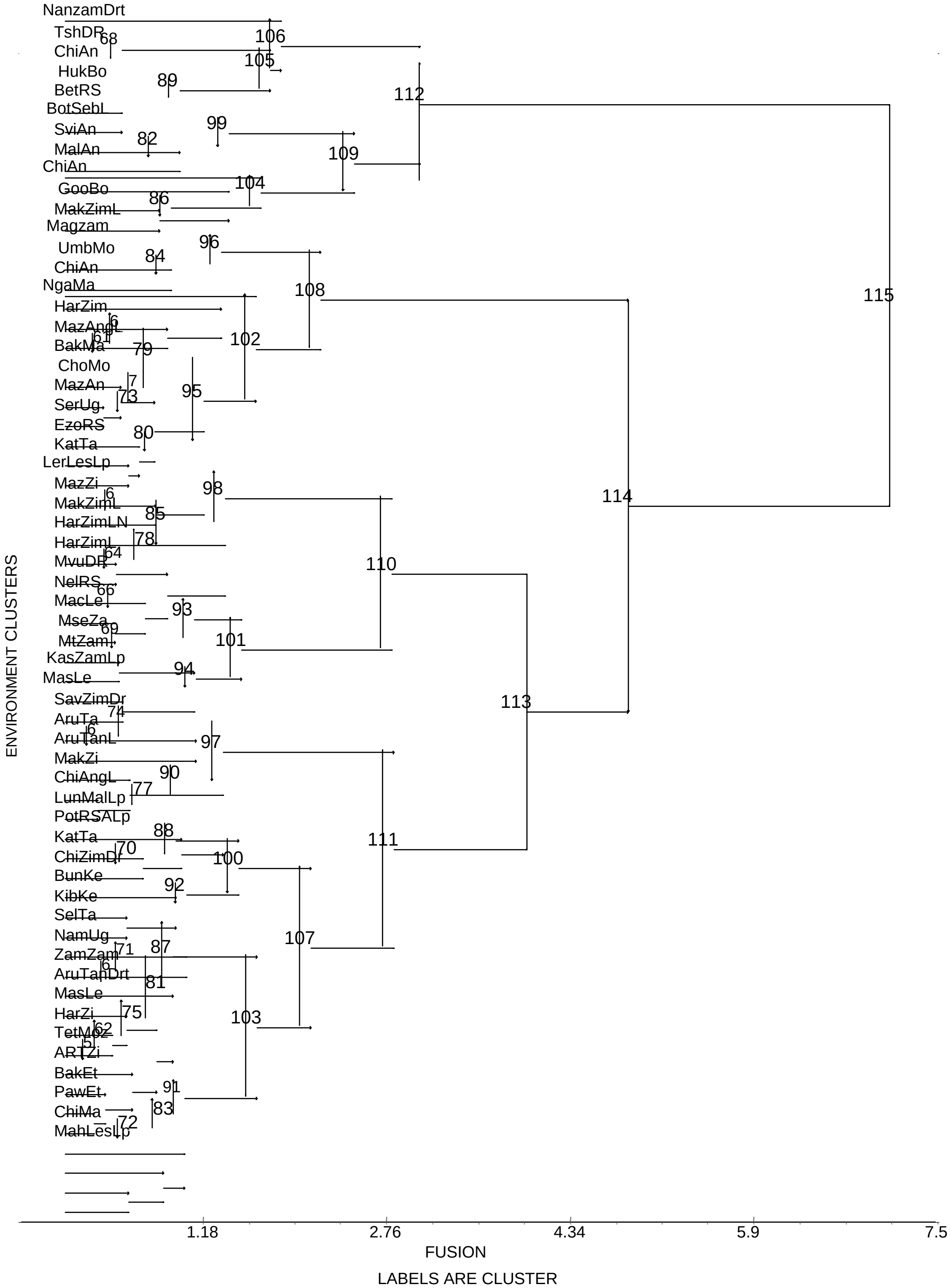

Fig. 2.12. Cluster dendrogram for maize testing locations in eastern and southern Africa for EPOP01.

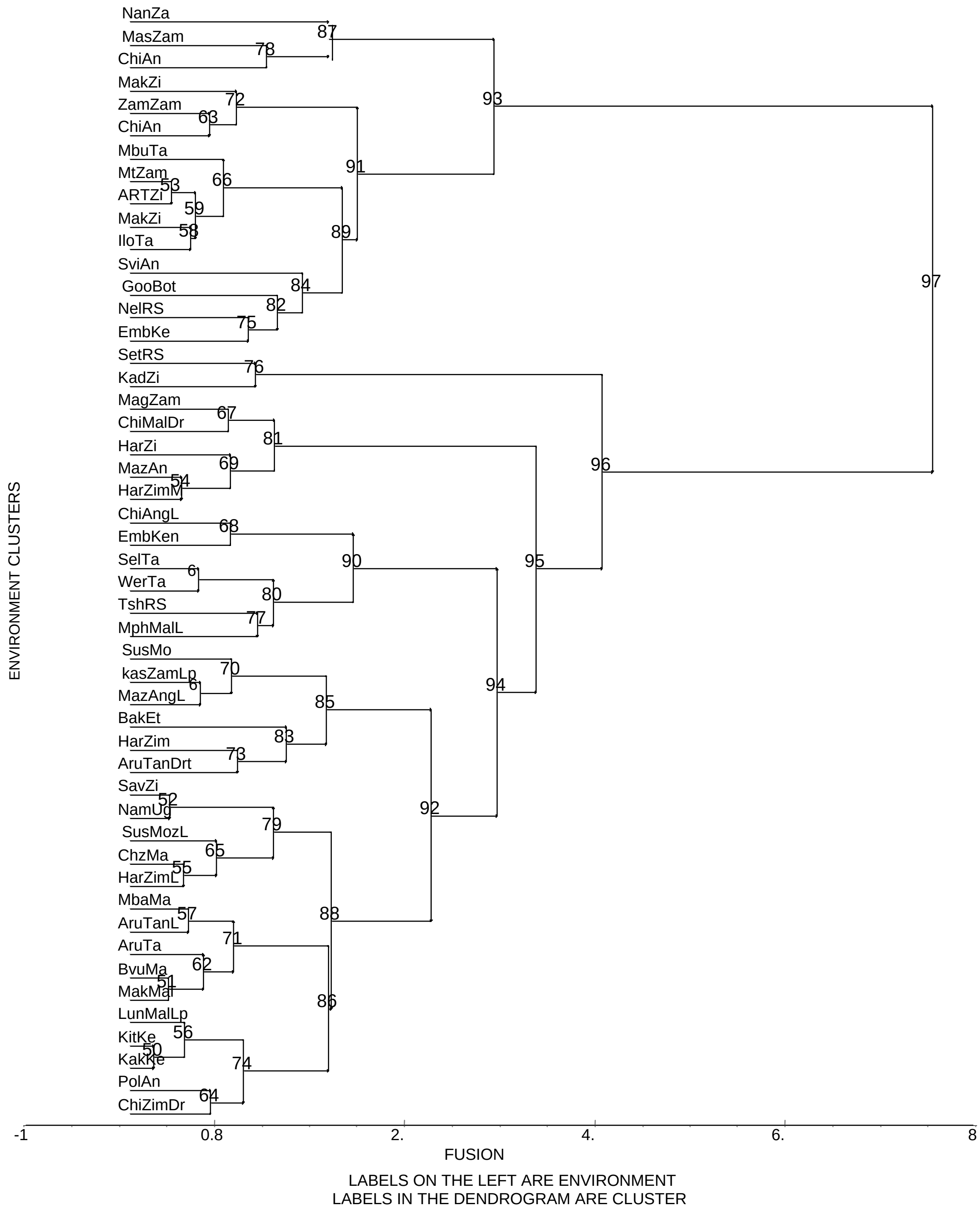

Fig. 2.13 Cluster dendrogram for maize testing locations in eastern and southern Africa for ILPOP01.

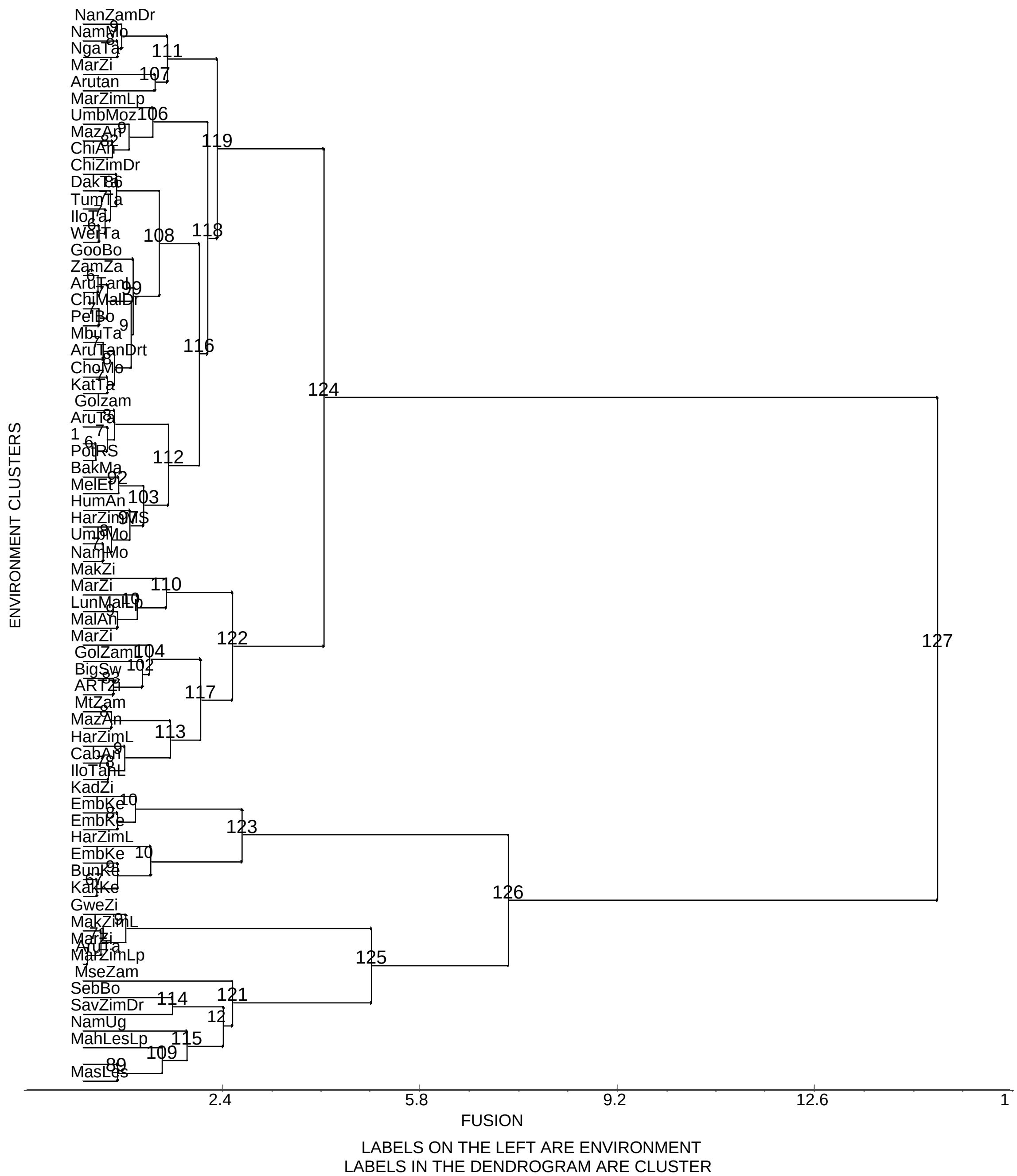

Fig. 2.14. Cluster dendrogram for maize testing locations in eastern and southern Africa for EIHYB02.

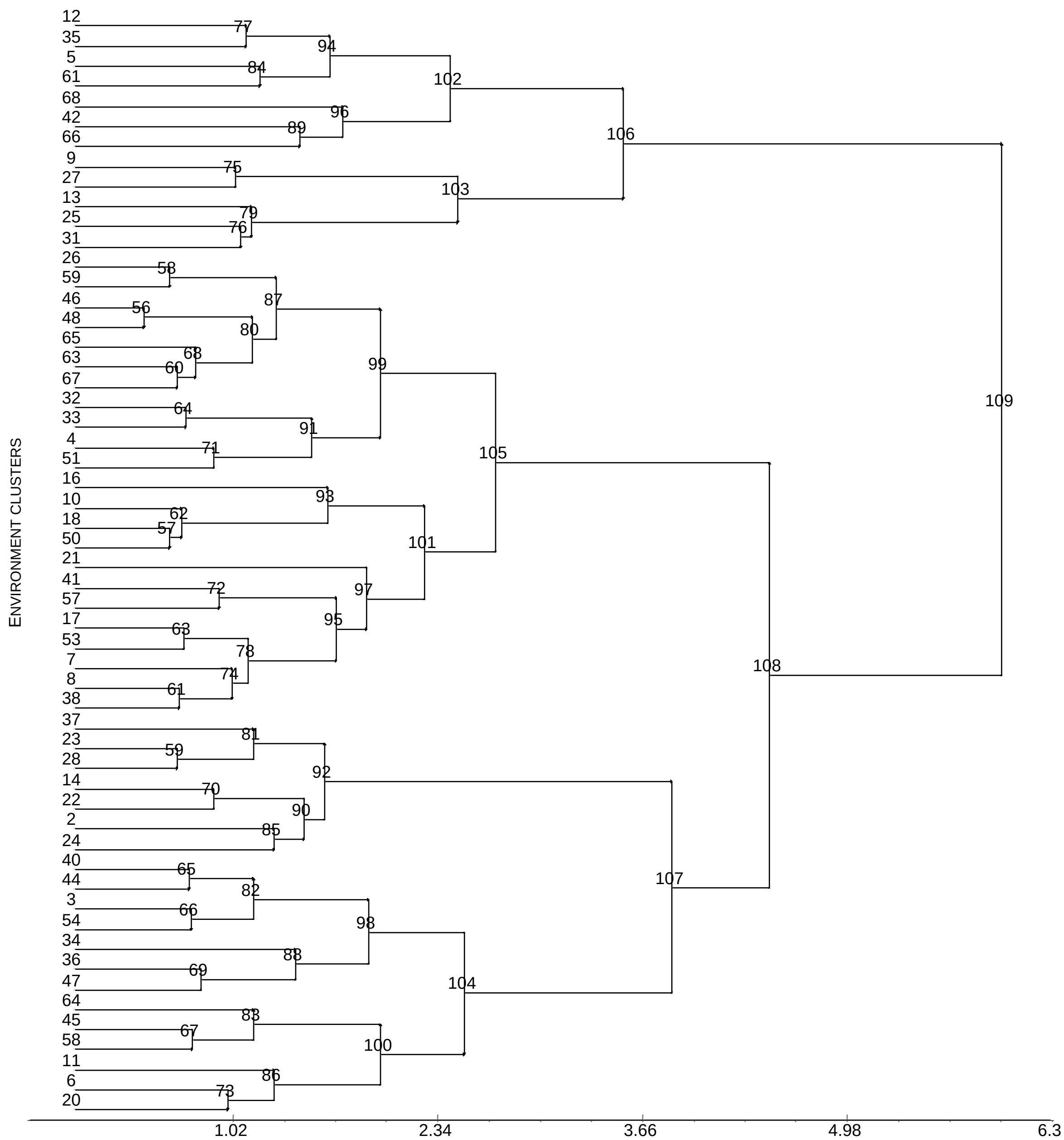

Fig.2.15. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILHYB02.

2	ZamKasLpH	33	BotPel
3	ZamMt_	34	ZimMar
4	ZamNanDrt	35	ZimMarLpH
5	SwaNhl	36	ZimMar
6	ZimART	37	ZimMar
7	ZimHarLN	38	ZamZam
8	ZimHarMSV	40	TanIloLN
9	ZimMak	41	TanMor
10	ZimChiDrt	42	TanKat
11	MozSus	44	TanIlo
12	MozNam	45	TanWer
13	MozSusLN	46	TanAru
14	MozLic	47	TanNga
16	AngHum	48	TanAruLN
17	AngChi	50	TanMbu
18	AngMaz	51	TanAru
20	AngMazLN	53	ZimHarLN
21	AngMal	54	ZimMakLN
22	MalChz	57	ZimMarLpH
23	MalBvu	58	KenBun
24	MalBem	59	ZimKad
25	MalChzLN	61	UgaNam
26	MalLunLpH	63	KenEmb
27	MalChiDrt	64	KenKak
28	MalChz	65	KenEmb
31	BotSeb	66	ZimMarLpH
32	BotGoo	67	KenEmb
		68	TanAru

Legend for cluster dendogram of ILHYB02

Figure 2.15 continued

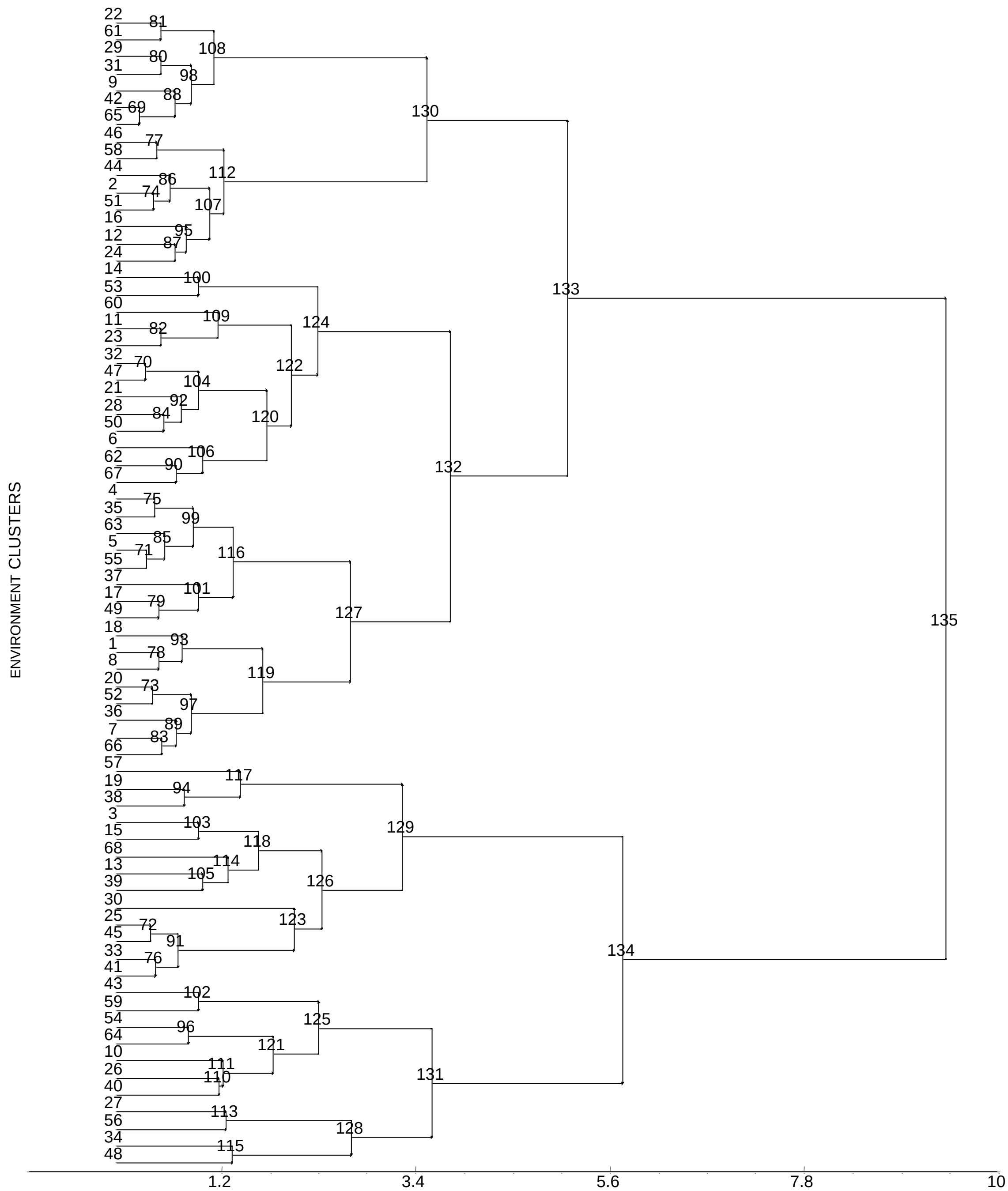

Fig. 2.16. Cluster dendrogram for maize testing locations in eastern and southern Africa for EPOP02.

Legend EPOP02

1	RSAGre	35	BotGoo
2	ZamMt_	36	BotPel
3	ZamMse	37	BotSebLN
4	ZamNanDrt	38	ZimMar
5	SwaMal	39	ZimMar
6	SwaLuv	40	ZimMarLpH
7	ZimART	41	ZimMar
8	ZimHarLN	42	ZamZam
9	ZimHarMSV	43	TanIloLN
10	ZimMak	44	TanKat
11	ZimChiDrt	45	TanDak
12	TanUki	46	TanIlo
13	LesMas	47	ZimArc
14	LesMahLpH	48	TanTum
15	LesNya	49	TanWer
16	MalBak	50	TanAruLN
17	MalChi	51	TanAru
18	MalChiDrt	52	TanAru
19	MalLunLpH	53	TanAruDrt
20	MozUmb	54	ZimSavDrt
21	MozCho	55	ZimHarLN
22	MozCho	56	ZimMakLN
23	MozNam	57	RSAEzo
24	MozUmb	58	RSANel
25	AngHum	59	NamMas
26	AngMal	60	ZimMarLpH
27	AngKil	61	ZimGwe
28	AngCab	62	ZimKad
29	AngChi	63	KenKib
30	AngMaz	64	KenEmb
31	AngChiLN	65	UgaNam
32	AngMazLN	66	UgaSer
33	RSAPot	67	KenKib
34	BotSeb	68	ZimMarLpH

Legend for cluster dendogram of EPOP02

Figure 2.16 continued

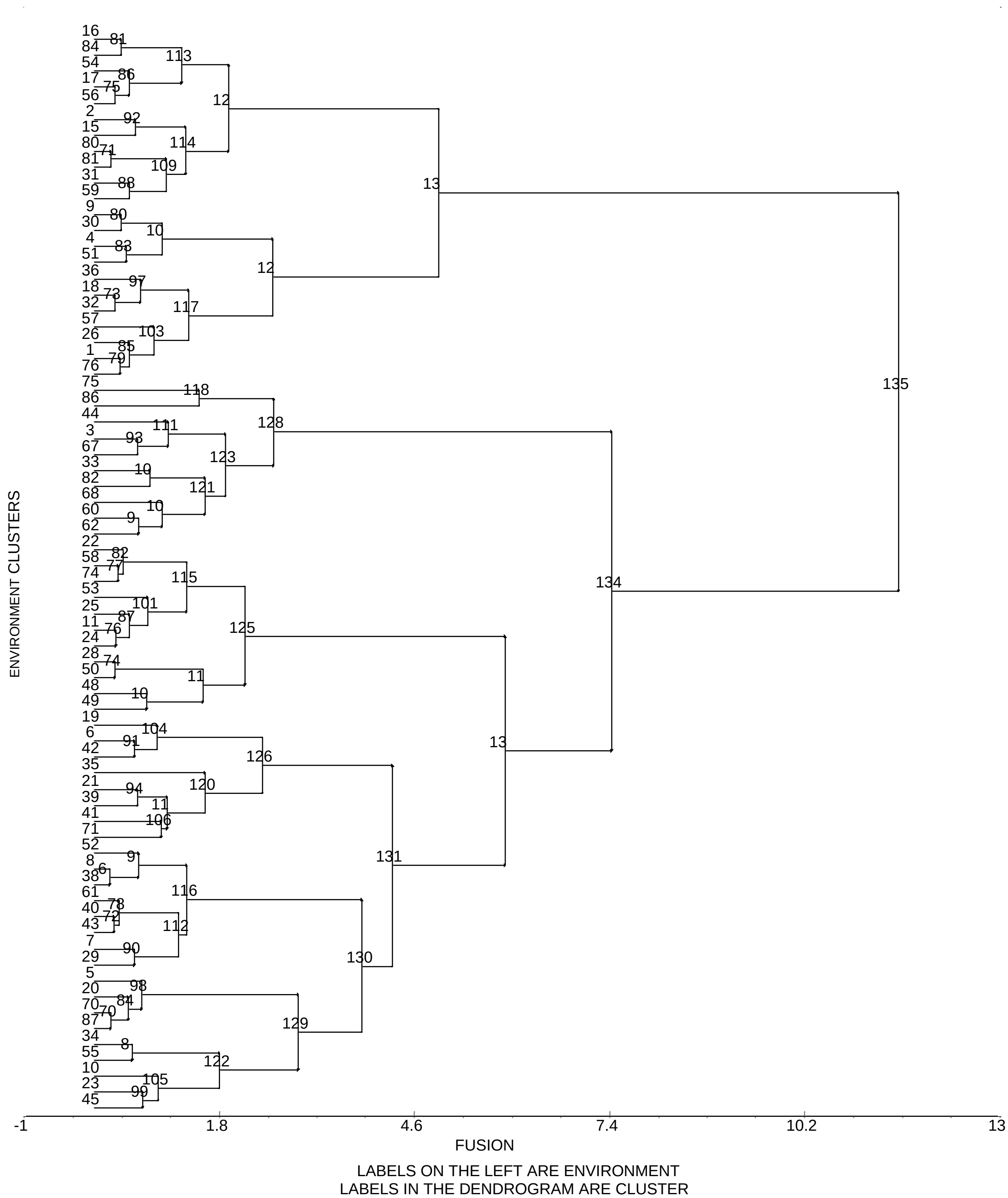

Fig. 2.17. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILPOP02.

1	ZamMt_	40	BotPel
2	ZamKasLpH	41	ZimMarLpH
3	ZamNanDrt	42	ZimMar
4	SwaMal	43	ZimMar
5	SwaNhl	44	ZimMar
6	ZimMak	45	ZamZam
7	ZimHarLN	48	TanIlo
8	ZimHarMSV	49	TanIloLN
9	ZimART	50	TanKat
10	ZimChiDrt	51	TanMor
11	TanUki	52	ZimArc
15	MalChz	53	TanTum
16	MalBvu	54	TanMbu
17	MalBem	55	TanAru
18	MalChiDrt	56	TanAru
19	MalLunLpH	57	TanAru
20	MalMak	58	TanWer
21	MalChzLN	59	TanAruLN
22	MozUmb	60	ZimSavDrt
23	MozLic	61	ZimHarLN
24	MozNam	62	ZimMakLN
25	MozSusLN	67	NamMas
26	MozLic	68	ZimMarLpH
28	AngMazLN	70	KenBun
29	AngMaz	71	EthMel
30	AngChiLN	74	ZimKad
31	AngChi	75	EthPaw
32	AngHum	76	EthBak
33	AngMal	80	KenKit
34	AngCel	81	KenEmb
35	AngKil	82	UgaNam
36	RSAPot	84	KenKak
38	BotGoo	86	ZimMarLpH
		87	TanAruDrt

Legend for locations of cluster dendogram of ILPOP02

Figure 2.17 continued

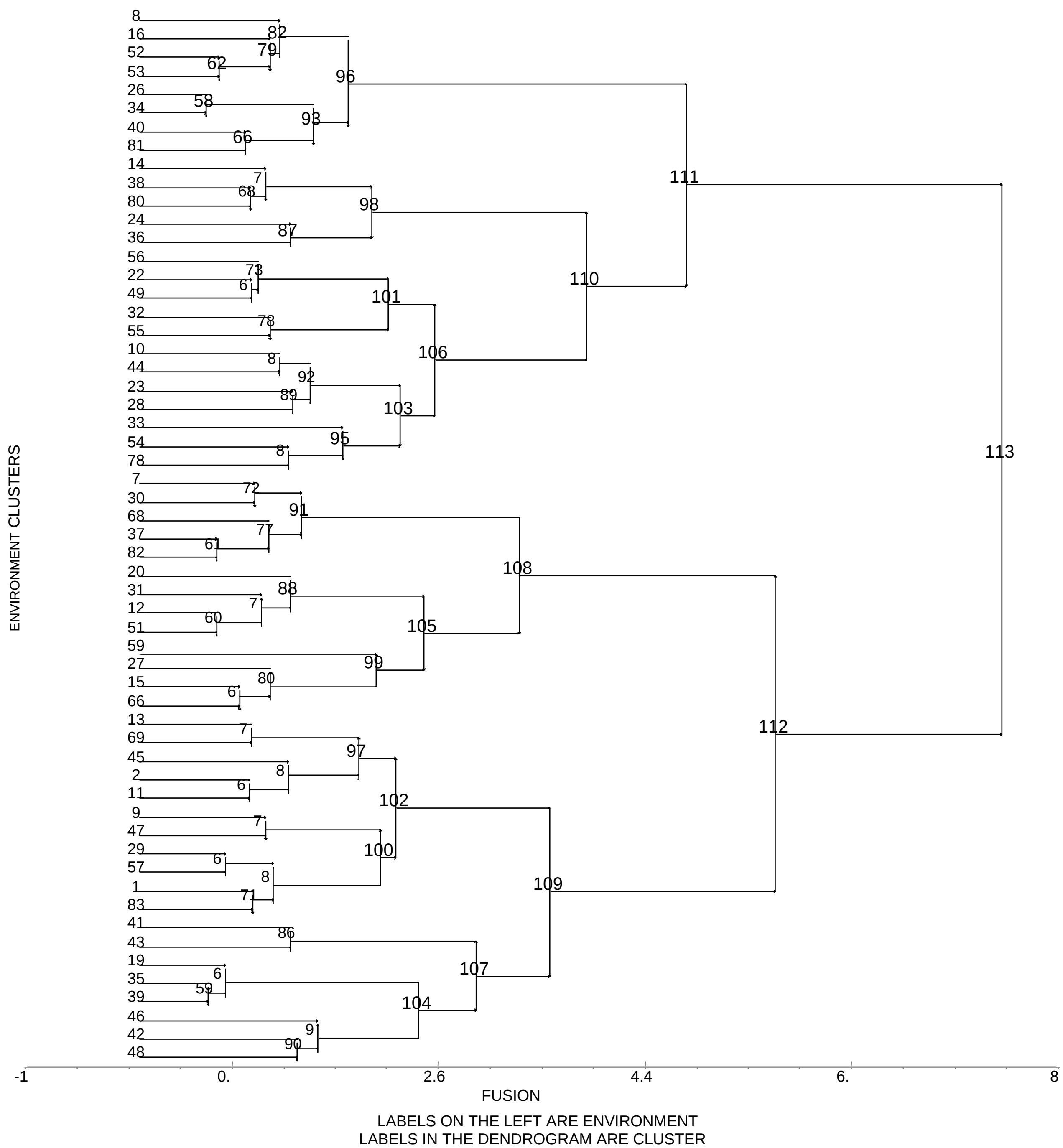

Fig. 2.18 Cluster dendrogram for maize testing locations in eastern and southern Africa for EIHYB03.

1	RSAGre	40	ZamKasLpH
10	BotPel	41	LesNya
11	BotGoo	42	LesMahLpH
12	TanMbu	43	LesMas
13	TanAru	44	MalBak
14	TanAru	45	MalChi
15	TanAruLN	46	MalChi
16	TanUki	47	MalLunLpH
19	AngHum	48	MozSus
2	RSAPot	49	MozNam
20	AngMaz	51	MozCho
22	AngMazLN	52	ZimHarLN
23	AngCab	53	ZimHar
24	AngCab	54	ZimMak
26	ZimHarMSV	55	ZimMar
27	ZimMak	56	ZimMarLpH
28	ZimChiLN	57	ZimMar
29	ZimART	59	EthBak
30	ZimKad	66	IndBan
31	MozUmb	68	UgaNam
32	ZimMar	69	UgaSer
33	ZimMarLpH	7	ZamZam
34	ZimRat	78	ZimSav
35	ZimKad	8	ZamChi
36	ZamNan	80	TanIlo
37	ZamMt_	81	TanIlo
38	ZamGolLN	82	KenBun
39	ZamGol	83	EthMel
		9	BotSeb

Legend for locations of cluster dendogram of EIHYB03

Figure 2.18 continued

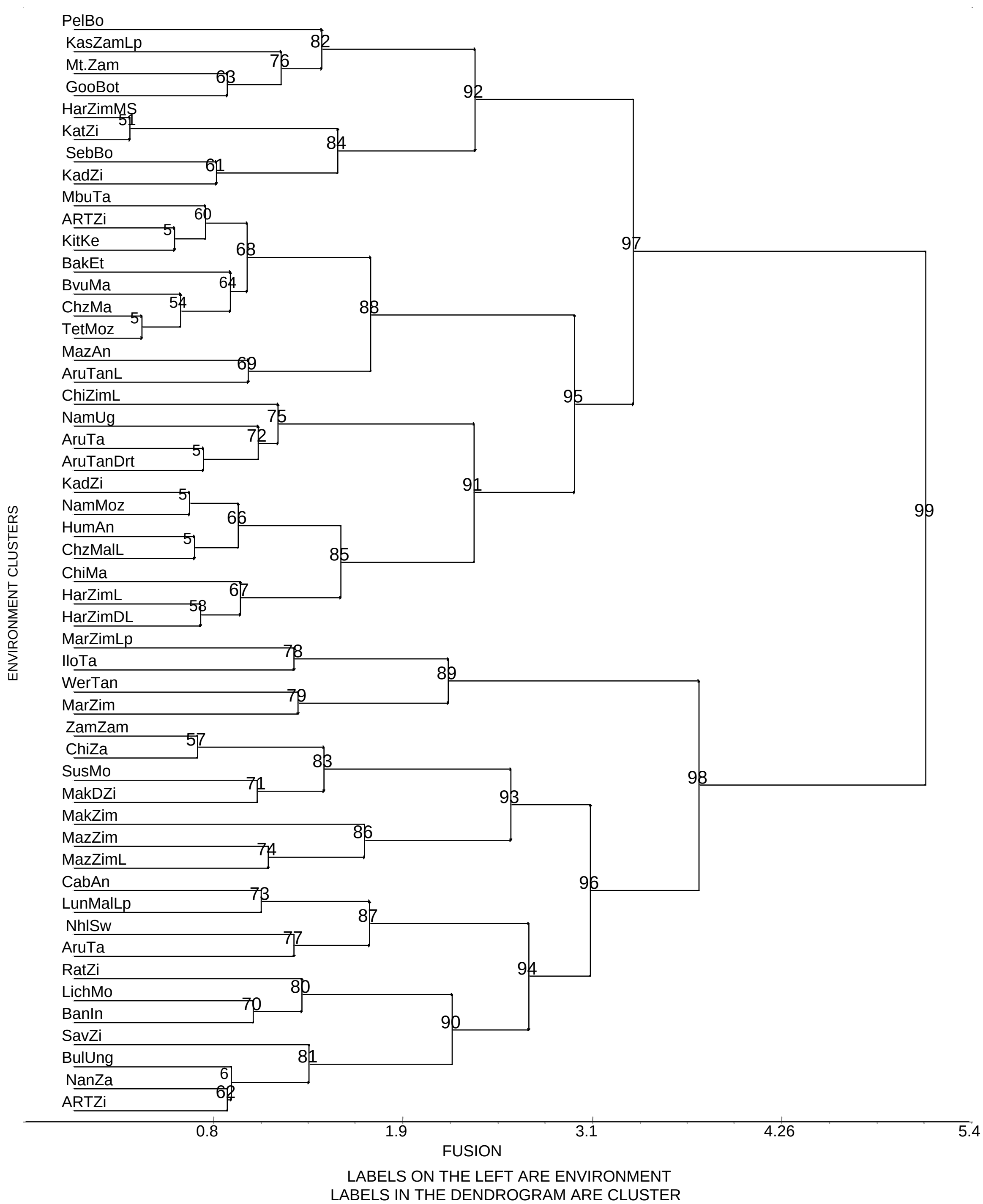

Fig. 2.19 Cluster dendrogram for maize testing locations in eastern and southern Africa for ILHYB03.

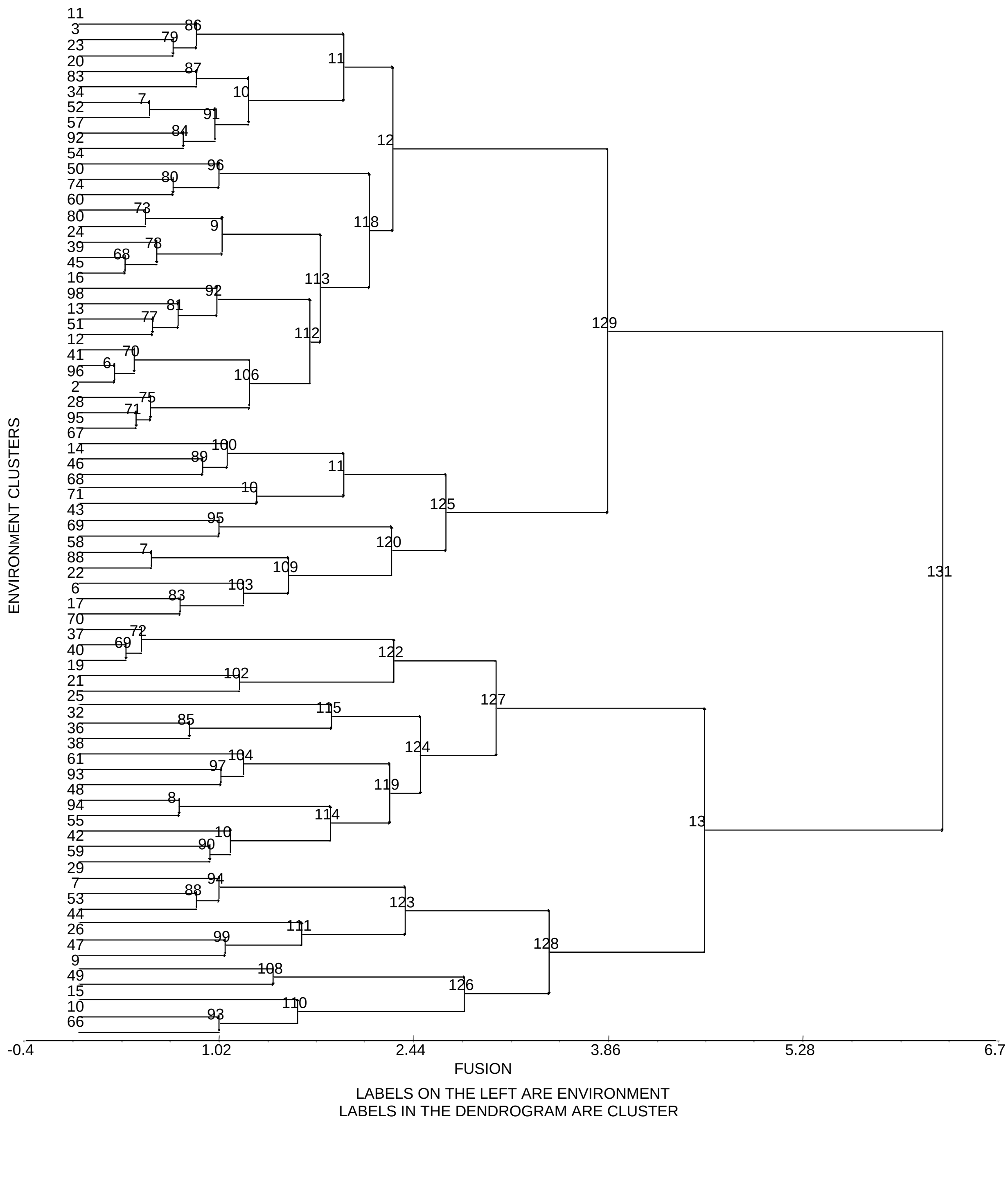

Fig. 2.20. Cluster dendrogram for maize testing locations in eastern and southern Africa for EPOP03.

2	RSAGre	43	ZimMar
3	RSAPot	44	ZimMarLpH
6	SwaMal	45	ZimRat
7	SwaShe	47	LesMas
9	ZamNan	48	LesNya
10	ZamMt_	49	LesMahLpH
11	ZamMse	50	MalChzLN
12	ZamGol	51	MalBak
13	ZamZam	52	MalLunLpH
14	ZamChi	53	MalChi
15	BotPel	54	MalChi
16	BotGoo	55	MozNam
17	BotGooLN	57	MozSus
19	BotSeb	58	MozCho
20	TanAruLN	59	RSANel
21	TanTum	60	RSAEzo
22	TanAru	61	RSAEzo
23	TanAru	66	ZimMar
24	TanUki	67	ZimMarLpH
25	AngMaz	68	ZimMar
26	AngMazLN	69	ZimMarLpH
28	AngHum	70	ZimHarLN
29	AngMaz	71	ZimMak
32	AngCab	74	EthBak
34	AngKil	80	UgaNam
36	AngCab	83	UgaSer
37	ZimHarMSV	88	IndChh
38	ZimMak	92	KenBun
39	ZimChiDrt	93	TanIlo
40	ZimHarDrt	94	TanIloLN
41	ZimART	95	MozUmb
42	ZimKad	96	EthMel
		98	ZimSav

Legend for locations of cluster dendogram of EPOP03

Figure 2.20 continued

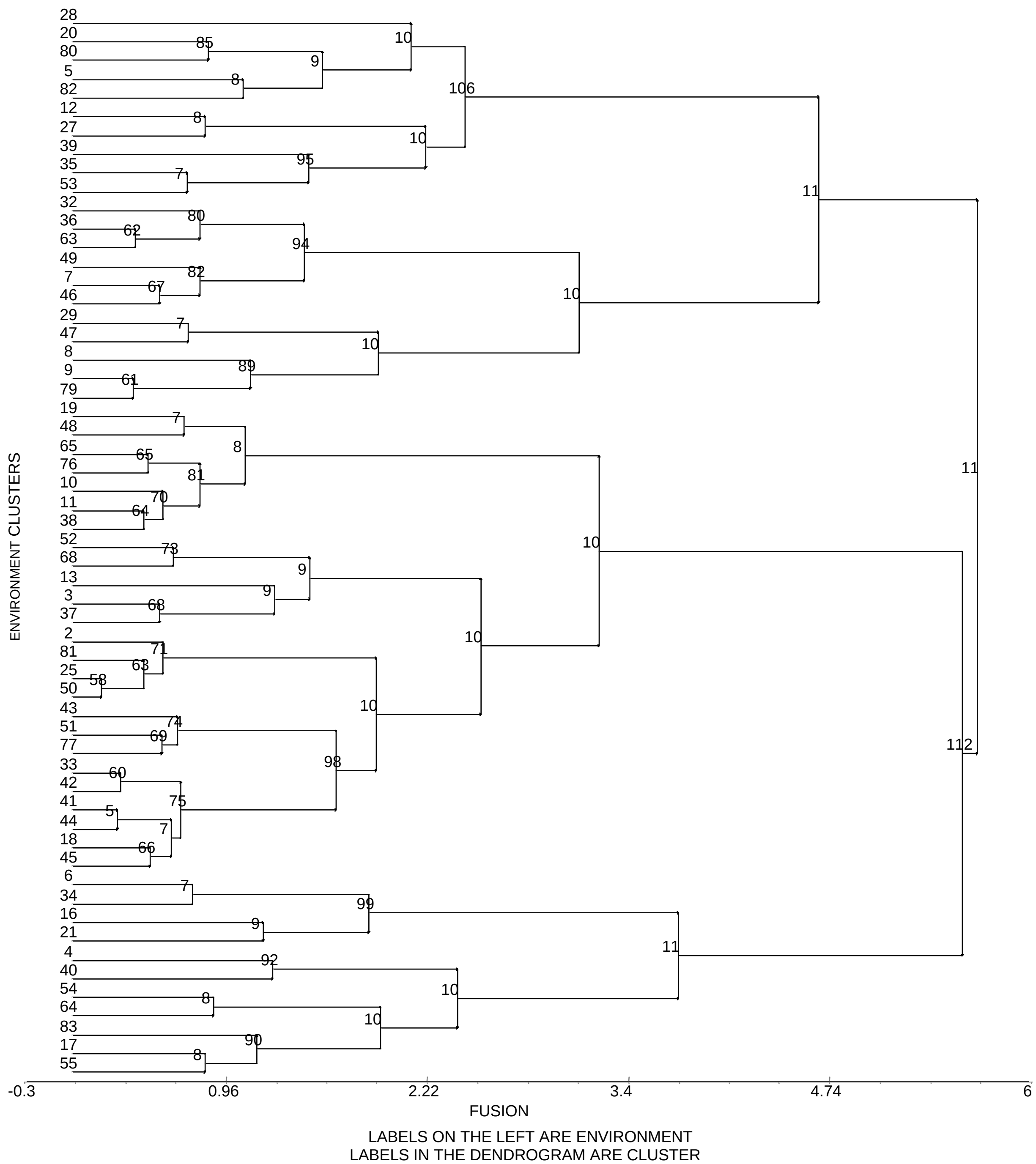

Fig. 2.21. Cluster dendrogram for maize testing locations in eastern and southern Africa for ILPOP03.

2	RSAPot	38	ZimKad
3	SwaNhl	39	ZimMar
4	SwaMal	40	ZimMarLpH
5	ZamNan	41	ZimRat
6	ZamMt_	42	ZimKad
7	ZamMse	43	MalChz
8	ZamKasLpH	44	MalBvu
9	ZamZam	45	MalMak
10	ZamChi	46	MalSal
11	BotPel	47	MalLunLpH
12	BotSeb	48	MozLic
13	BotGoo	49	MozSus
16	TanMbu	50	MozTet
17	TanAru	51	Moz
18	TanAruLN	52	ZimMar
19	TanTab	53	ZimMarLpH
20	TanAru	54	ZimMar
21	AngMaz	55	ZimMarLpH
25	AngHum	63	ZimHarLN
27	AngMaz	64	ZimMak
28	AngMazLN	65	MalChzLN
29	AngCab	68	EthBak
32	AngKil	76	ZimSav
33	ZimHarMSV	77	IndChh
34	ZimMak	79	UgaNam
35	ZimChiLN	80	UgaBul
36	ZimHarLN	81	KenKit
37	ZimART	83	TanIlo

Legend for locations of cluster dendogram for ILPOP03

Figure 2.21 continued

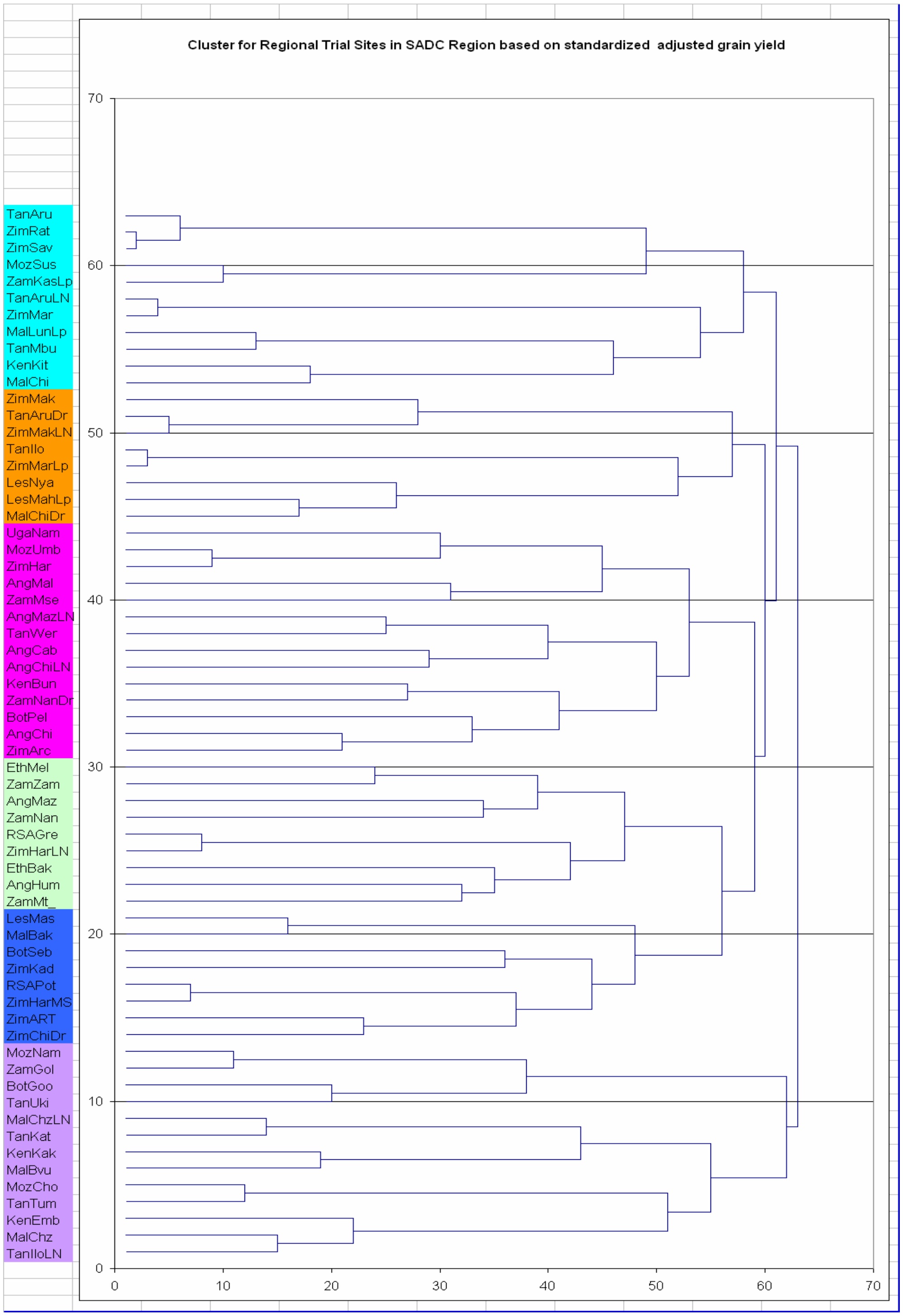

Fig. 2.22. Cluster dendrogram for maize testing locations for regional trials from 1999 to 2003 based on standardized adjusted grain yield.

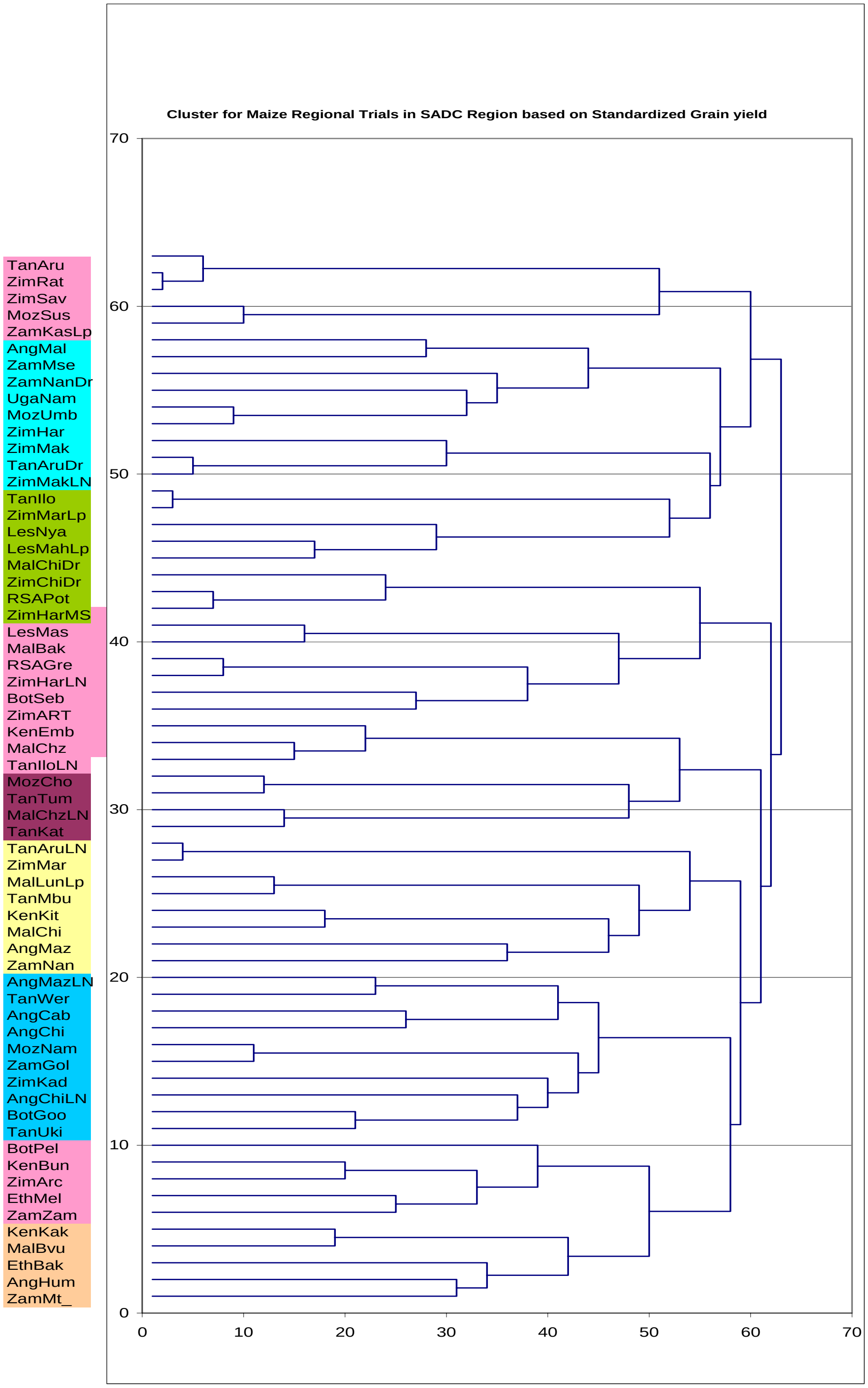

Fig. 2.23. Cluster dendrogram for maize testing locations for regional trials from 1999 to 2003 based on standardized grain yield.

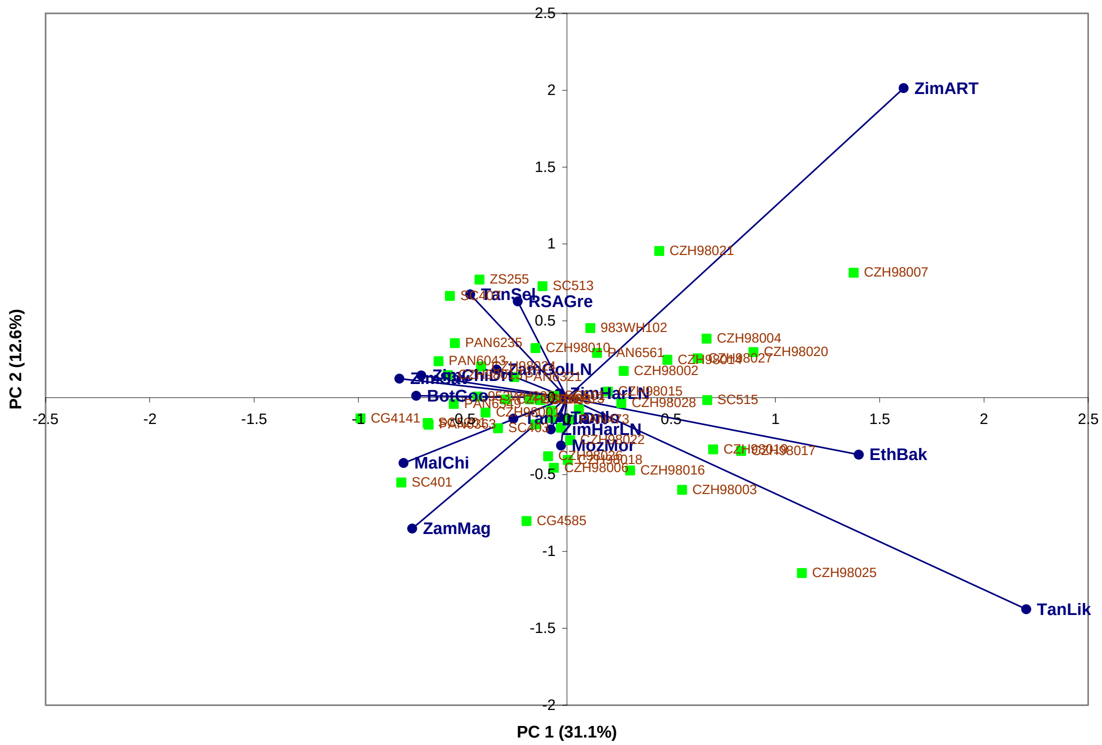

Fig. 2.24. Biplot for entries and maize testing locations for early to intermediate hybrids (EIHYB) for 1999.

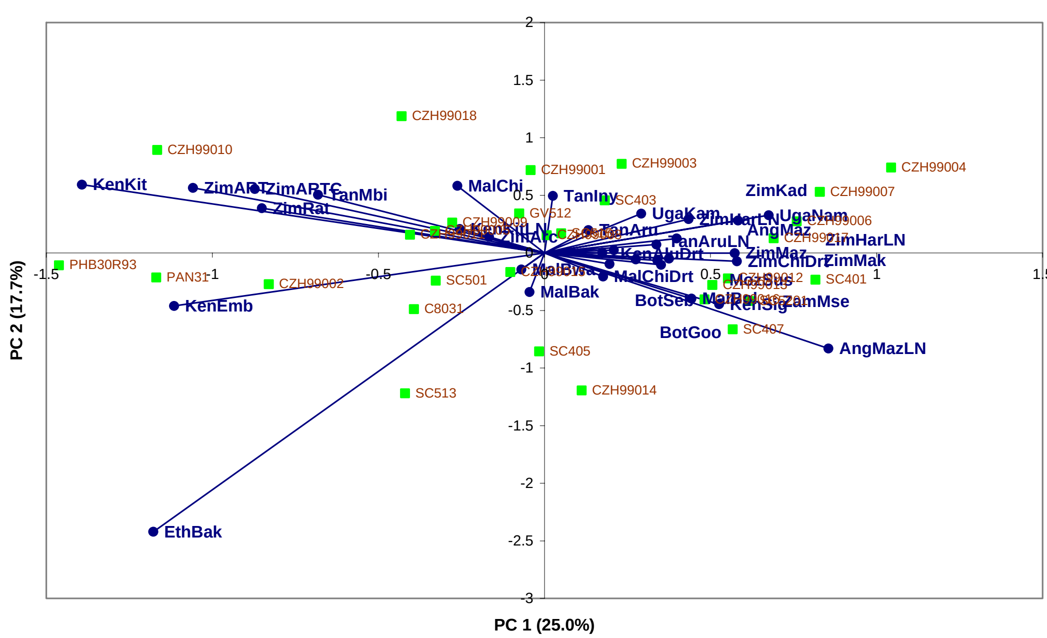

Fig. 2.25. Biplot for entries and maize testing locations for early to intermediate hybrids (EIHYB) for 2000.

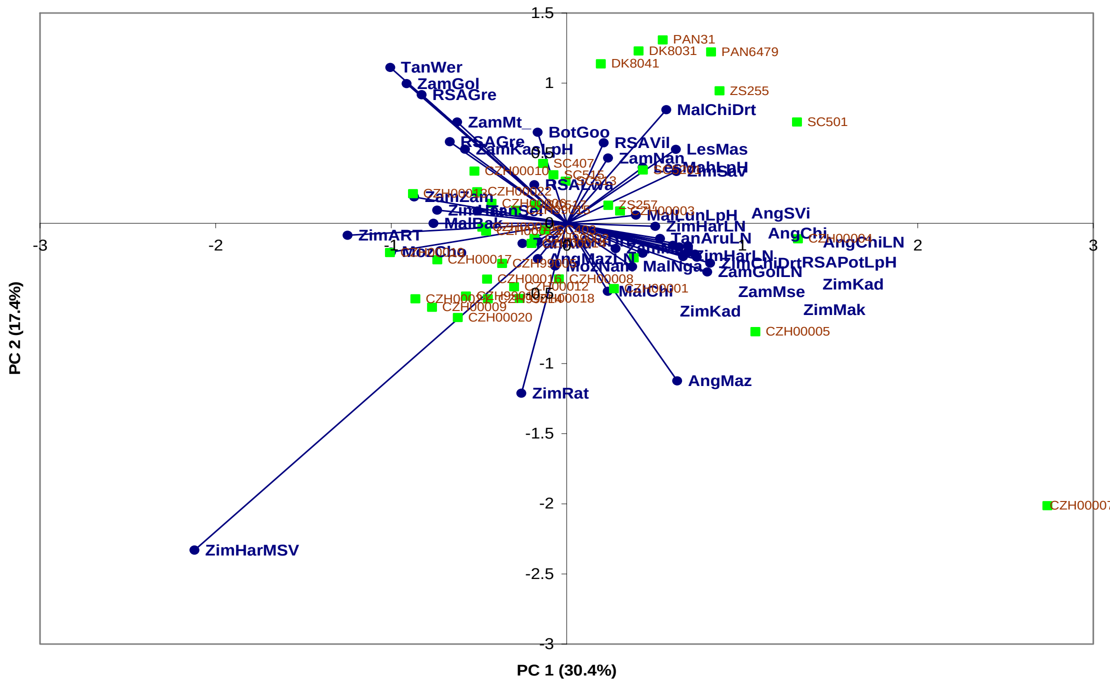

Fig. 2.26. Biplot for entries and maize testing locations for early to intermediate hybrids (EIHYB) for 2001.

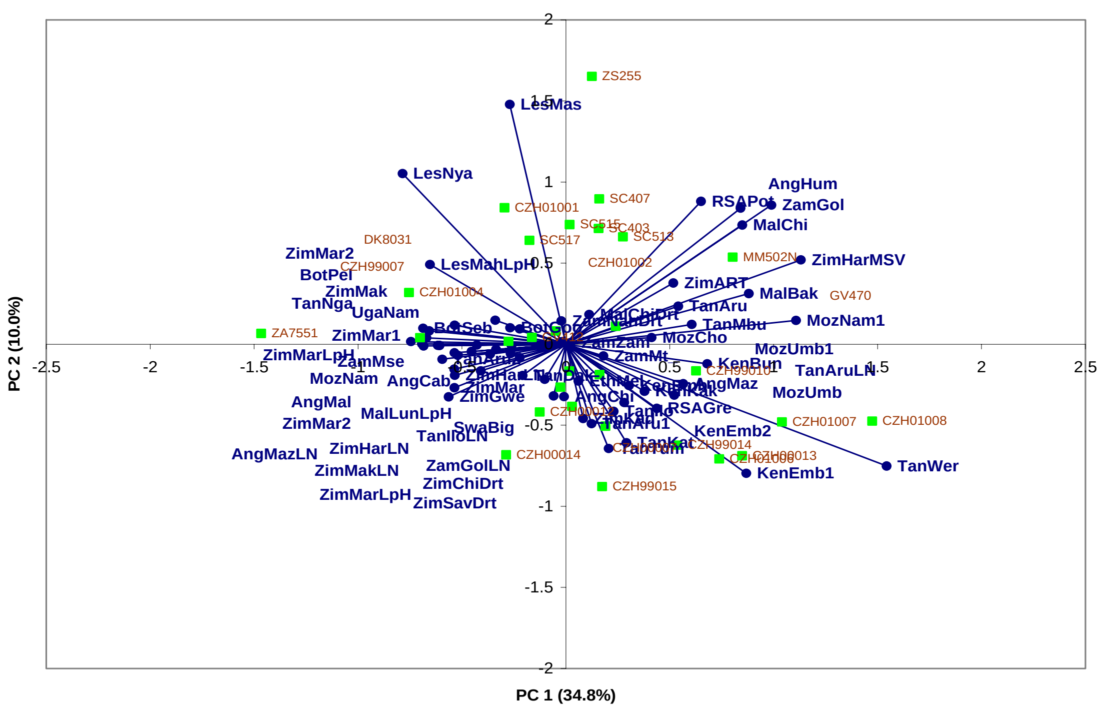

Fig. 2.27. Biplot for entries and maize testing locations for early to intermediate hybrids (EIHYB) for 2002.

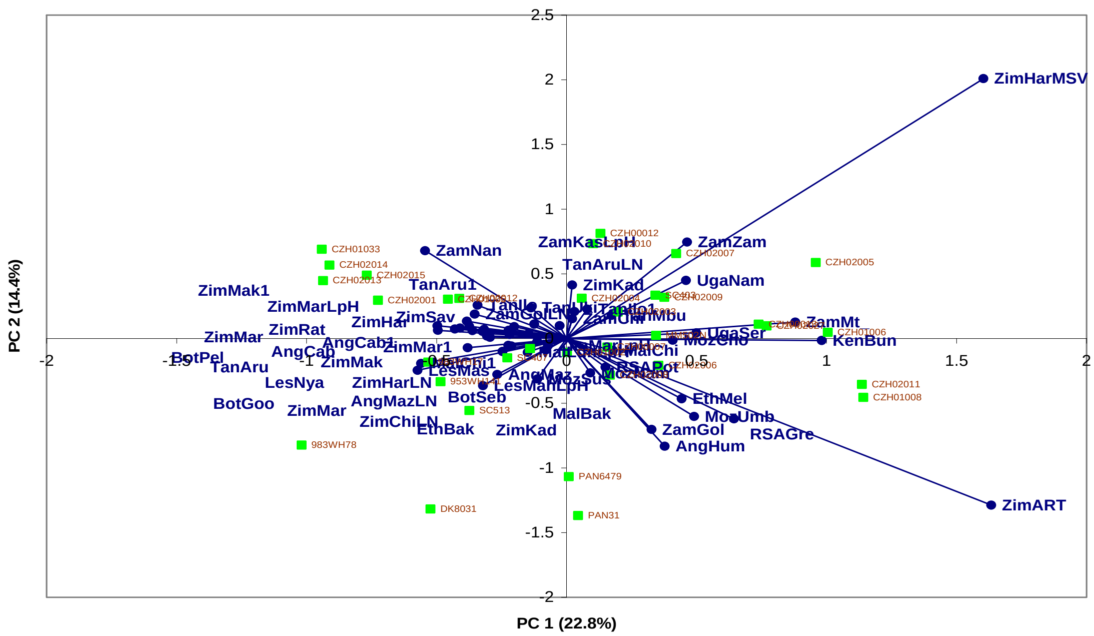

Fig. 2.28. Biplot for entries and maize testing locations for early to intermediate hybrids (EIHYB) for 2003.

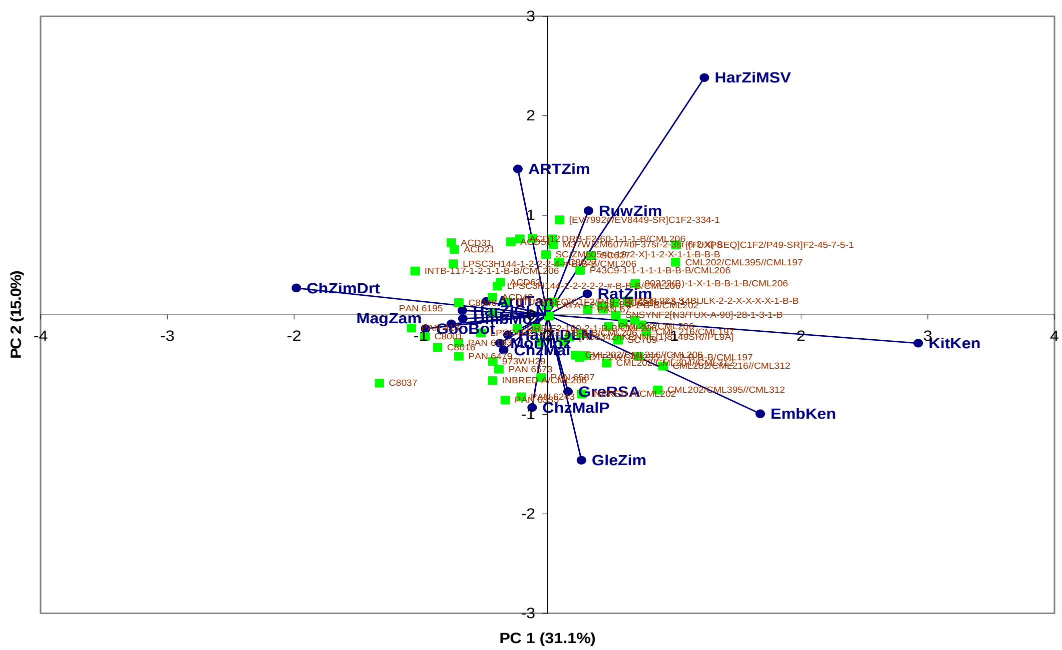

Fig. 2.29. Biplot for entries and maize testing locations for intermediate to late hybrids (ILHYB) for 1999.

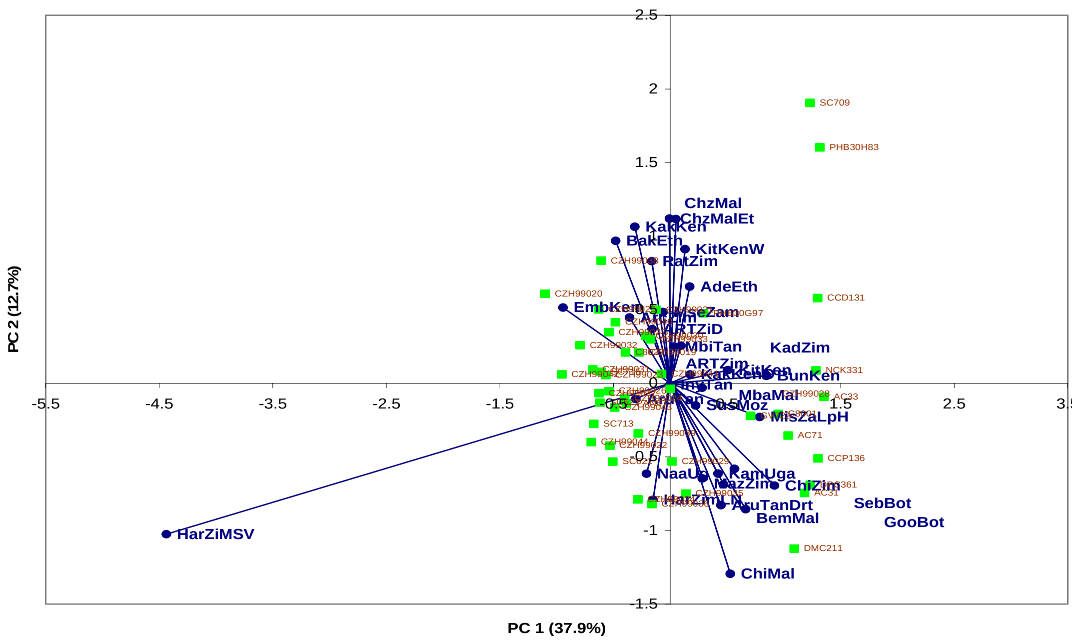

Fig. 2.30. Biplot for entries and maize testing locations for intermediate to late hybrids (ILHYB) for 2000.

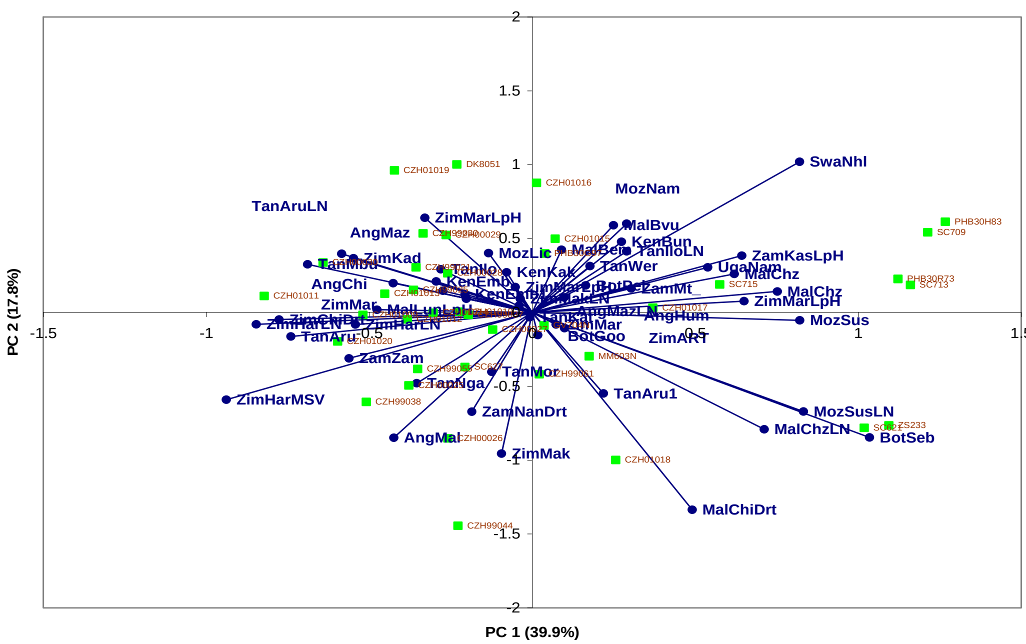

Fig. 2.31. Biplot for entries and maize testing locations for intermediate to late hybrids (ILHYB) for 2001.

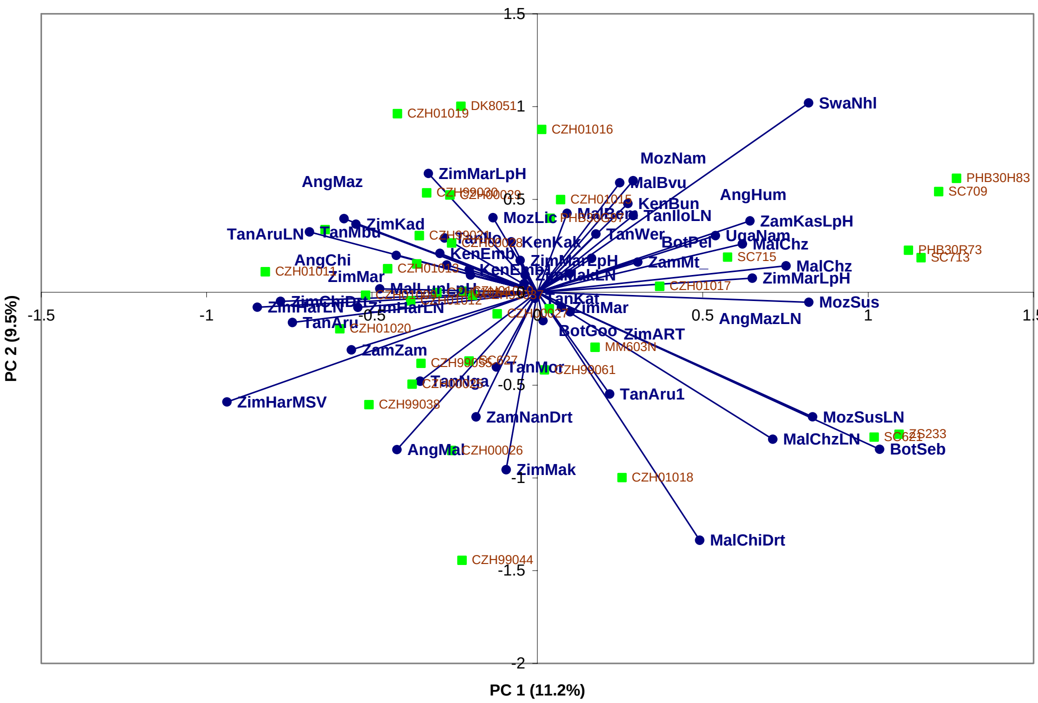

Fig. 2.32. Biplot for entries and maize testing locations for intermediate to late hybrids (ILHYB) for 2002.

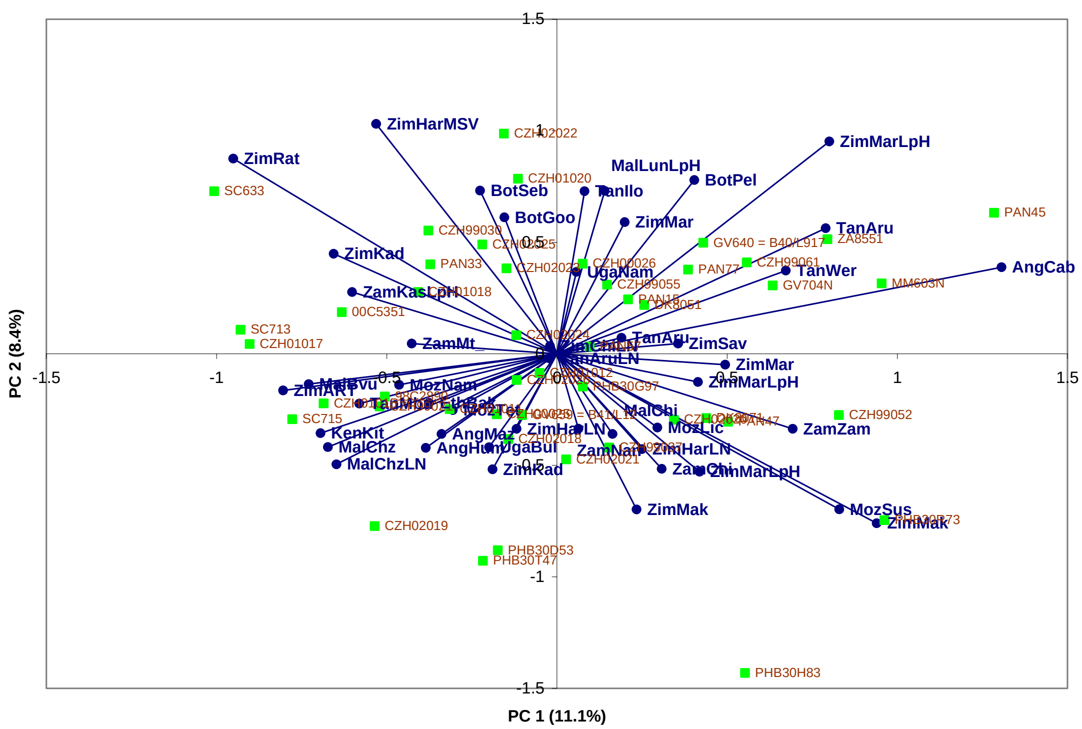

Fig. 2.33. Biplot for entries and maize testing locations for intermediate to late hybrids (ILHYB) for 2003.

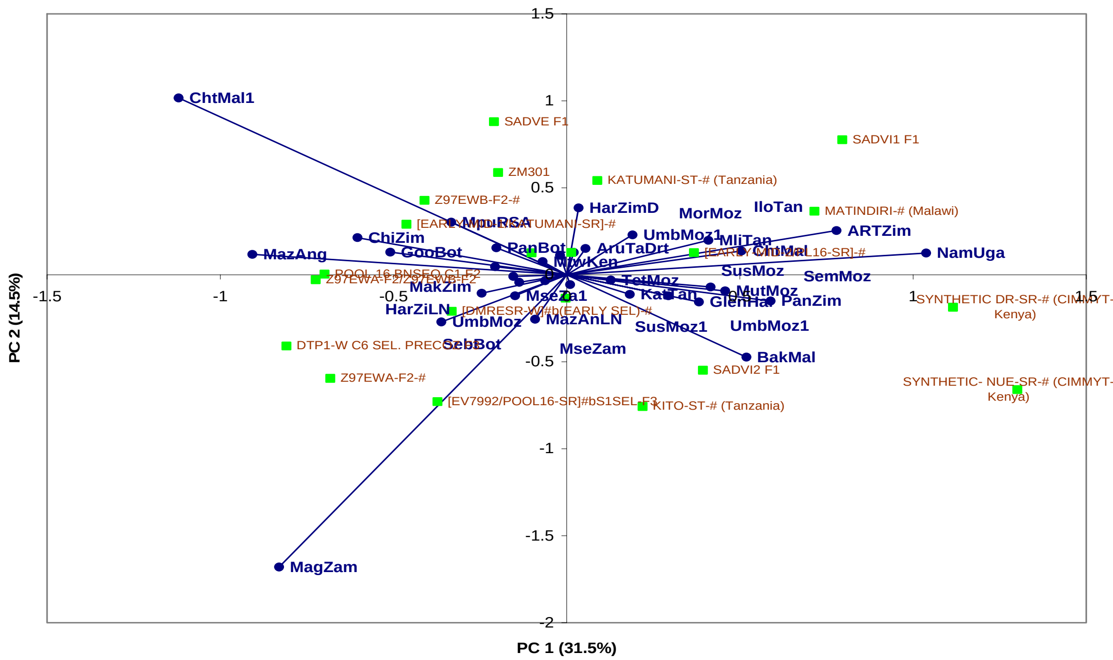

Fig. 2.34. Biplot for entries and maize testing locations for early populations (EPOP) for 1999.

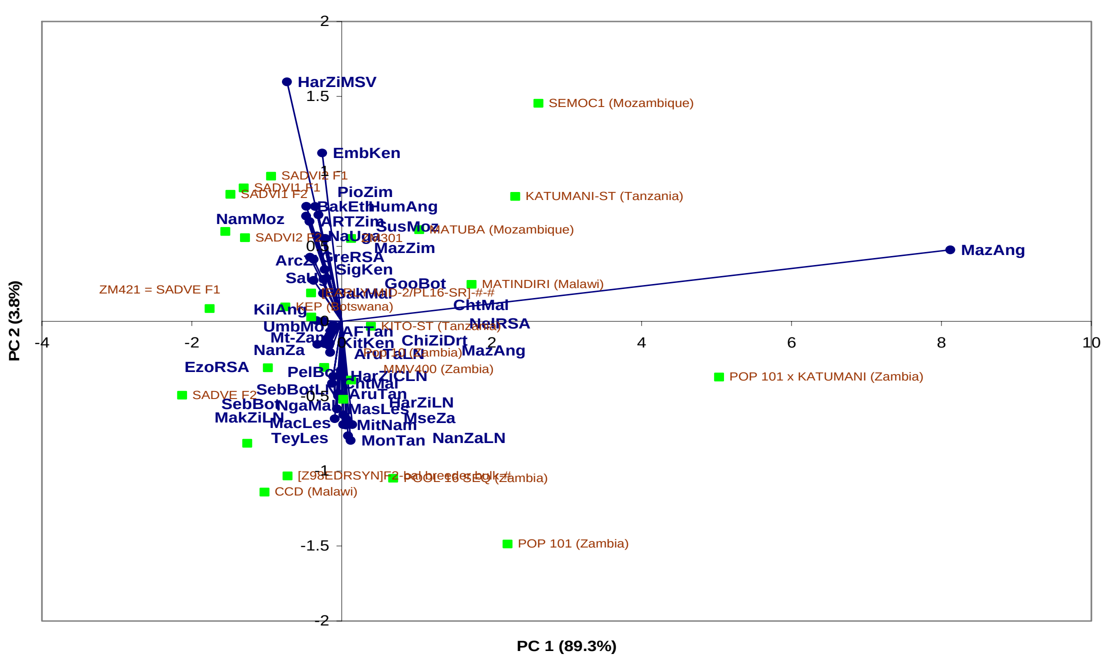

Fig. 2.35. Biplot for entries and maize testing locations for early populations (EPOP) for 2000.

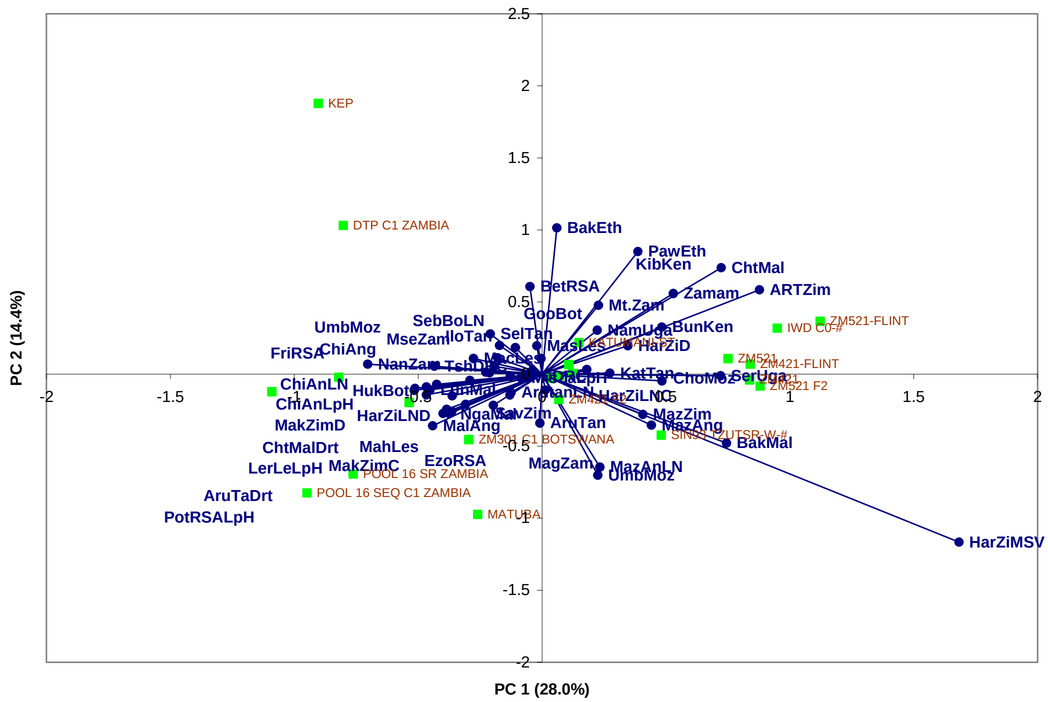

Fig. 2.36. Biplot for entries and maize testing locations for early populations (EPOP) for 2001.

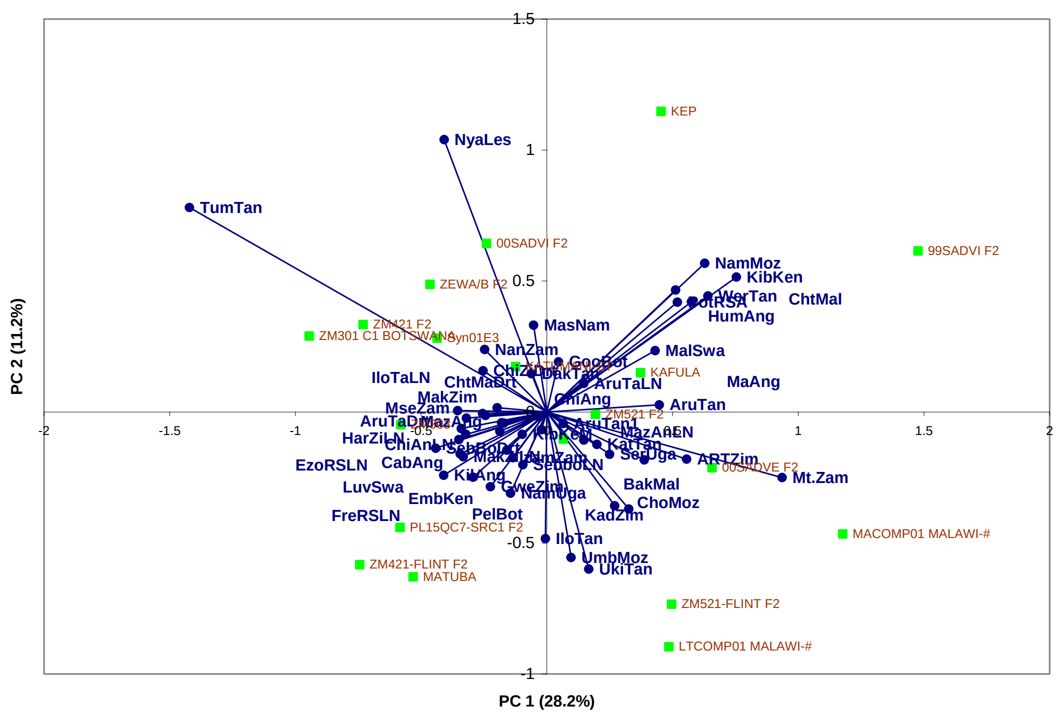

Fig. 2.37. Biplot for entries and maize testing locations for early populations (EPOP) for 2002.

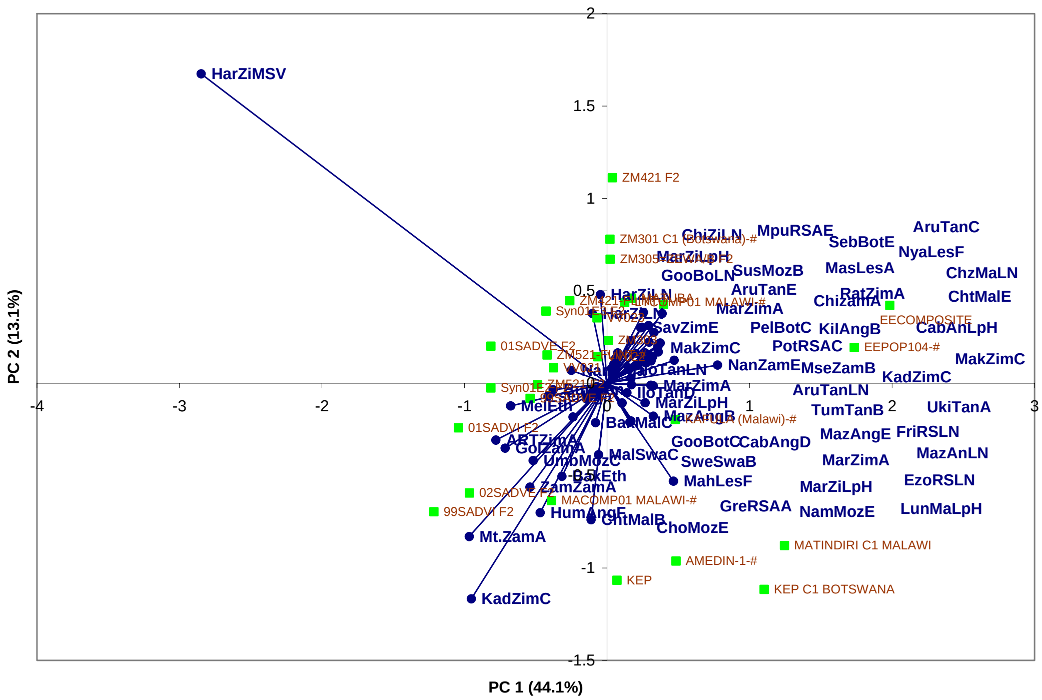

Fig. 2.38. Biplot for entries and maize testing locations for early populations (EPOP) for 2003.

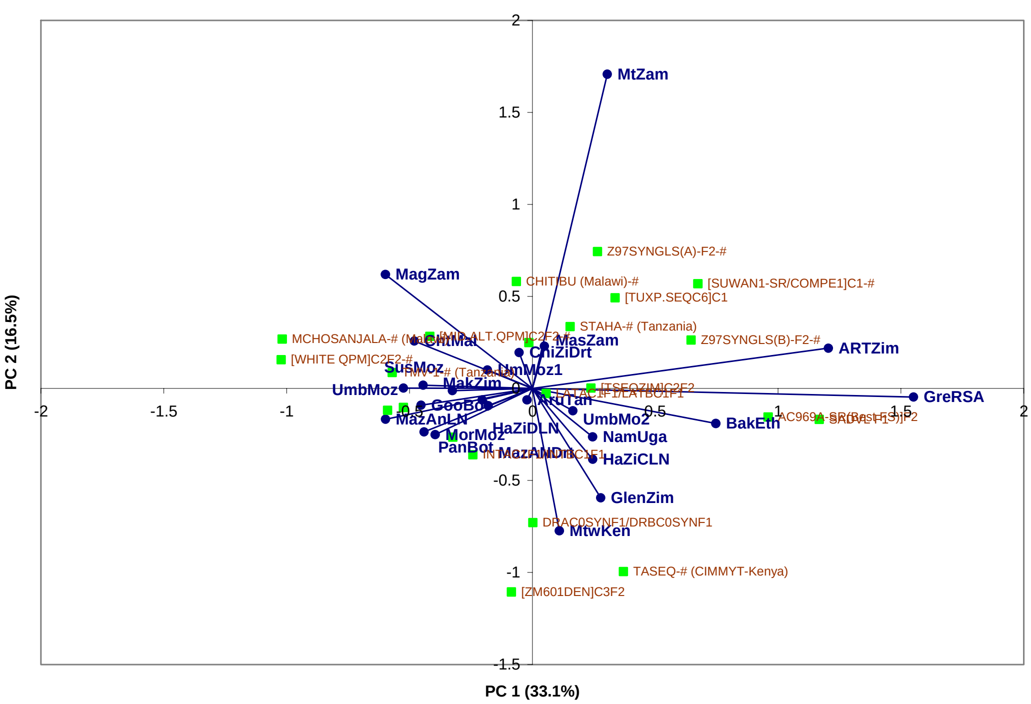

Fig. 2.39. Biplot for entries and maize testing locations for intermediate to late populations (ILPOP) for 1999.

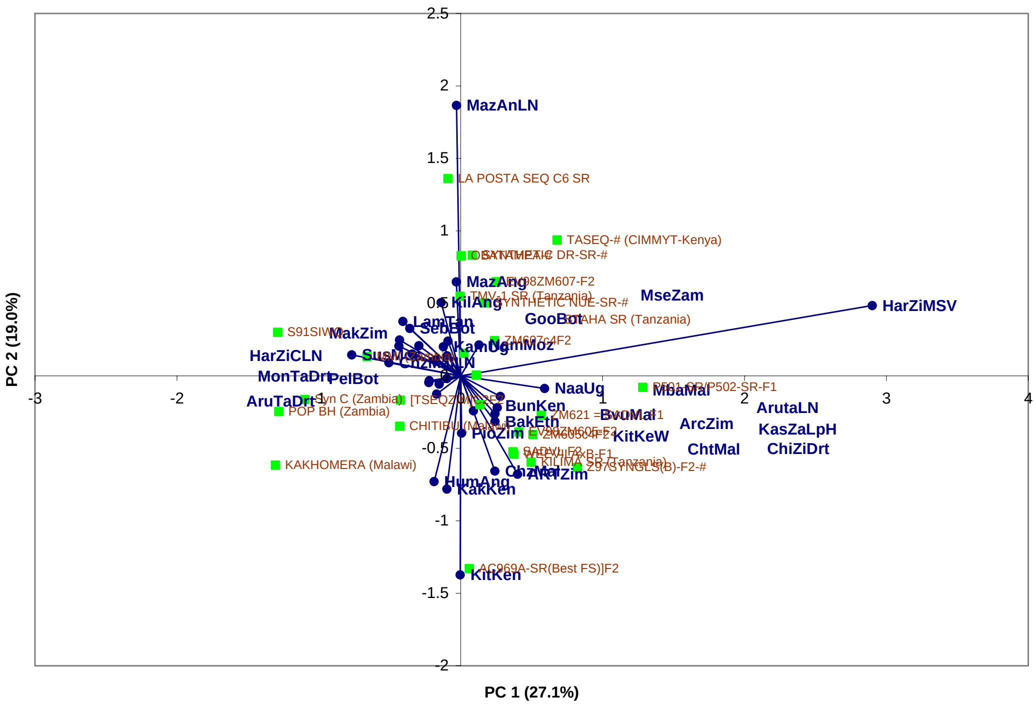

Fig. 2.40. Biplot for entries and maize testing locations for intermediate to late populations (ILPOP) for 2000.

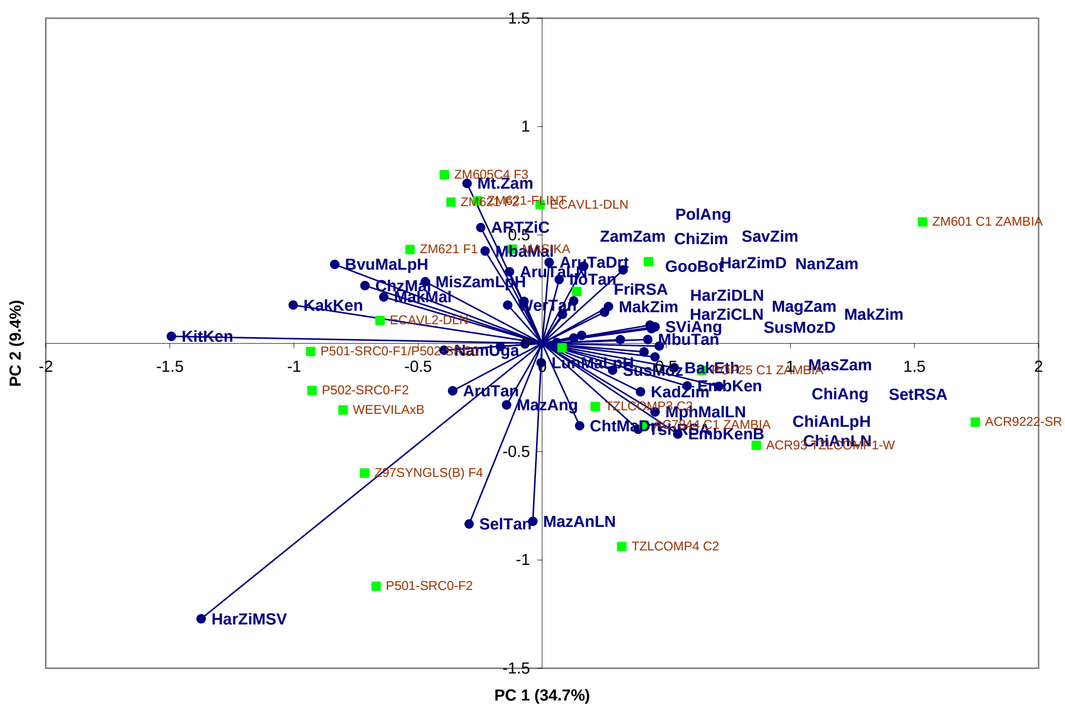

Fig. 2.41. Biplot for entries and maize testing locations for intermediate to late populations (ILPOP) for 2001.

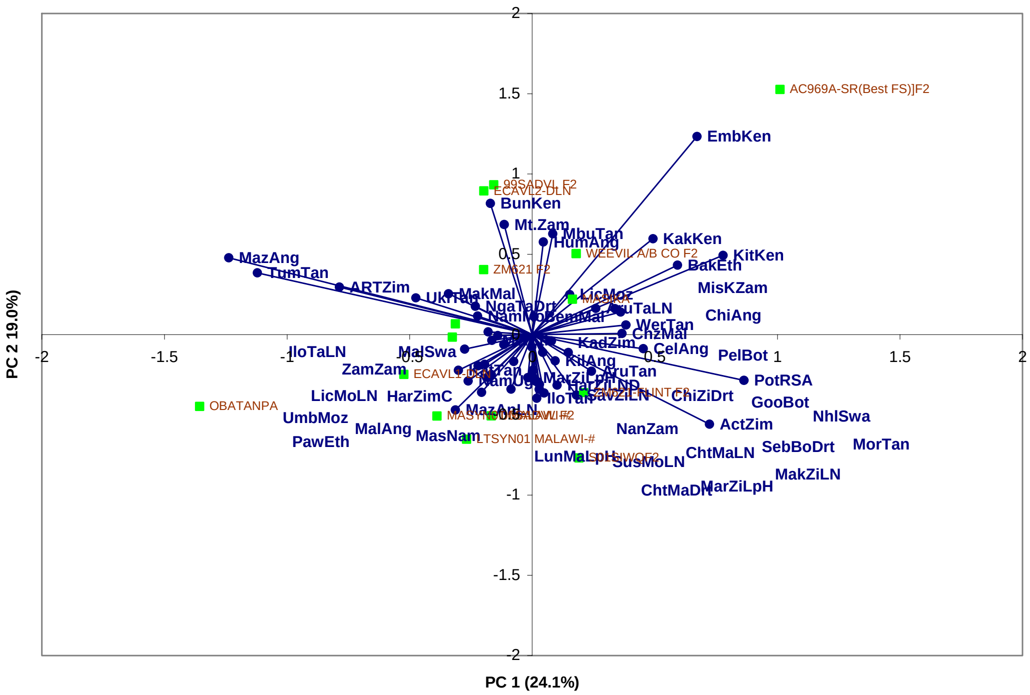

Fig. 2.42. Biplot for entries and maize testing locations for intermediate to late populations (ILPOP) for 2002.

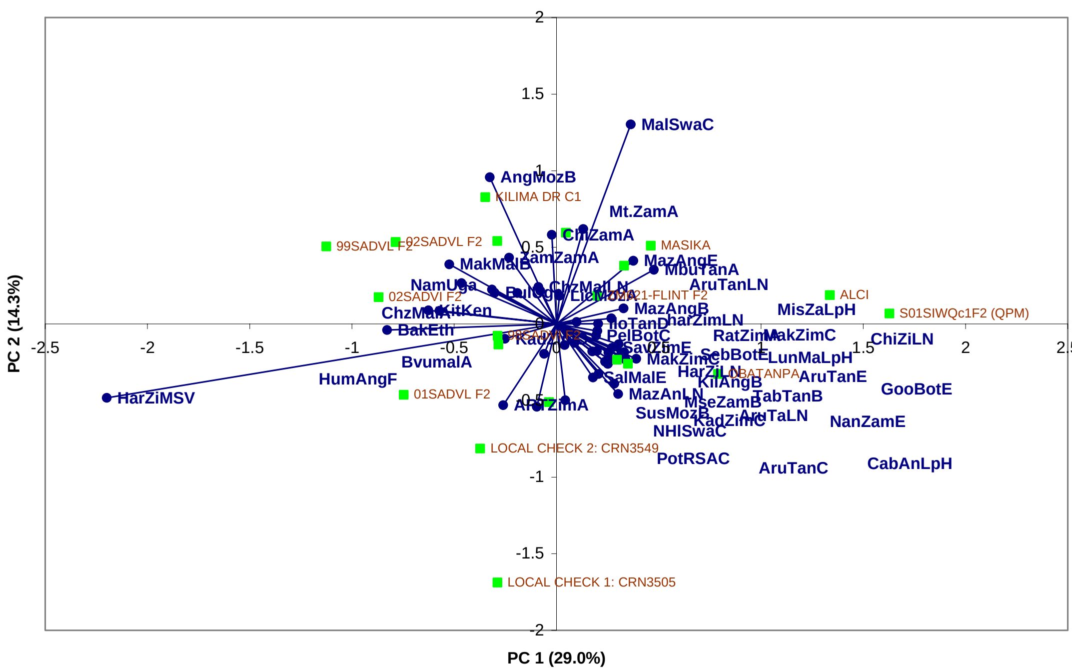

Fig. 2.43 Biplot for entries and maize testing locations for intermediate to late populations (ILPOP) for 2003.

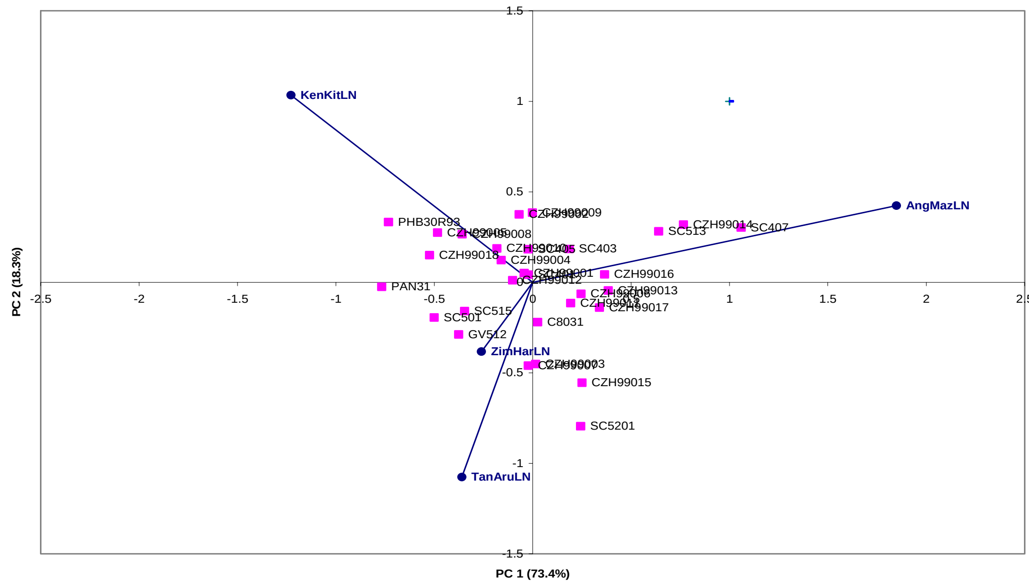

Fig. 2.44. Biplot for low nitrogen locations and entries for early to intermediate hybrids (EIHYB) in 2000.

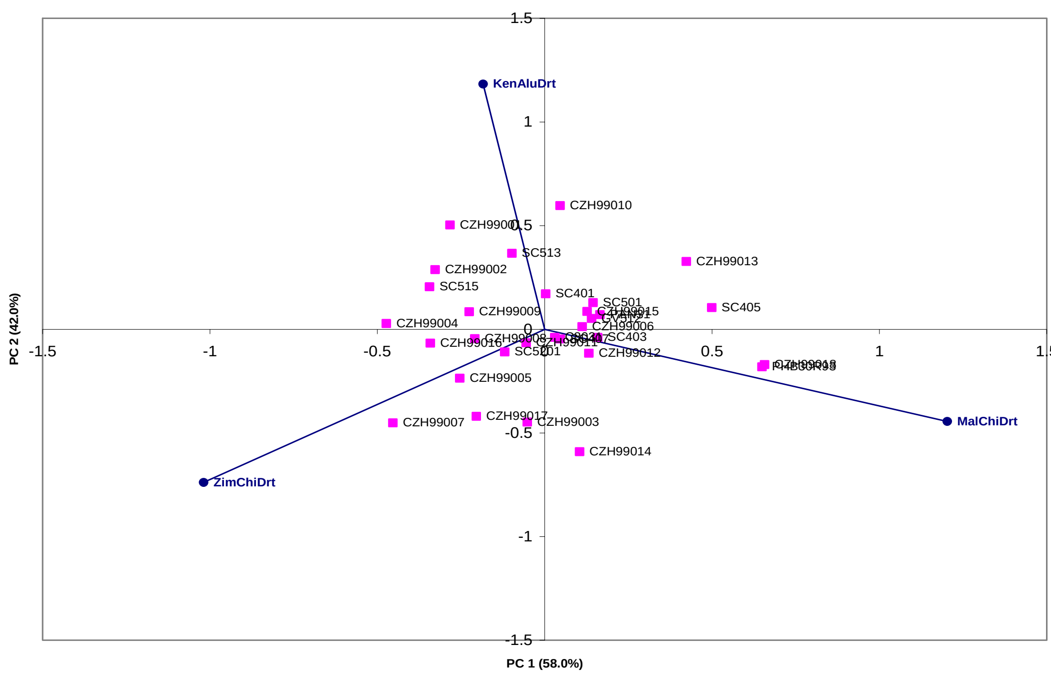

Fig. 2.45. Biplot for drought locations and entries for early to intermediate hybrids (EIHYB) in 2000.

CHAPTER III

PHENOTYPIC AND GENETIC ANALYSIS OF MAIZE TESTING EVALUATIONS IN EASTERN AND SOUTHERN AFRICA

INTRODUCTION

Maize (*Zea mays L.*) is the most important food crop in eastern and southern Africa. It is produced by the medium and small scale farmers; others operating on a half a hectare mixed cropping year after year. For these farmers, maize is used as a staple food, and the surplus may be used for sale. Maize germplasm improvement will therefore have a direct impact of livelihoods of millions of families of eastern and southern Africa. Higher yields of maize among smallholder farmers may result in surplus which may be used for sale and this could result in increased demand of non farm goods and services which exert positive influence on the macro economies of the countries in the region.

The region has a wide range of maize growing conditions, from bimodal annual rainfall patterns of Namulonge, Uganda to Namib and Kalahari Deserts of Namibia and Botswana. From low elevations of Cape Town, South Africa to East African highlands of Kilimanjaro, Tanzania, with varying soil nutrition levels and management conditions. Although plant breeders may aim breeding for wide adaptation, it is difficult to accomplish that with such variability in maize growing areas and conditions. For institutions that are involved in regional germplasm development, international multi-location testing of pre-released material is essential and CIMMYT has been actively involved in germplasm development and deployment activities for the region for many years. Maize regional trials are conducted annually to test advanced materials for performance, suitability and adaptation. As materials are tested in different locations, their performance usually changes from one location to the next (Easton and Clement, 1973) and this is the manifestation of genotype x environment interaction.

Genotype x environment interactions may be defined as the failure of genotypes to have similar relative performance from one location to another; the effects of genotypes and locations are statistically non-additive, which means that differences between genotypes depend on the locations (Baker, 1988a; Yang and Baker, 1991). Such interactions pose a real challenge to germplasm development, because they limit the usefulness and gains of selection in any single location as this GL "noise" reduces the heritability of the character, thereby affecting breeding progress owing to inaccurate selections.

Knowledge of the presence and type of genotype x environment interaction can help breeders make informed decisions to optimize breeding methods, selection intensity, and testing procedures (Baker, 1969). Studies dealing with genotype x environment interaction have suggested that they are usually due to inconsistent genotypic responses to temperature, soil moisture, soil type, or fertility level from location to location and year to year (Liang et al., 1966). Variation in these locations, environmental and management factors can therefore cause yield and its components (e.g., kernel number and kernel weight) to vary from one location to another. The partitioning of variance into its components permits an estimation of the relative importance of the various determinants of the phenotype, in particular the role of heredity versus environment. The relative importance of a source of variation is its variance as a proportion of total phenotypic variance, and the relative importance of heredity in determining phenotypic values is heritability of a character.

Characterization of maize testing locations for eastern and southern Africa in this study is based crop performance which is the maize phenotypic expression. The analysis and subsequent test location characterization in this study are based on mean grain yield. The dissimilarities among the test locations are harnessed in the total variation, which is the phenotypic variation and is the sum of various separate components. The total variation (Vp) is the sum of genotypic variation (Vg) and environmental variation (Ve) (Falconer and Mackay, 1996).

Estimation of variance components in a germplasm development program can provide useful information to enable breeders to determine the most efficient design of genotype evaluation (Hansche et al., 1972; Tancred et al., 1995). While variance basically measure spread of the entries in a sample or population, components of variation show the partition of variation due to different sources (e.g., genotypes, environments, genotype x environment). There is not much information about components of variation for grain yield in maize evaluated under stress both abiotic and biotic (Bänziger and Meyer, 2002). Therefore, this study was conducted with the objective of estimating components of variation and repeatabilities for the regional maize trials conducted under different locations under optimum, low nitrogen, drought and low pH managed conditions.

REVIEW OF LITERATURE

In eastern and southern Africa, maize is produced is mainly grown by smallholder farmers whose land holding is less than 0.5 ha in some countries like Malawi. The crop is grown under less favorable conditions than those experienced in research stations. Most farmers do not afford inorganic fertilizers, and depend on rainfall, and therefore low nitrogen and drought are the common stress conditions experienced by the maize farmers in the region. Other farmers experience low pH conditions.

Hoffman et al (1999), reviewing heritable variation ad evolution under favorable and unfavorable conditions, noted that genetic variability in quantitative traits could change as a direct response to the environmental conditions in which those traits, like grain yield in maize, present themselves. They pointed out that the phenotypic variance (VP) for a trait can be expressed as VP = VA + VD + VI + VE; where, VA is the additive genetic variance, VD the dominance variance, VI the variance resulting from epistatic interactions between genes, and VE the environmental variance. They said that different components can be estimated from appropriate quantitative genetic breeding designs or from selection experiments, although the estimation of epistatic and dominance variance components is difficult and required special genetic designs. Changes in the narrow- (h^2 = VA/ VP) or broad- [h^2 = (VA + VD + VI)/ VP] sense heritabilities can be caused by changes in the genetic or environmental components of variance. When comparing heritability estimates across two (or more) environments, heritabilities can differ because there is a difference in variance of breeding values among the environments or the genetic correlation across the environments is less than one. Therefore performance of breeding material in a range of environments is affected by the environment in which the evaluation and selection is made (Allen et al., 1978; Fox and Rosielle, 1982; Cecarrelli et al., 1991; Simmonds, 1991). Choice of an environment to maximize genetic gain is crucial in cultivar development programs.

Bouzerzour and Dekhili (1995) looked at heritabilities, gains from selection and genetic correlations for grain yield of barley grown in two contrasting environments in eastern Algeria. Barley is the only possible rain fed crop, and is produced in a fallow cereal system. They evaluated a set of 15 barley lines for three years (1988/89 – 1990/91). The error variance (σ^2_e) and genetic variance (σ^2_g) were estimated by bivariate analysis. Components of variance and their standard errors were also estimated by combined analysis by letting the mean squares equal to their expectations (Comstock and Moll, 1963). Estimates of heritability were determined on mean basis as $h^2 = \sigma^2_g / (\sigma^2_g + \sigma^2_e)$. The results indicated that the genotype x location interaction variance component was greater than genetic variance component. They suggested that genotype × environment interactions, particularly related to seasonal effects, seriously limited selection for increased barley grain yield. Their effect was to reduce the genetic variance component, heritability estimates and genetic correlation coefficients. They also contended that selection in a high-yielding location does not identify genotypes suitable for low-yielding environments, which are more representative of the production conditions of a most smallholder farmers in sub-Saharan Africa.

Earlier work in maize suggested that cultivar development under stress conditions may significantly reduce selection gains (Arboleda-Rivera and Compton, 1974; Hallauer and Sears, 1969). Blum (1988) reported that heritability for grain yield, and thus effectiveness of selection is reduced under moisture stress conditions.

Grüneberg et al, 2004 reported on variance component estimations and allocation of resources for breeding sweet potato (*Ipomea batatus* L.) under east African conditions. This work was conducted to generate qualitative data for improvement of efficiencies in variety testing and the overall sweet potato breeding system. An international genotype by environment trial of sweet potato was conducted between 1999 and 2001 in several countries of Sub-saharan Africa. The data set comprised of 15 genotypes, three locations, three seasons and two crop durations (there were two crops per season). The analysis of variance was carried out using SAS 6.12 (SAS Institute Inc. 1997) using procedure MIXED, the method Restricted Maximum Likelihood (REML) (Patterson, 1997) and the model statement x_i = G +L+S+LS+GS+GL+GLS+BL(L,S); where, G = genotype, L = location, S = season, BL= block. The results indicated that estimated variance components were significant for all traits measured including storage root yield. The genotypes x environment interactions variances ($\Phi^2_{GL} + \Phi^2_{GS} + (\Phi^2_{GLS})$ were consistently larger than genotypic variances (Φ^2_{γ}). They also reported that the error variances (Φ^2_{γ}) were often the largest. These findings were consistent with those obtained by Ortiz et al. (2001) when they looked at heritability and correlations among genotype-by-environment stability statistics for grain yield in bread wheat in south western and eastern highlands of Uganda. The study was carried out in three growing seasons from August 1994 to March 1996 and at two locations; Kalengyere and Buginyanya. Analyses of variance were carried out on mean grain yield. After equating the observed mean squares with their model II, expected values (Griffing, 1956), they calculated the components of variance and the interaction among them from which estimates of the additive genetic (Φ^2_A) and phenotypic (Φ^2_P) components were obtained to obtain narrow sense heritabilities (h^2) following Hill et al. (1998). They reported that locations accounted for 70.5% of the total variation, while genotypes and the GE interaction explained 8.7% and 19.6%, respectively, of the total variation for grain yield.

Repeatability is another measure of the relative importance of genetic variation among a fixed set of genotypes. It is determined by estimating variation components, in a similar manner to the calculations to estimate heritability. Repeatabilities are calculated as the proportion of genetic variation over the total phenotypic variation (Fehr, 1987). They represent an upper limit for broad-sense heritabilities. It's a limited and biased estimate of levels of inheritance as its determination refers only to the materials that are in the trial; not extrapolating to a wider population (Betran, per. comm. 2005). Repeatability has been used as a measure of progress in plant breeding by many workers. Hakizimana et al. (2000) estimated repeatability and genotype x environment interaction of coleoptile length measurements in winter wheat. This was an integral of a wider effort to optimize breeding methods, selecting intensity and testing procedures.

MATERIALS AND METHODS

The data sets and maize germplasm

The data sets are from the CIMMYT maize regional trials, which had been conducted routinely and annually to test suitability, adaptation which facilitate germplasm dissemination and exchange in eastern and southern Africa. The data was collected from 1999 to 2003. These trials evaluated elite pre-released and released maize germplasm supplied by CIMMYT, National Agricultural Research Programs and private seed companies from eastern and southern Africa. The maize germplasm has been described in Chapter II.

Trial management

The trials were planned and facilitated by CIMMYT and were managed by various collaborators who included national programs and seed companies in eastern and southern Africa. The collaborators were encouraged to plant the trials under optimal, managed stress for low N, drought, low pH stress, and under under artificial inoculations/infestation for leaf diseases, stem borers and maize grain weevils (see Chapter II for details).

Data analysis

Estimation of components of variation

The estimation of variance components across locations was conducted in Statistical analysis system (SAS) using Proc Mixed. All the variables were considered random. The sources of variation were environment (location), replication (env), block (rep*env), entry (or genotype), entry*environment, and error.

Repeatability

Repeatability was calculated as the proportion of genetic variation to total variation. It was calculated both on plot bases and on family bases. Only repeatability on family bases is presented here. Repeatability of grain yield on plot and on family basis was conducted for each location and managed environment in each year from 1999 to 2003.

Repeatability (on plot basis) was calculated as $R = \dfrac{\sigma^2{}_g}{\sigma^2{}_g + \dfrac{\sigma^2{}_e}{r}}$ where $\sigma^2{}_g$ is the genotypic variation, $\sigma^2{}_e$ is the error variance and r is the number of replications for a single environment. Across environments (family basis), repeatability was calculated as

$R = \dfrac{\sigma^2{}_g}{\sigma^2{}_g + \dfrac{\sigma^2{}_{ge}}{e} + \dfrac{\sigma^2{}_e}{re}}$ where $\sigma^2{}_g$ is the genotypic variation, $\sigma^2{}_{ge}$ is the genotype x environment variance, $\sigma^2{}_e$ is the error variance, e is the number of environments, and r is the total number of replications.

RESULTS AND DISCUSSION

Components of variation for early to intermediate hybrids (EIHYB)

The components of variation for yield for early to intermediate maize hybrids (EIHYB) are shown in Tables 3.1, 3.2, 3.3, 3.4 and 3.5. for years 1999, 2000, 2001, 2002 and 2003, respectively. The combined analysis of variance across the locations indicated that all the variation sources were highly significant ($P<0.01$), both across all locations and locations under optimal conditions. However, under stress conditions, genotype and genotype x location interaction were not significant ($P<0.05$) in influencing grain yield. An increase in error under stress might have contributed to the loss in significance in these two sources of variation.

The proportion of each of the sources of variation was also calculated to determine the magnitude of genetic versus non genetic variation. This was calculated and presented as percentage of total variation. The analysis of variation across locations showed that most of the variation was due to the environment. In 1999, for EIHYB, 71.84% of total variation was due to environment (location), 13.8% to error, only 1.95% to genotypes, and 6.32% to genotype by location. This partition is similar on evaluation across optimum locations, where location, error, genotype by environment interaction and genotype contributed 72.58%, 13.08%, 6.78% and 2.03% to the total variation, respectively. Chapman et al. (1997) also showed that most of the variation observed in trials across locations is due to environments. They reported that environments made up of 97.9% of total sum of squares, genotype by environment interaction accounted for 1.4% and the genotype 0.6% of total sum of squares when they looked at genotype by environment effects and selection of drought tolerance in tropical maize. Casanoves et al. (2005) evaluated multi-environment trials in peanuts and also reported that environments (combinations of years and locations) constituted a source of important variation (90.5%) of total variation. It should be noted though that the high variation due to environmental differences is expected in multi-environmental trials conducted through several years (Yan and Kang, 2003). The highly environmental effects could be attributed to the abiotic and biotic differences across locations and growing seasons (Ortiz, 2001). It should be noted though that environmental factors may be repeatable while others could not be repeatable. In the case of climatic factors, although there is a general climatic long term trend for specific locations, the season to season presentation or occurrence of climatic factors may be highly variable. Rainfall and temperature are the most notable factors which vary from season to season. Soil factors generally remain the same and are therefore highly repeatable. Management factors can be fully controlled by growers and therefore may sometimes provide a much needed opportunity to change the overall phenotype of a character. It is not uncommon to describe a site as a good testing site for the regional maize testing in eastern and southern Africa, while referring to the quality of evaluation. This therefore emphasizes the need for appreciation of the role of the location on the phenotypic expression of the various traits. The determination of the various components of variation in the regional trials will significantly direct further planning and design of trials to maximize gains in selection.

Analysis across stress locations showed that error accounted for most of the variation. In trial EIHYB99, error accounted for 48.75% of total variation while environment accounted for 17.2% and genotype for 6.42% of total variation observed. This trend is consistent in the other years. There is a slight increase in the influence of the genotype, a significant increase of error and a significant reduction in the contribution of environment to the total variation. This trend is similar under drought and low nitrogen conditions.

Table 3.1 Components of variation for grain yield across drought, low N, optimum and all locations for EIHYB in 1999.

Sources of variation	**DRT†**	**TV%‡**	**LN**	**TV%**	**OPT**	**TV%‡**	**ALL**	**TV%**
ENVIRONMENT	0.29	17.20	0.20	13.41	5.38	72.58	4.62	71.84
REP (ENV)	0.05	2.87	0.01	0.70	0.17	2.31	0.13	1.97
BLOCK (ENV*REP)	0.26	15.49	0.35	23.08	0.24	3.21	0.26	4.12
ENTRY	0.11	6.42	0.16	10.42	0.15	2.03	0.13	1.95
ENV*ENTRY	0.16	9.27	0.17	11.59	0.50	6.78	0.41	6.32
RESIDUAL	0.83	48.75	0.62	40.79	0.97	13.08	0.89	13.80
REPEATABILITY	**0.56±0.15**		**0.55±0.12**		**0.69±0.07**		**0.75±0. 06**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.2. Components of variation for grain yield across drought, low N, optimum and all locations for EIHYB in 2000.

Sources of variation	DRT†	TV%‡	LN	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	0.90	54.19	1.55	47.61	3.86	65.21	3.82	66.83
REP(ENV)	0.06	3.86	0.06	1.74	0.15	2.49	0.13	2.27
BLOCK (ENV*REP)	0.22	13.60	0.50	15.47	0.30	5.00	0.31	5.49
ENTRY	0.04	2.57	0.12	3.74	0.17	2.87	0.14	2.39
ENV*ENTRY	0.04	2.18	0.10	3.09	0.67	11.39	0.55	9.66
RESIDUAL	0.39	23.60	0.92	28.35	0.77	13.05	0.76	13.36
REPEATABILITY	**0.53±0.05**		**0.53±0.06**		**0.91±0.02**		**0.95±0.01**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.3. Components of variation for grain yield across drought, low N, low pH, optimum and all locations for EIHYB in 2001.

Sources of variation	DRT	TV%‡	LN	TV%	LpH	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	0.12	7.13	1.28	66.00	6.78	77.29	4.70	64.57	4.80	67.26
REP (ENV)	0.13	7.71	0.01	0.33	0.10	1.19	0.07	0.98	0.07	0.92
BLOCK(EN*RP)	0.28	16.58	0.16	8.34	0.09	1.06	0.48	6.56	0.38	5.38
ENTRY	0.02	1.37	0.04	1.92	0.08	0.92	0.39	5.38	0.32	4.48
ENV*ENTRY	0.46	27.03	0.10	5.40	0.31	3.56	0.39	5.36	0.44	6.19
RESIDUAL	0.69	40.18	0.35	18.01	1.40	15.97	1.25	17.15	1.13	15.78
Repeatability	**0.27±0.32**		**0.50±0.06**		**0.22±0.24**		**0.94±0.02**		**0.95±0.01**	

† DRT, LN LpH and OPT = drought, low nitrogen, low pH and optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.4. Components of variation for grain yield across all locations for EIHYB in 2002.†

Sources of variation	ALL	TV%‡
ENVIRONMENT	5.28	76.40
REP (ENV)	0.09	1.30
BLOCK (ENV*REP)	0.17	2.47
ENTRY	0.40	5.76
ENV*ENTRY	0.39	5.63
RESIDUAL	0.58	8.44
REPEATABILITY	**0.97±0.02**	

† There were no stress locations
‡ TV% = Percentage of total variation

Table 3.5 Components of variation for grain yield across low pH, low N, optimum and all locations for EIHYB in 2003.

Sources of variation	LpH†	TV%‡	LN	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	0.60	56.34	0.68	48.09	5.88	85.14	6.12	85.71
REP (ENV)	0.03	2.55	0.05	3.82	0.09	1.25	0.08	1.11
BLOCK (ENV*REP)	0.18	16.85	0.11	7.51	0.14	2.08	0.14	1.95
ENTRY	0.05	4.22	0.06	4.60	0.06	0.81	0.06	0.80
ENV*ENTRY	0.02	1.57	0.03	1.95	0.20	2.94	0.21	2.90
RESIDUAL	0.20	18.48	0.48	34.04	0.54	7.78	0.54	7.54
REPEATABILITY	**0.52±0.19**		**0.63±0.11**		**0.85±0.04**		**0.85±0.04**	

† LN LpH and OPT = drought, low nitrogen, low pH and optimum locations respectively
‡ TV% = Percentage of total variation

For early to intermediate hybrids in 2001, some sites were planted to an additional stress of low pH (Table 3.4). The components of variation partition was similar under low pH to those observed under low nitrogen, i.e. increased error and slight reduction of the influence of location when compared to optimum conditions. In 2003, there was no data from stress sites due to severe drought in the region which resulted in the loss of all stressed locations.

Repeatability for grain yield in early to intermediate hybrids (EIHYB)

An increase in error results in reduction in repeatability. It is a useful measure of the proportion of phenotypic expression that can be exploit to accomplished genetic gain. The individual and across location repeatabilities for EIHYB are shown in tables and figures 3.1, 3.2, 3.3, 3.4 and 3.5. This trial set (EIHYB) was conducted in 17 locations in 1999. Out of these, 9 sites, representing 53%, had repeatabilities over 0.5. The highest repeatability (0.94) was observed at ART Farm in Harare, Zimbabwe. The lowest repeatability was observed at Selian in Tanzania (0.15). In 2000, EIHYB were evaluated in 34 locations with 21 of these locations (62%) having repeatabilities above 0.5. Once again, the highest repeatability was observed at ART Farm in Harare, Zimbabwe. Locations in Makoholi, Zimbabwe, Sebele, Botswana and Morogoro, Tanzania showed repeatabilities equal to 0, and Msekera, Zambia and Chitala, Malawi, showed very low repeatabilities of 0.05. In 2001, EIHYB were evaluated in 39 locations and 27 of them (69%) had repeatabilities above 0.5. High repeatabilities (>0.9) were observed in Greytown, South Africa, Baka, Malawi and Harare, Zimbabwe. EIHYB were evaluated in 54 locations in 2002 and out of these, 44 (81%) had repeatabilities above 0.5. It should be noted that only optimum locations were reported in this season. In 2003, EIHYB were evaluated in 47 locations and 25 (53%) of these had repeatabilities of at least 0.5. Repeatabilities equal 0 were observed in Sebele in Botswana, Mazozo and Cabinda in Angola, and Save Valley in Zimbabwe. Repeatabilities across locations were determined for all, optimum, drought, low nitrogen and low pH locations within a season for EIHYB. The highest repeatability across all locations was 0.97 in 2002. This might have been due to high number of locations and that were all the observed under optimum conditions. Repeatability across stress locations (drought, low nitrogen, low pH) was lower that that across optimum and all locations. The lowest repeatability (0.22) was observed across low pH locations for EIHYB in 2001.

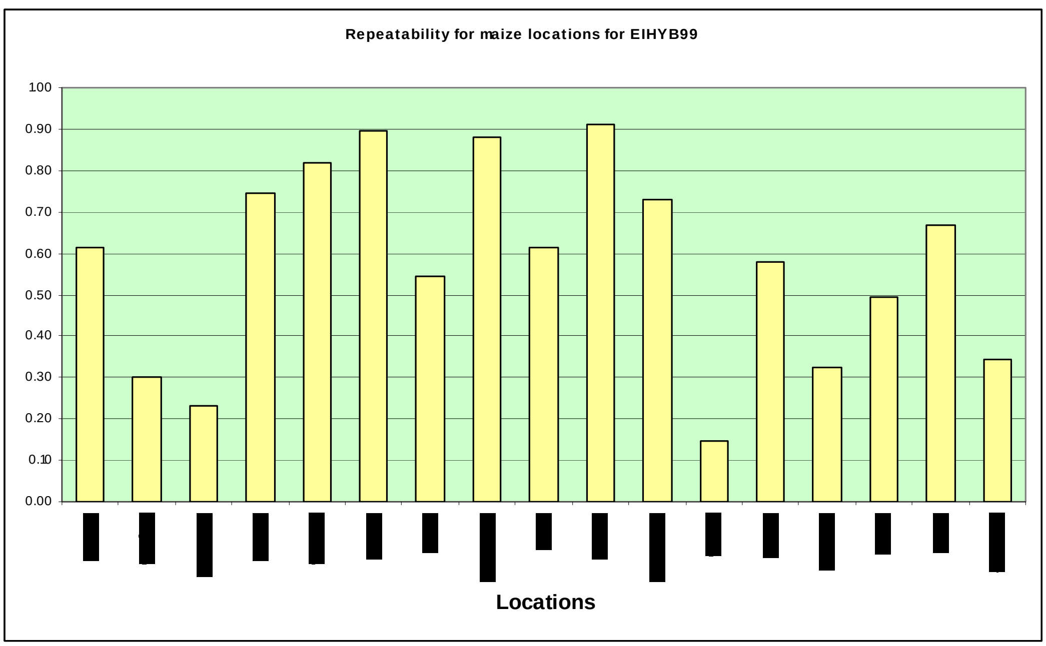

Fig. 3.1. Repeatability for grain yield for all maize testing locations for early to intermediate hybrids in 1999.

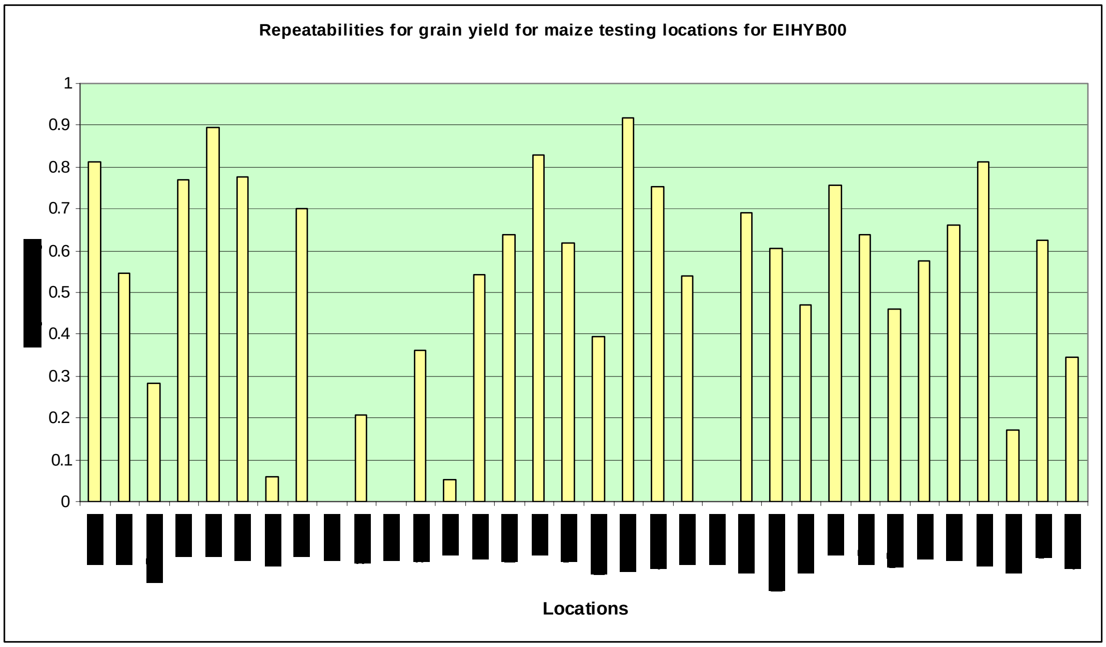

Fig. 3.2. Repeatability for grain yield for all the maize testing locations for early to intermediate hybrids in 2000.

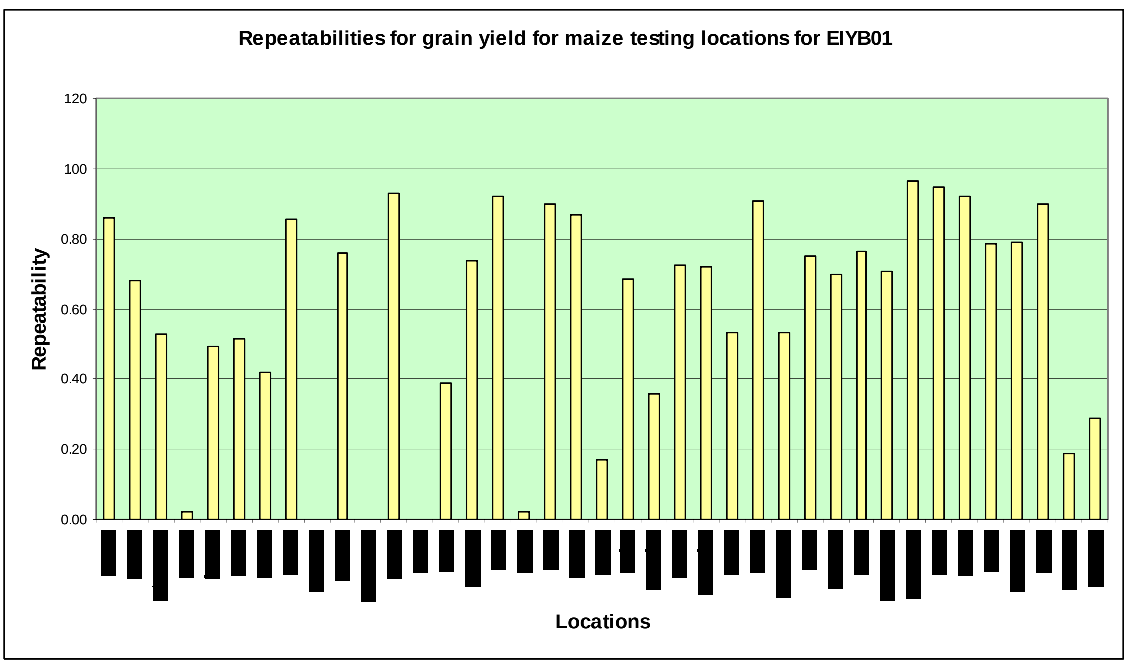

Fig. 3.3. Repeatability for grain yield for all the maize testing locations for early to intermediate hybrids in 2001.

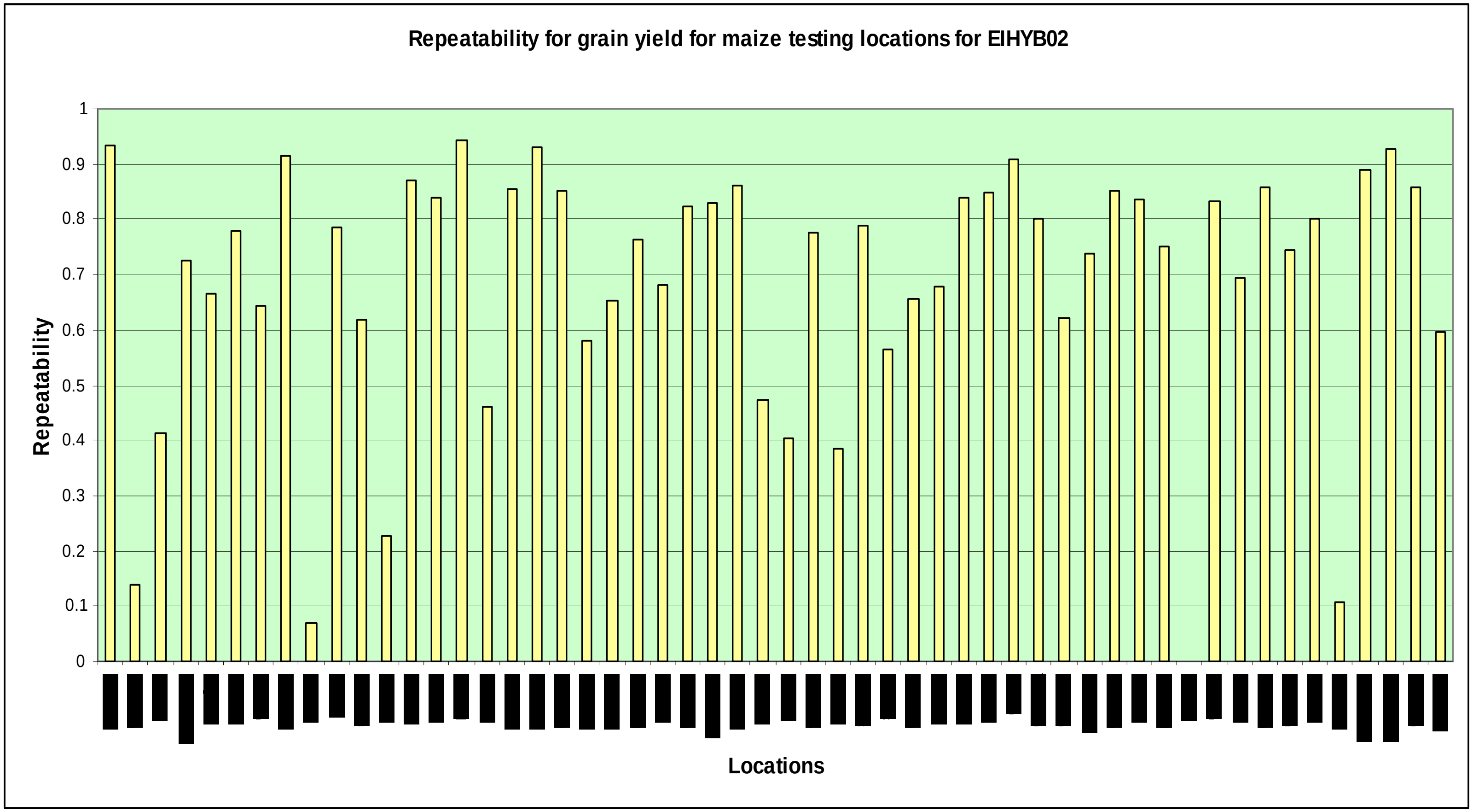

Fig. 3.4. Repeatability for grain yield for all the maize testing locations for early to intermediate hybrids in 2002.

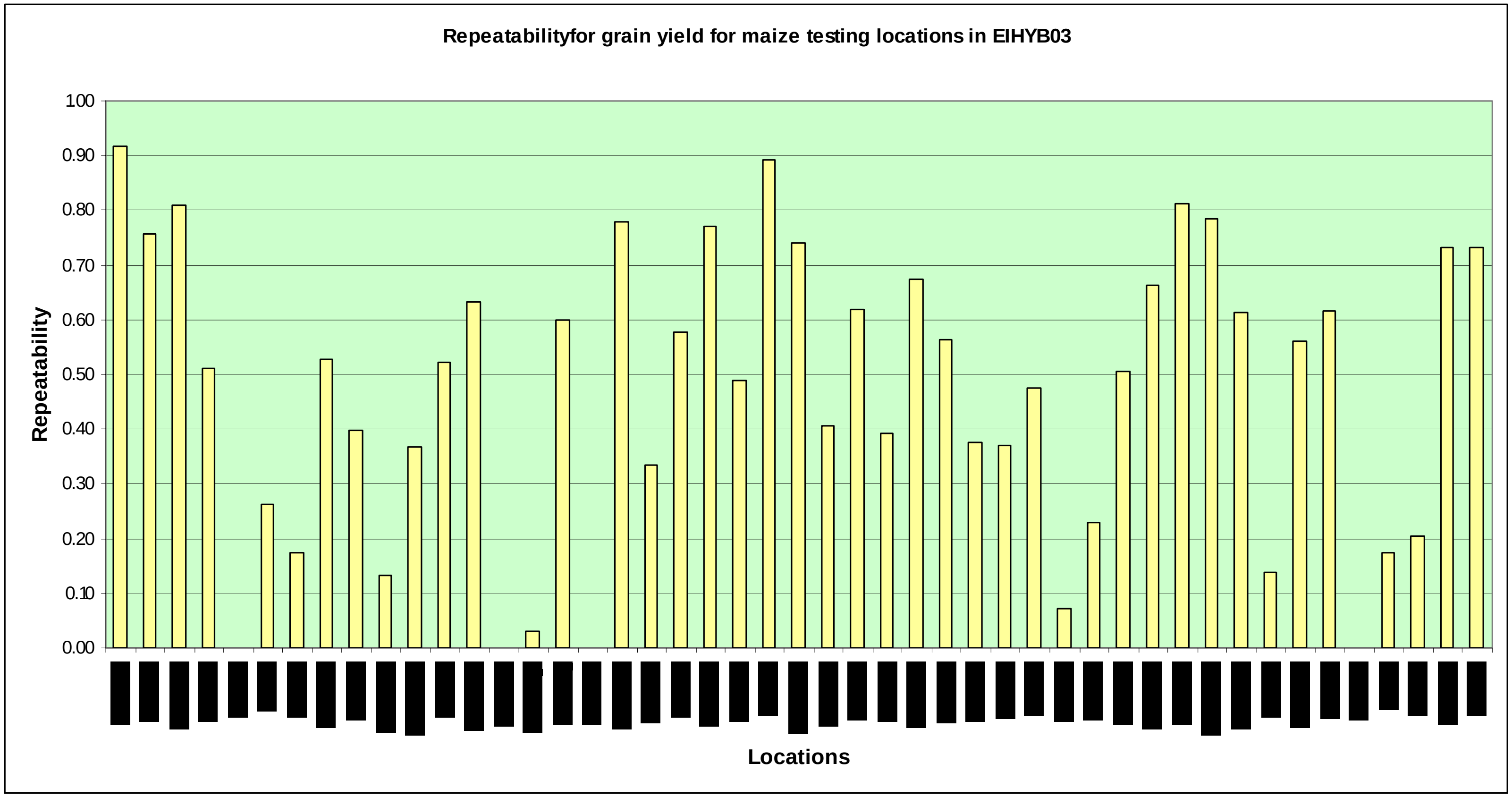

Fig. 3.5. Repeatability for grain yield for all the maize testing locations for early to intermediate hybrids in 2003.

Regression of repeatability estimates for early to intermediate hybrids (EIHYB)

Repeatability trends with respect to grain yield for EIHYB from 1999 to 2003 are shown in figures 3.6, 3.7, 3.8, 3.9, 3.10. Figure 3.11 shows the trends across all seasons. Repeatability trend with respect to yield for the test in 1999 shows that is virtually no relationship between repeatability and grain yield (R^2 = 0.00067) (Fig. 3.6). The stress locations have low repeatability and lower yields, and although the R^2 is less than 0.5, the general trend observed was that the lower yield were observed in locations with low repeatability and vice versa. The low yields were observed in stress locations and this validates the common assertion that low heritability for maize grain yield is observed under stress conditions (Bänziger, 2004). The repeatability trends across the five growing season (Fig. 3.12) clearly showed that stress and poor growing locations are associated with low repeatabilities. Locations that are consistently showing high repeatability include ART Farm in Zimbabwe and Greytown in South Africa. Locations in Angola are consistently showing low repeatability. This assessment can be important to adopt testing locations and conditions that increase genetic variation, reduce error and consequently increae repeatabilities.

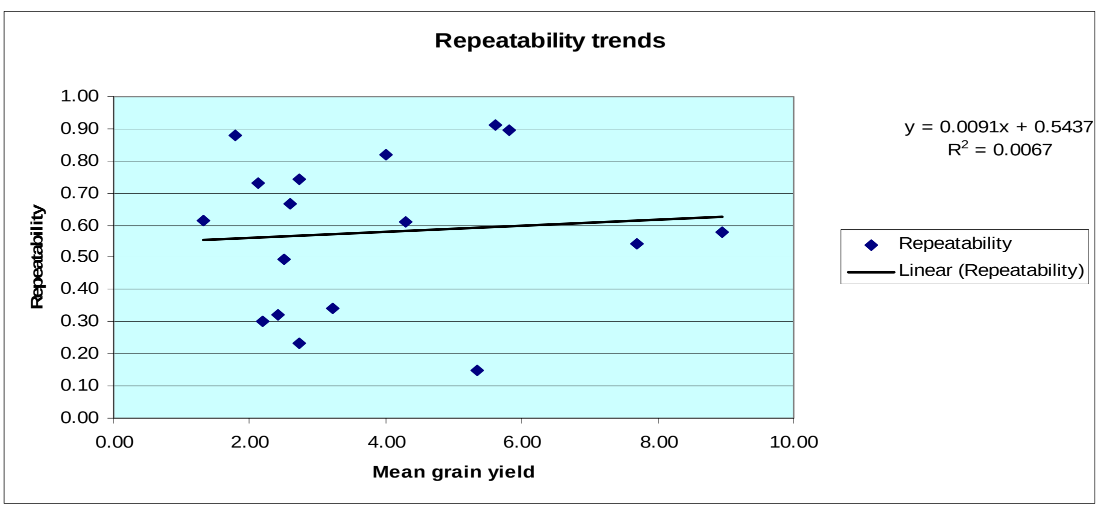

Fig. 3.6. Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations in 1999.

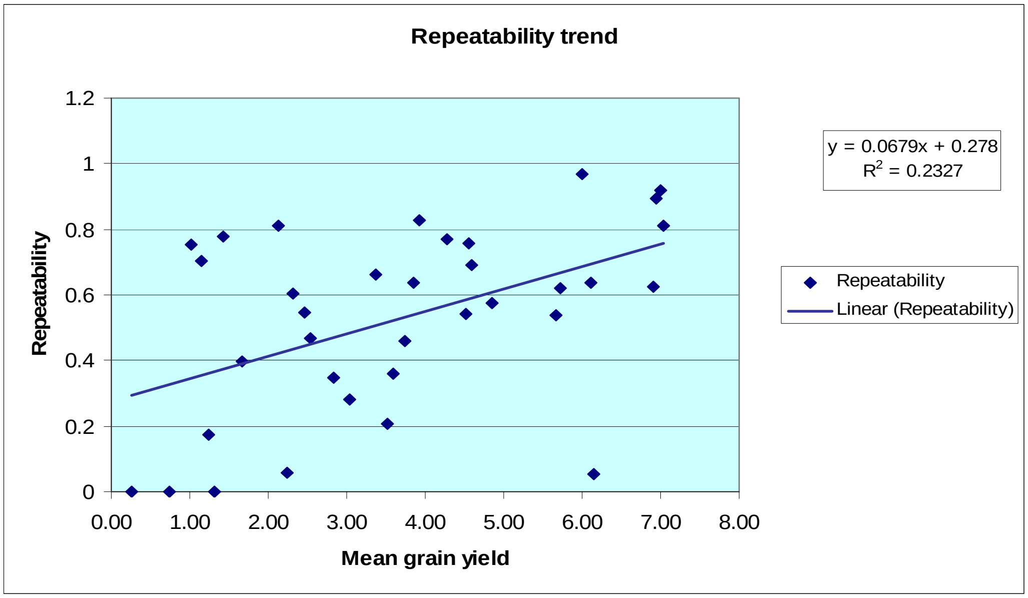

Fig. 3.7. Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations in 2000.

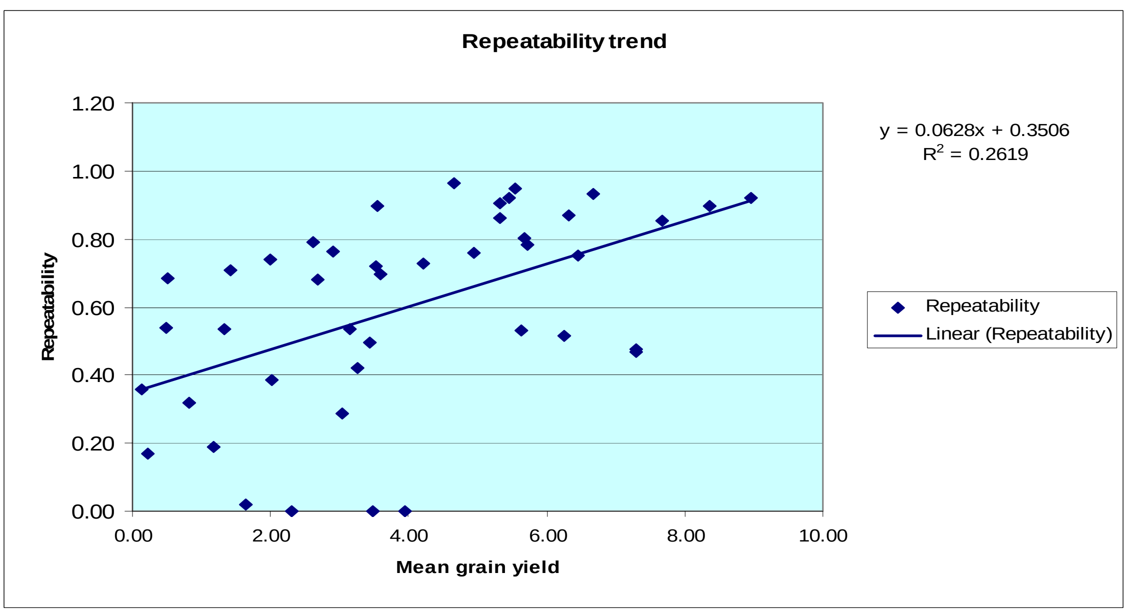

Fig. 3.8. Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations in 2001.

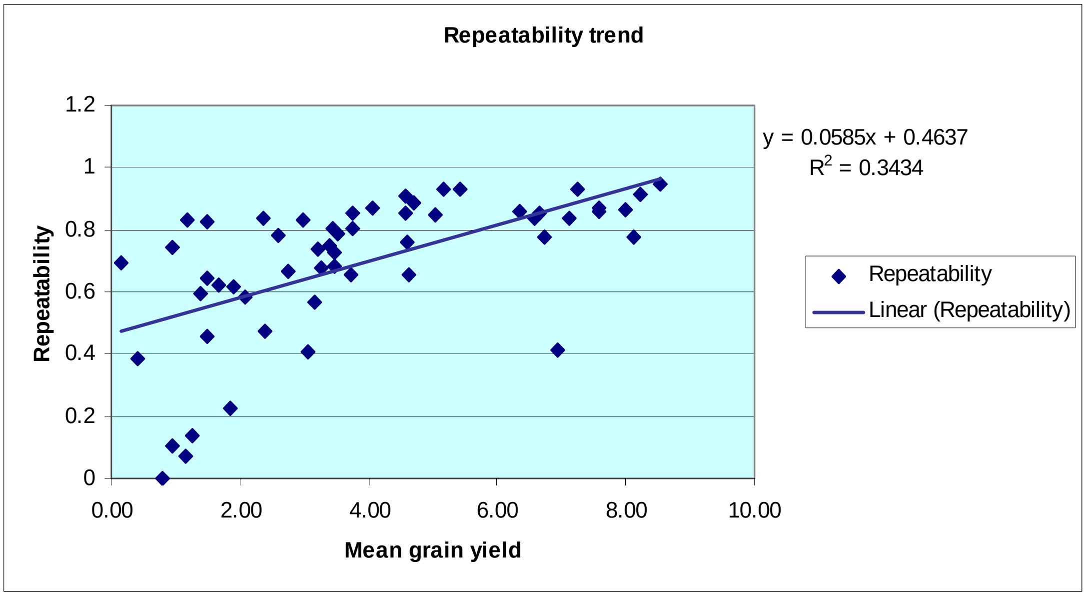

Fig. 3.9. Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations in 2002.

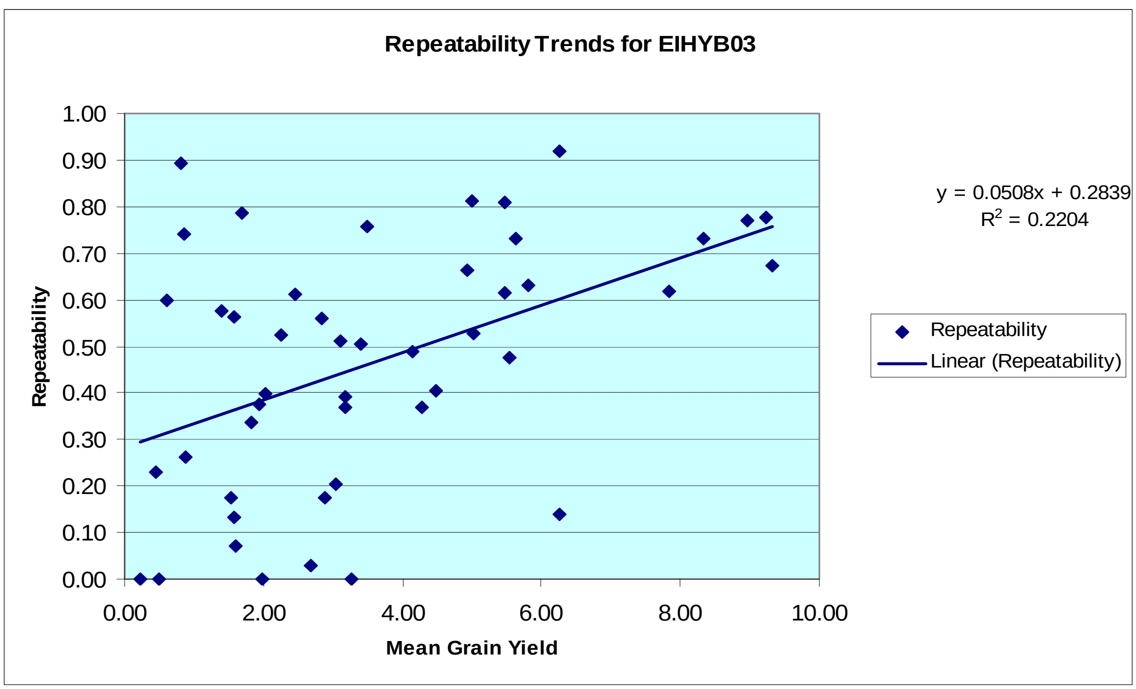

Fig. 3.10 Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations in 2003.

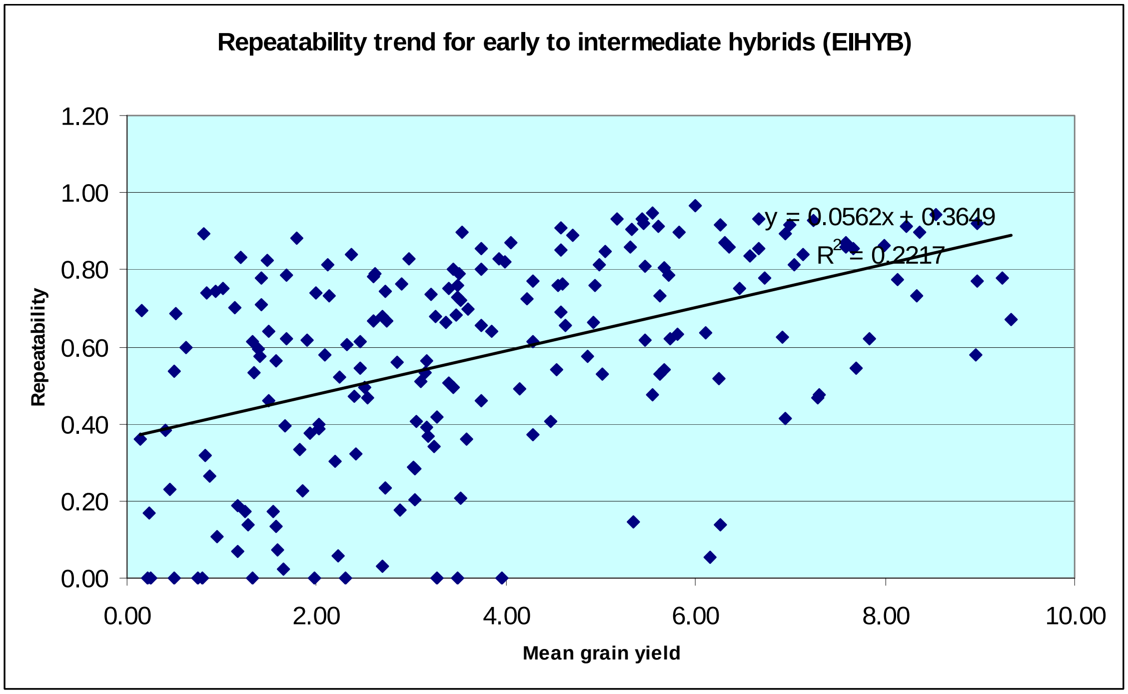

Fig. 3.11. Regression of repeatability estimates with respect to average yield per location for early to intermediate hybrids for all locations across seasons (1999-2003).

Regression of genotypic variation and residual for EIHYB

Regression of genotypic variation and residual contributes to an understanding of the relationships among variance components in various maize testing locations in eastern and southern Africa. The genotype and residual trends for EIHYB in 1999 to 2003 are shown in figures 3.12, 3.13, 3.14, 3.15 and 3.16. The trends across the five season 1999-2003 is shown in figure 3.17. There was no significant correlation between grain yields and genotypic variation and residual in 2001 (Fig. 3.14). However, there was significant correlation between grain yield and genotypic variance in 2002 and 2003, and residual in 1999 (Fig. 3.13). High yielding locations had high genotypic variability and residual. The stressed locations showed less genotypic variability and residual. Although there were slight differences in the slope both within and across seasons trends for genotypic variance and residual trends were similar (Fig. 3.18). Greater genotypic variance in optimal environments than in stress environments has been already reported in maize (Bolaños et al., 2002).

The stress locations showed less genetic variability and residual. Reduced expression of phenotypic traits can be a consequence of limited growth observed under stress. There is much more consistent correlation between genotypic variance and grain yield, than there is between residual and grain yield. Although the slopes are not exactly the same, they both (genotypic variance and residual) have a positive slope. High variability is obtained in optimum locations.

To determine whether you can select for stress conditions in optimum locations, it is necessary to determine the genetic correlation between the two growing conditions. If the correlated response to selection (CRx) is higher than the direct response (Rx), then indirect selection may be beneficial and if it is lower, and then direct selection may be a better option. Brancourt-Hulmel et al. (2000) indicated that the level of genetic correlation between the two growing environments (stress and optimum) varies considerably, mainly depending on the variable under consideration, the genetic material the type of stress as well as its intensity and efficiencies in conducting basic agronomic cultural practices. For instance, Bänziger et al. (1997) showed that genetic correlation between grain yields of maize under low and high nitrogen levels decreased with increasing N stress intensity which was estimated by the relative yield reduction under low N. Cooper et al. (1997) obtained similar results in wheat. With regard to differences in the stress factor itself, Atlin and Frey (1989) reported for phosphorus and nitrogen deficiencies lower genetic correlation between phosphorus deficient and non-stress environments than between N deficient and non-stress environment for grain yield in oat. N stress had a higher influence on performance than phosphorus stress.

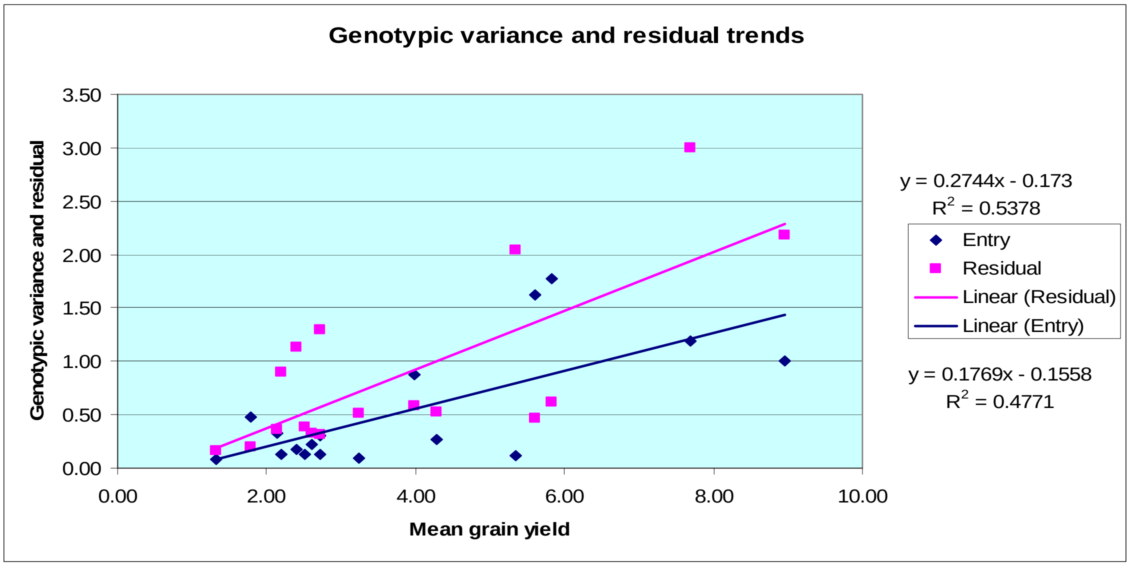

Fig 3.12 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations in 1999.

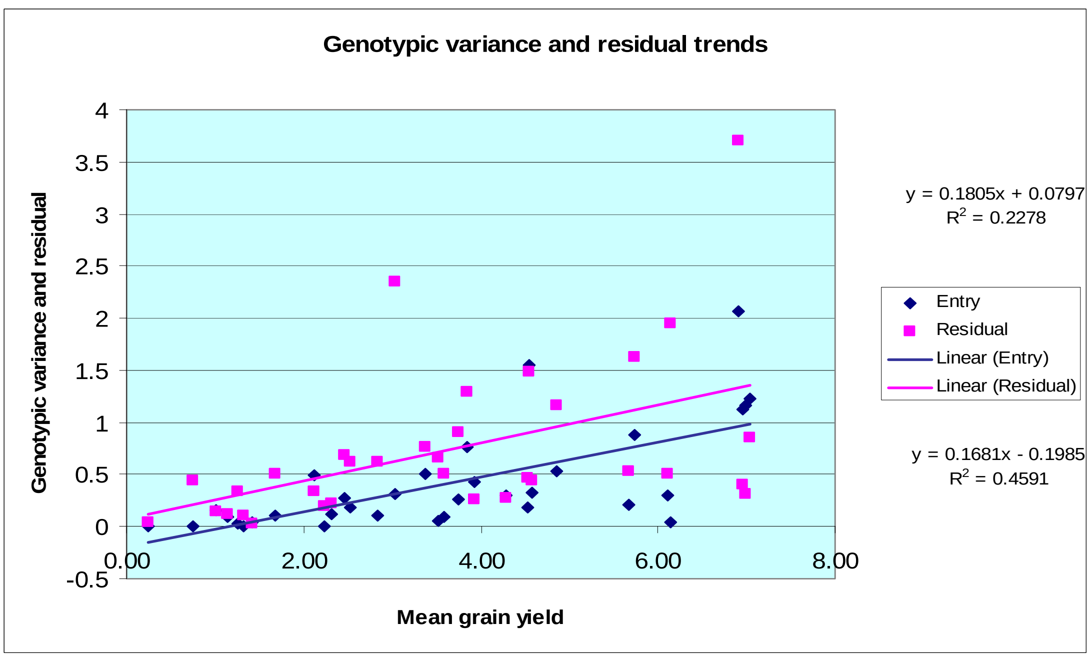

Fig 3.13 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations in 2000.

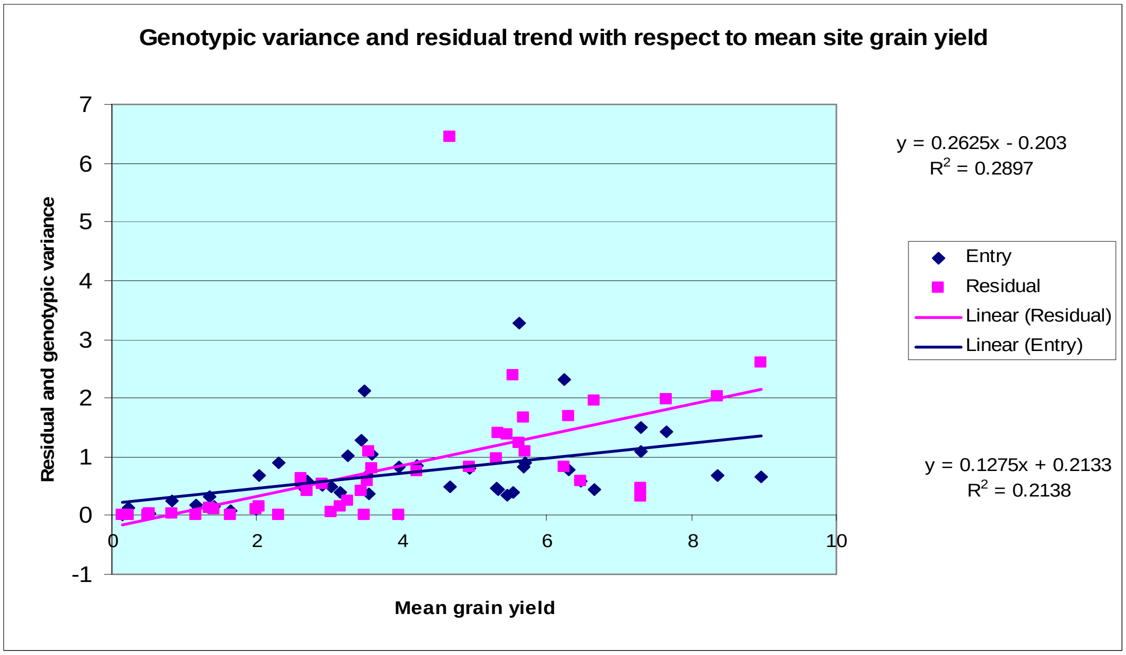

Fig 3.14 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations in 2001.

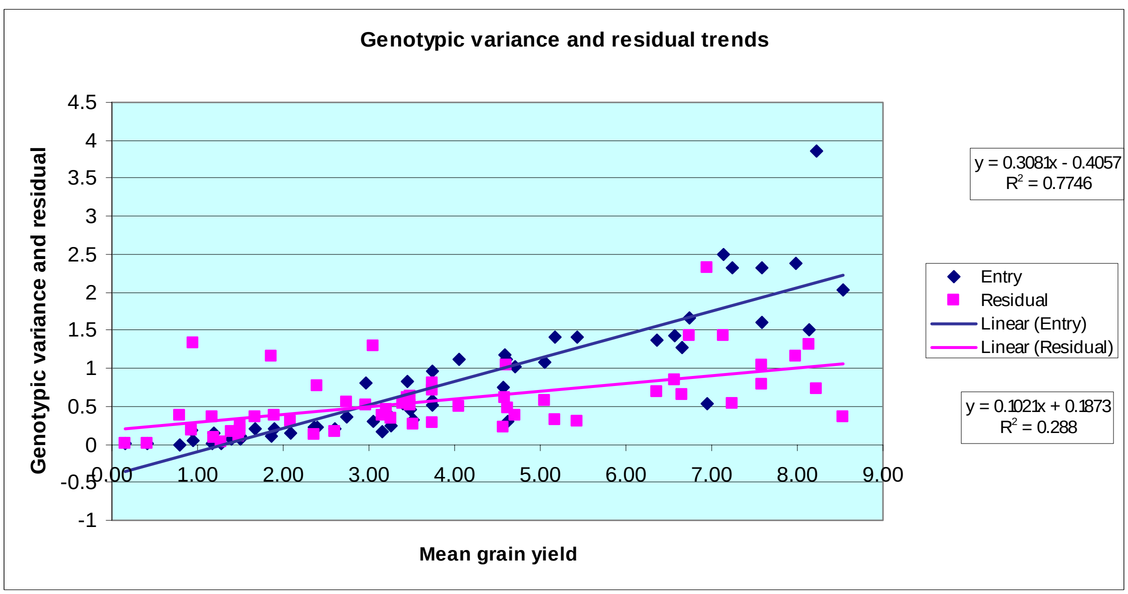

Fig 3.15 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations in 2002.

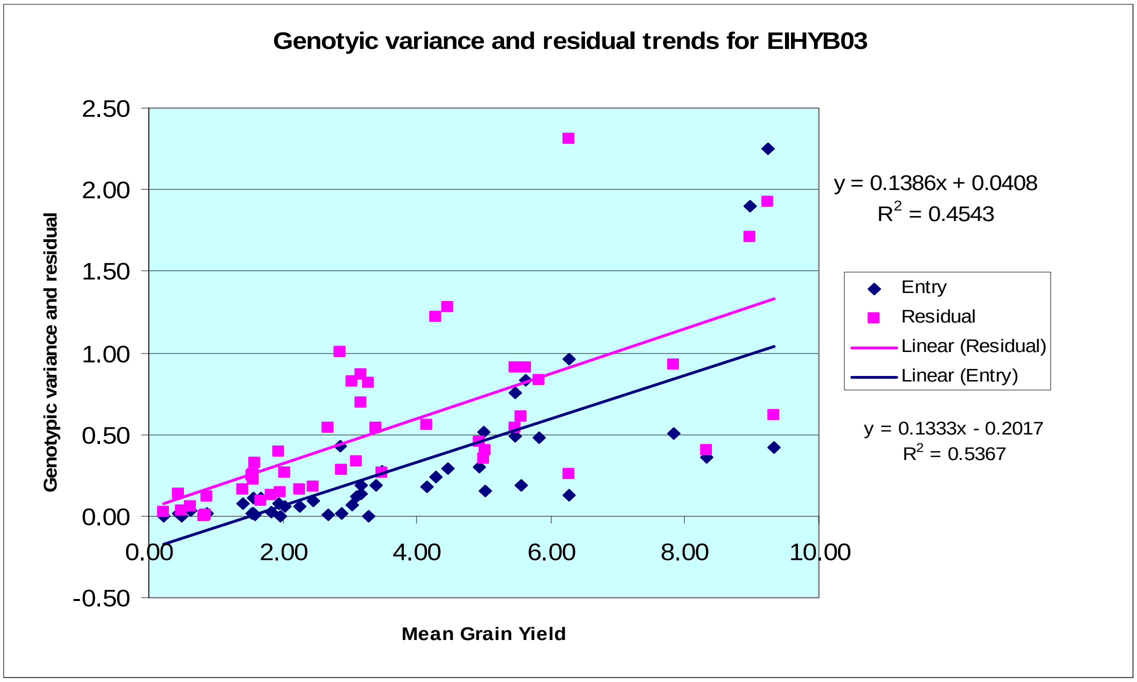

Fig 3.16 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations in 2003.

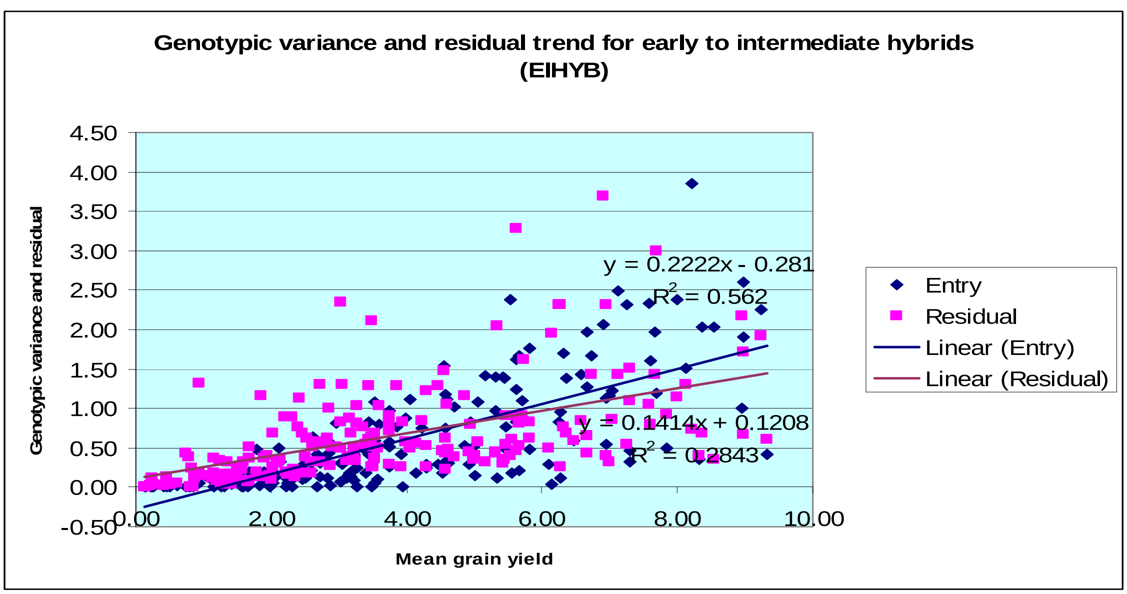

Fig 3.17 Regression of genotypic and residual variances on average yield of early to intermediate hybrids for all maize testing locations across seasons (1999- 2003).

Components of variation for intermediate to late hybrids (ILHYB)

Components of variation for intermediate to late hybrids are shown in Tables 3.6, 3.7, 3.8, 3.9 and 3.10 for years 1999, 2000, 2001, 2002 and 2003, respectively. Most of the variation observed was attributed to locations, 62.6% under optimum conditions and 65.2% across all locations in 1999. Under low nitrogen stress, 33.7% of total variation was due to locations, 16.5% to genotypes, and 24.8% to error. In 2002, for example, repeatability across optimum conditions was 0.91, across drought locations was 0.61, across low N was 0.69, and across low pH was 0.11. There was significant increase in error variation under stress conditions. Increased error under stress would also effect a reduction in heritability/repeatability. This finding is consistent with those of Ud-din et al. (1992), Calhoun et al. (1994), Bänziger et al. (1997), Bertin and Gallais (2000), and Sinebo et al. (2002) who stated that heritabilities are generally lower under lower input level or in stressed conditions than under optimum or high input conditions. In fact, the spread of components of variation in intermediate to late hybrids (ILHYB) was not particularly different from the one obtained in evaluations of early to intermediate hybrids (EIHYB) (Table 3.10). As previously observed, low pH also resulted in the lowest repeatability among all environments. Repeatability was 0.93 across all locations, 0.91 across optimum conditions, 0.11 across low pH, 0.61 across drought locations, and 0.69 across low N. Most of the variation across all locations (75%) was due to location.

Table 3.6. Components of variation for grain yield across low N , optimum and all locations for ILHYB in 1999.

Source of Variation	LN†	TV%‡	OPT	TV%	ALL	TV%
ENV	0.48	33.70	4.79	62.62	5.12	65.23
REP(ENV)	0.05	3.55	0.28	3.66	0.23	2.99
BLOCK(ENV*REP)	0.16	11.46	0.21	2.79	0.19	2.38
ENTRY	0.24	16.52	0.40	5.20	0.35	4.52
ENV*ENTRY	0.14	9.96	0.61	7.91	0.74	9.41
RESIDUAL	0.35	24.81	1.36	17.82	1.21	15.46
REPEATABILITY	**0.64±0.09**		**0.84±0.03**		**0.85±0.02**	

† LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.7. Components of variation for grain yield across optimum and all locations for ILHYB in 2000.

Source of Variation	OPT†	TV%‡	ALL	TV%
ENVIRONMENT	4.03	57.72	4.45	58.85
REP(ENV)	0.34	4.86	0.34	4.51
BLOCK(ENV*REP)	0.49	7.05	0.55	7.28
ENTRY	0.47	6.77	0.49	6.52
ENV*ENTRY	0.34	4.88	0.47	6.22
RESIDUAL	1.31	18.72	1.26	16.62
REPEATABILITY	**0.95±0.02**		**0.95±0.02**	

† OPT = Optimum locations
‡ TV% = Percentage of total variation

Table 3.8. Components of variation for grain yield across optimum and all locations for ILHYB in 2001.

Source of Variation	OPT†	TV%‡	ALL	TV%
ENVIRONMENT	6.20	69.06	6.82	73.74
REP(ENV)	0.22	2.50	0.18	1.95
BLOCK(ENV*REP)	0.26	2.87	0.26	2.76
ENTRY	0.65	7.27	0.44	4.77
ENV*ENTRY	0.68	7.54	0.75	8.16
RESIDUAL	0.97	10.77	0.80	8.63
REPEATABILITY	**0.90±0.02**		**0.94±0.01**	

† OPT = Optimum locations
‡ TV% = Percentage of total variation

Table 3.9. Components of variation for grain yield across drought, low N, low pH, optimum and all locations for ILHYB in 2002.

Source of Variation	DRT†	TV%‡	LN	TV%	LpH	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	1.23	53.46	1.41	59.31	1.02	29.50	5.21	70.12	5.97	75.05
REP(ENV)	0.09	3.72	0.20	8.45	0.00	0.00	0.29	3.88	0.23	2.92
BLOCK(EN*RP)	0.35	15.03	0.19	8.10	1.69	48.98	0.47	6.35	0.46	5.74
ENTRY	0.08	3.68	0.07	2.76	0.01	0.33	0.19	2.60	0.15	1.91
ENV*ENTRY	0.13	5.74	0.11	4.54	0.07	2.00	0.23	3.16	0.27	3.44
RESIDUAL	0.42	18.37	0.40	16.83	0.66	19.19	1.03	13.88	0.87	10.94
Repeatability	**0.61±0.09**		**0.69±0.08**		**0.11±0.48**		**0.91±0.02**		**0.93±0.02**	

† DRT, LN, LpH and OPT = drought, low nitrogen, low pH and optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.10. Components of variation for grain yield across low pH, low N, optimum and all locations for ILHYB in 2003.

Source of Variation	LpH†	TV%‡	LN	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	0.45	33.73	0.20	18.13	8.00	84.34	7.78	83.47
REP(ENV)	0.07	5.59	0.03	2.55	0.11	1.18	0.10	1.05
BLOCK(ENV*REP)	0.42	31.21	0.28	25.88	0.21	2.19	0.23	2.48
ENTRY	0.02	1.36	0.13	11.79	0.15	1.58	0.15	1.56
ENV*ENTRY	0.04	3.30	0.10	9.19	0.25	2.63	0.35	3.80
RESIDUAL	0.33	24.81	0.35	32.46	0.77	8.08	0.71	7.65
REPEATABILITY	**0.38±0.09**		**0.49±0.19**		**0.91±0.02**		**0.94±0.01**	

† LN LpH and OPT = drought, low nitrogen, low pH and optimum locations respectively
‡ TV% = Percentage of total variation

Repeatability for intermediate to late hybrids (ILHYB)

Per location repeatabilities for grain yield in ILHYB are shown in Figs. 3.18, 3.19, 3.20, 3.21 and 3.22 for 1999, 2000, 2001, 2002 and 2003, respectively. In 1999, 15 out of the total of 18 sites (83.3%) had repeatabilities of 0.6 or greater. The least repeatability was observed in Katrin, Tanzania (0.36). In 2000, 20 out of 33 (60.6%) locations showed repeatability of 0.6 or greater. The least repeatability was 0.04 at a low pH location at Misamfu, Zambia. Locations in Harare continue to show high repeatabilities. In 2001, there were a total of 35 sites and out of these 26 (74.3%) had repeatability of at least 0.6. Matopos in Matabeleland in Zimbabwe had the highest repeatability (R = 0.95) and Kadoma in Zimbabwe the least (R = 0.0). In 2002, the number of location was increased to 45 but only 17 locations (37.8%) reported repeatability of at least 0.6. Repeatability was equal 0 for Namulonge in Uganda, Makoholi in Zimbabwe and at a low nitrogen location in Chitedze, Malawi. In 2003, evaluation for ILHYB was conducted in 42 locations and repeatability of at least 0.6 was observed in 18 locations (42.8%). While the number of locations is increasing we noted that fewer locations are reporting moderate to high repeatability. Locations in Zimbabwe generally show high repeatability.

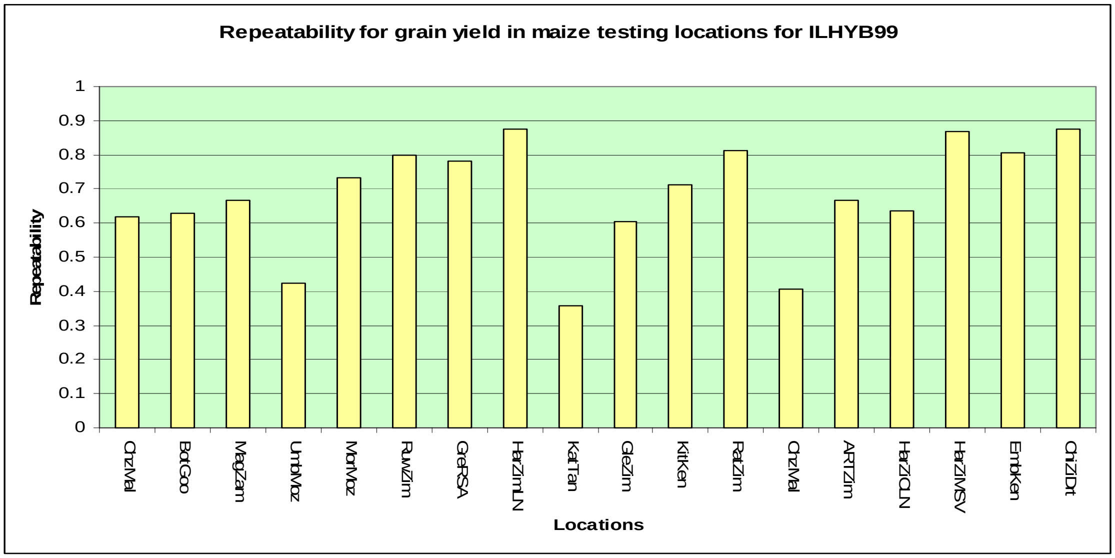

Fig. 3.18. Repeatability for grain yield for all maize testing locations for intermediate to late hybrids in 1999.

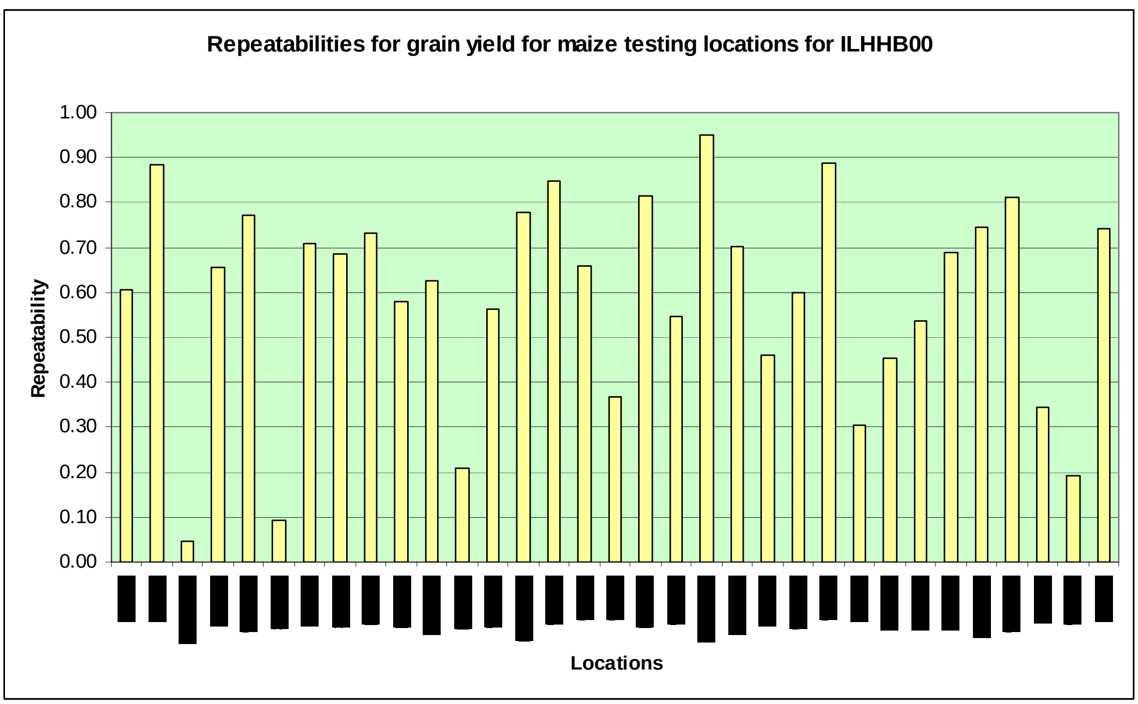

Fig. 3.19. Repeatability for grain yield for all maize testing locations for intermediate to late hybrids in 2000.

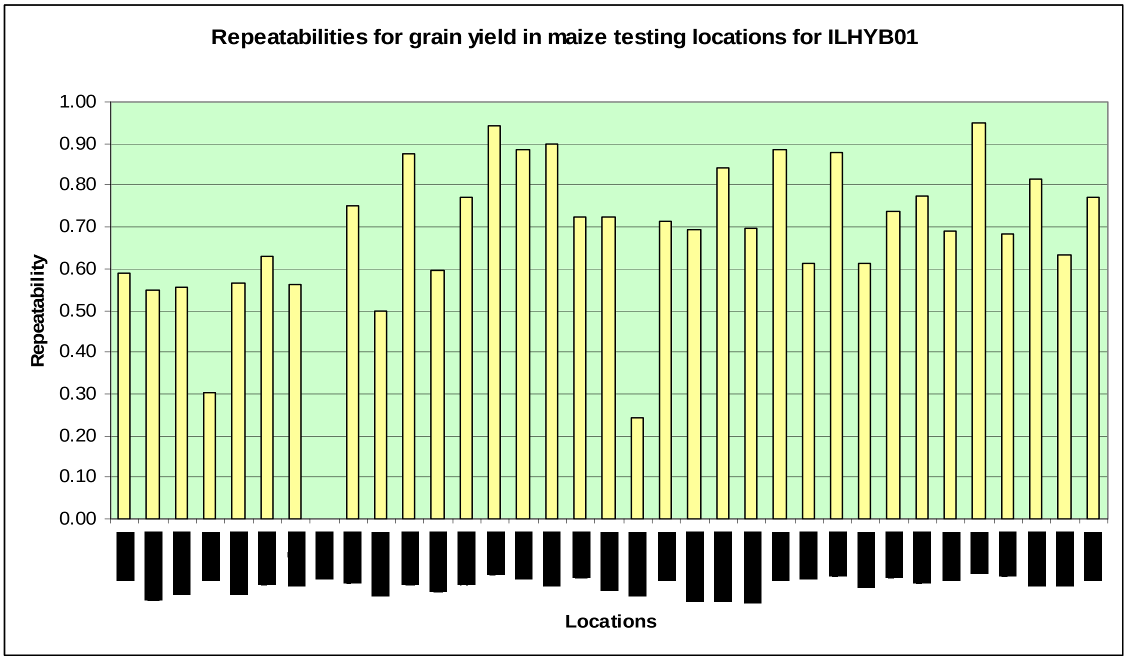

Fig. 3.20. Repeatability for grain yield for all maize testing locations for intermediate to late hybrids in 2001.

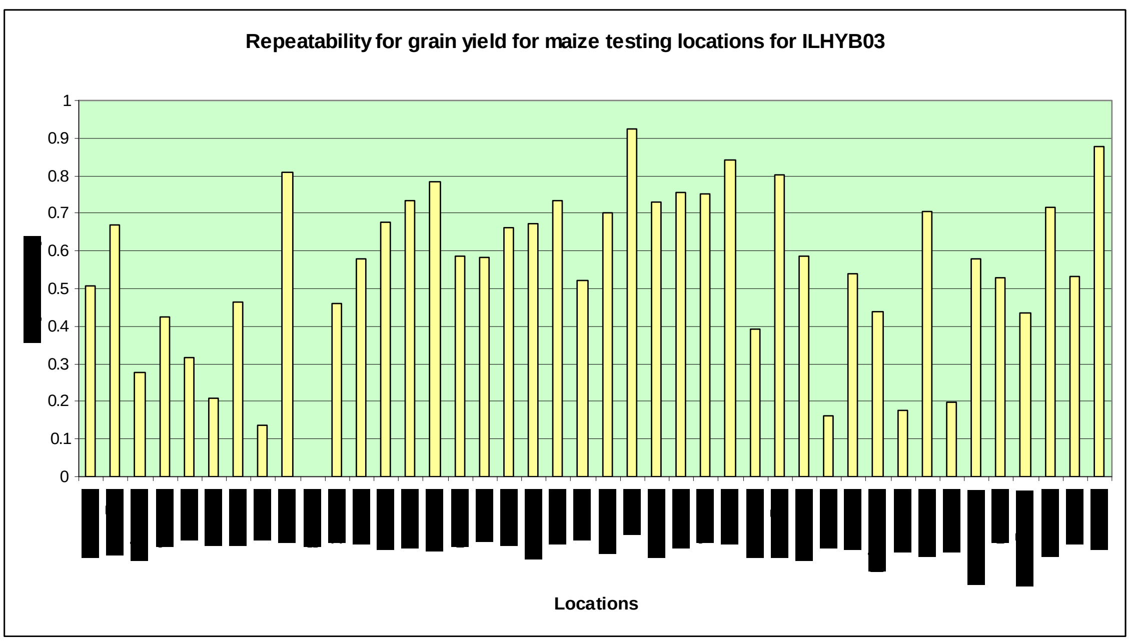

Fig. 3.21. Repeatability for grain yield for all maize testing locations for intermediate to late hybrids in 2003.

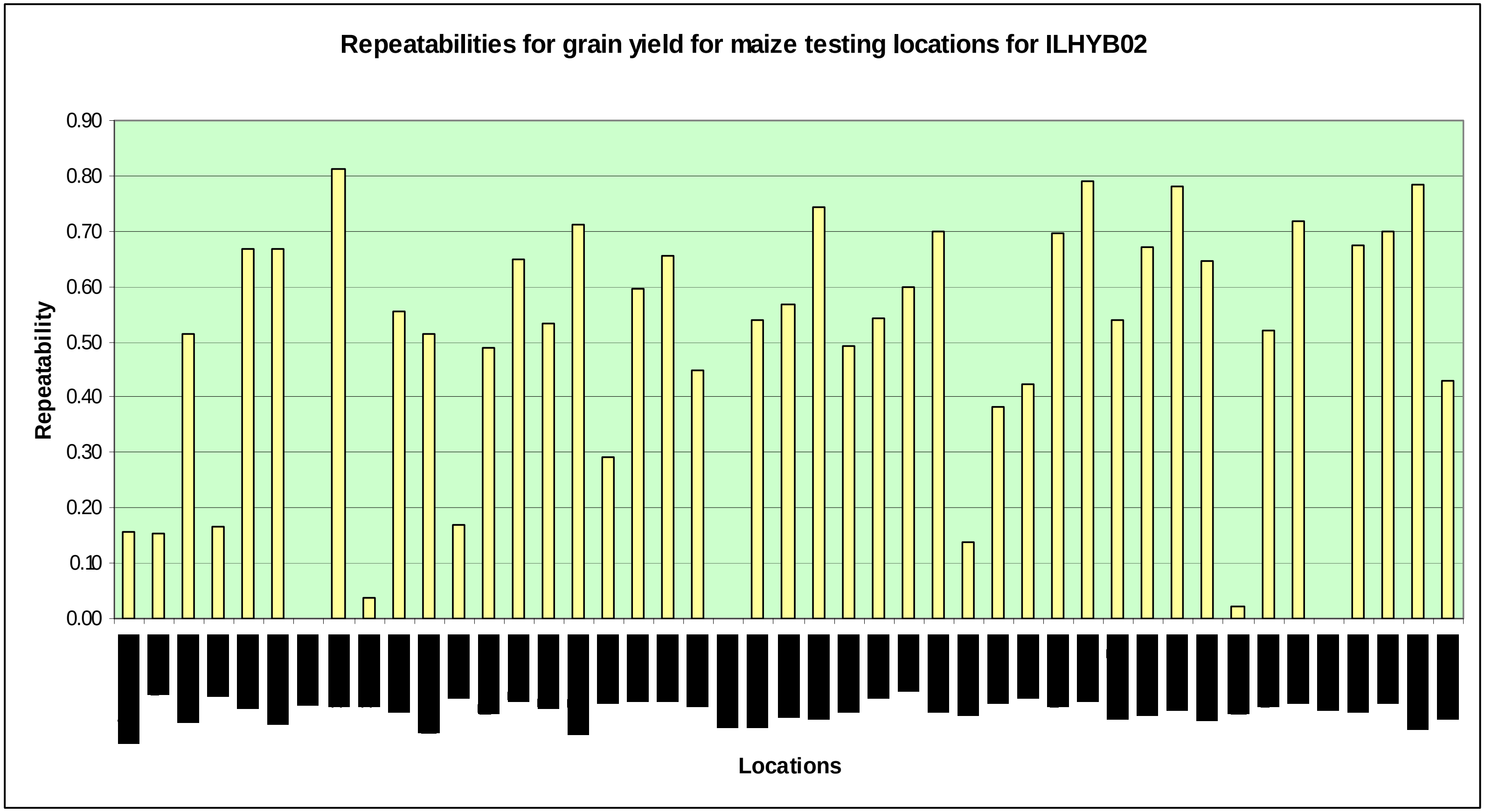

Fig. 3.22. Repeatability for grain yield for all maize testing locations for intermediate to late hybrids in 2002.

Regression of repeatability estimates for intermediate to late hybrids (ILHYB)

Repeatability trends for intermediate to late hybrids (ILHYB) are shown in Figs. 3.23, 3.24, 3.25, 3.26, 3.27 for 1999, 2000, 2001, 2002 and 2003, respectively. The trend across seasons is shown in figure 3.28. There was no correlation or any meaningful relationship between average grain yield locations and repeatabilities (R^2 = 0.16) in all seasons. However, the consistent positive slope suggested that higher repeatability is observed in higher performing locations (Fig. 3.29). This assertion has also been advanced by previous studies (Bänziger et al., 1997).

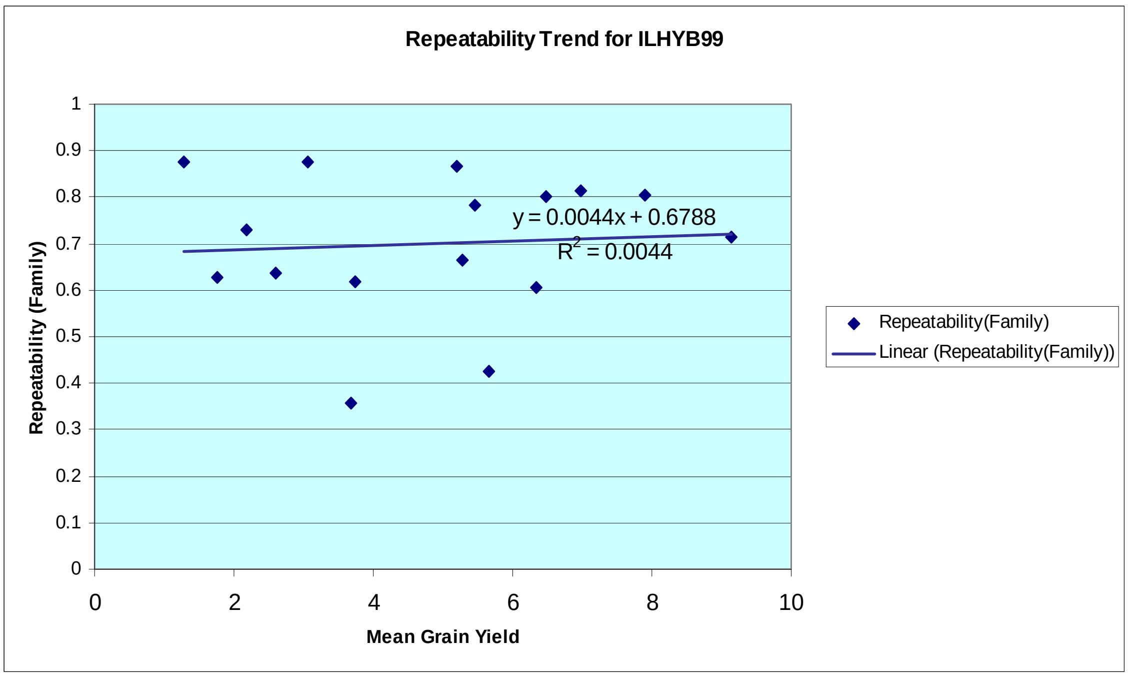

Fig. 3.23. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations in 1999.

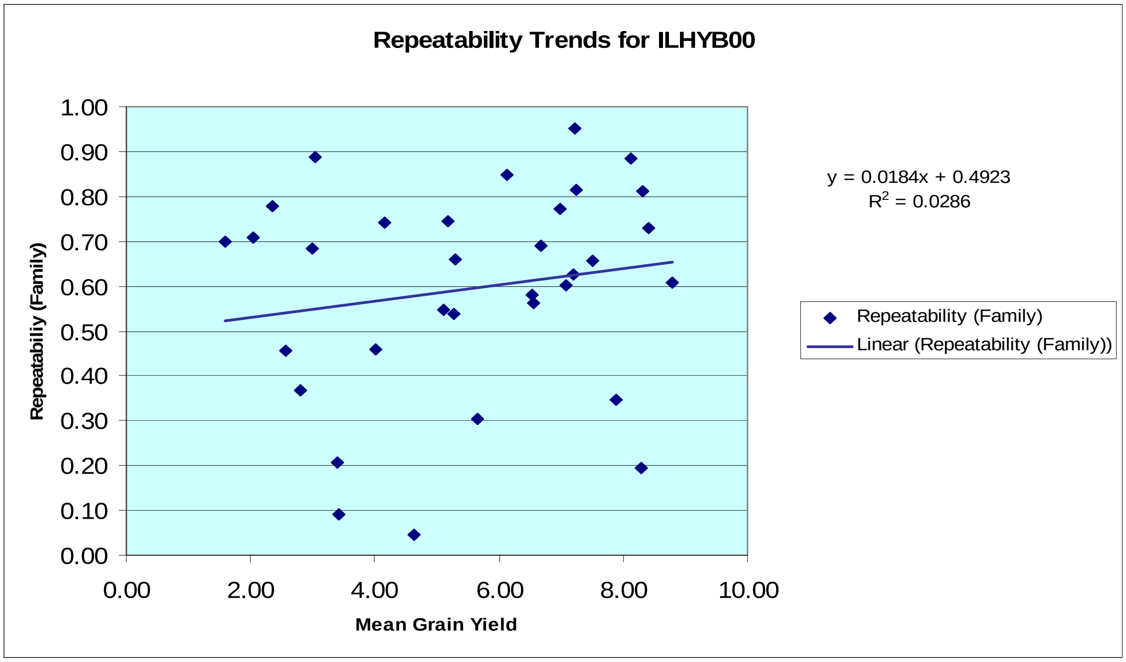

Fig. 3.24. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations in 2000.

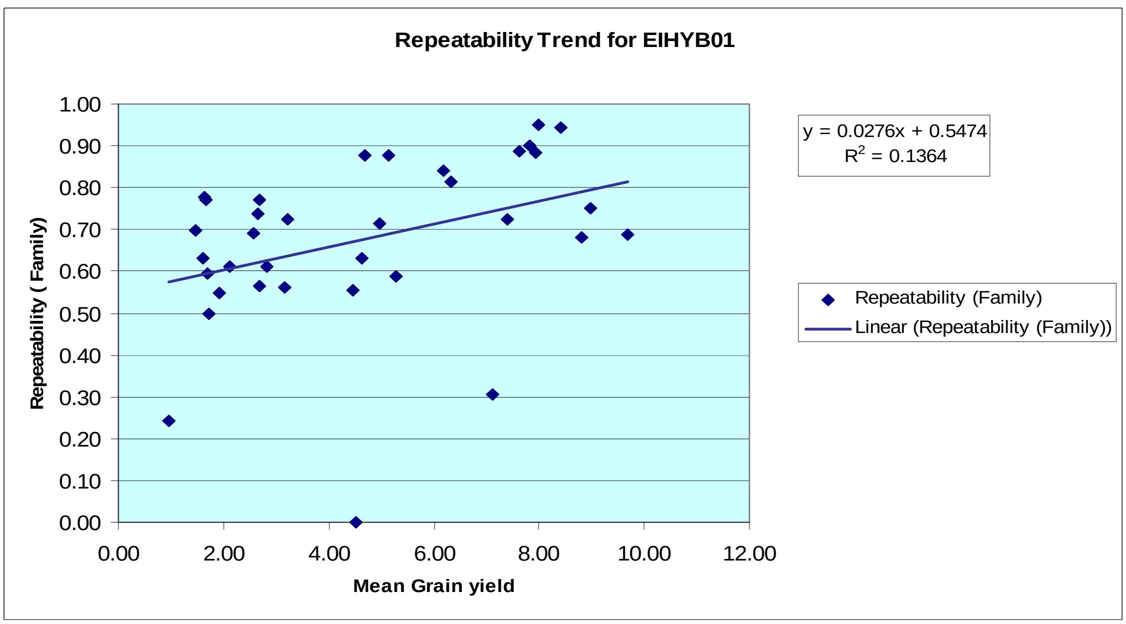

Fig. 3.25. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations in 2001.

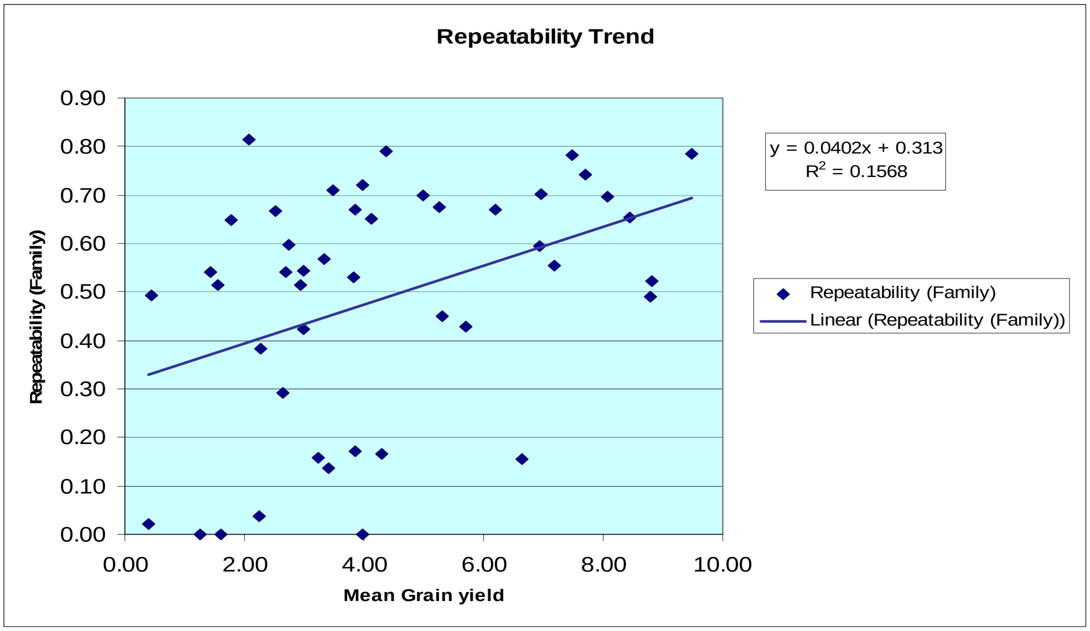

Fig. 3.26. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations in 2002.

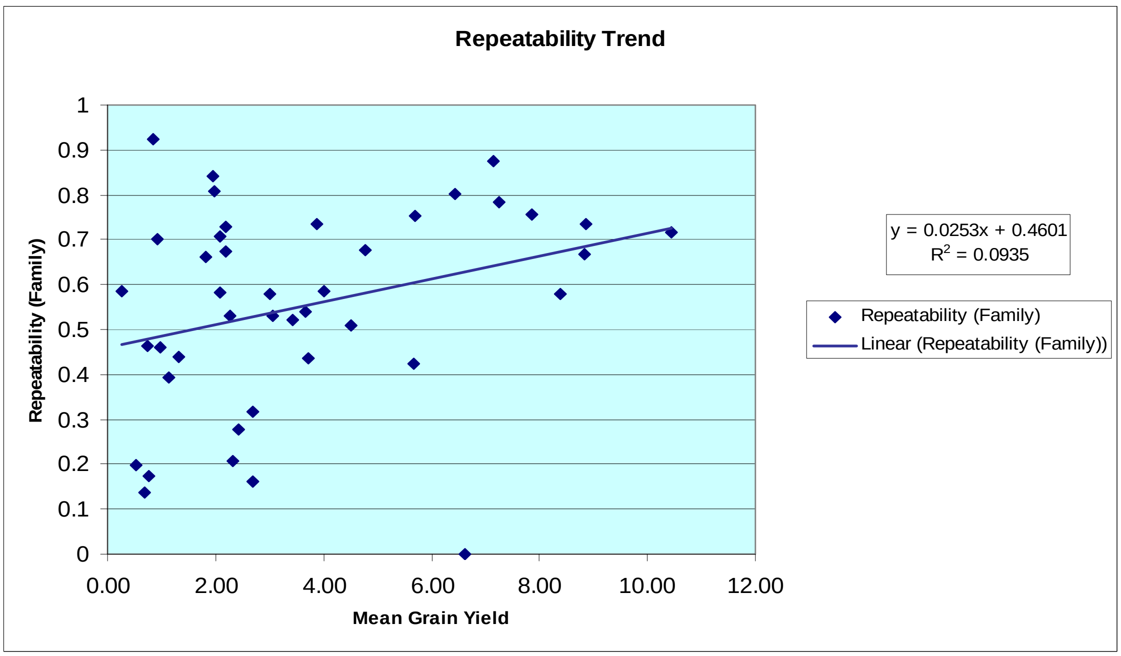

Fig. 3.27. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations in 2003.

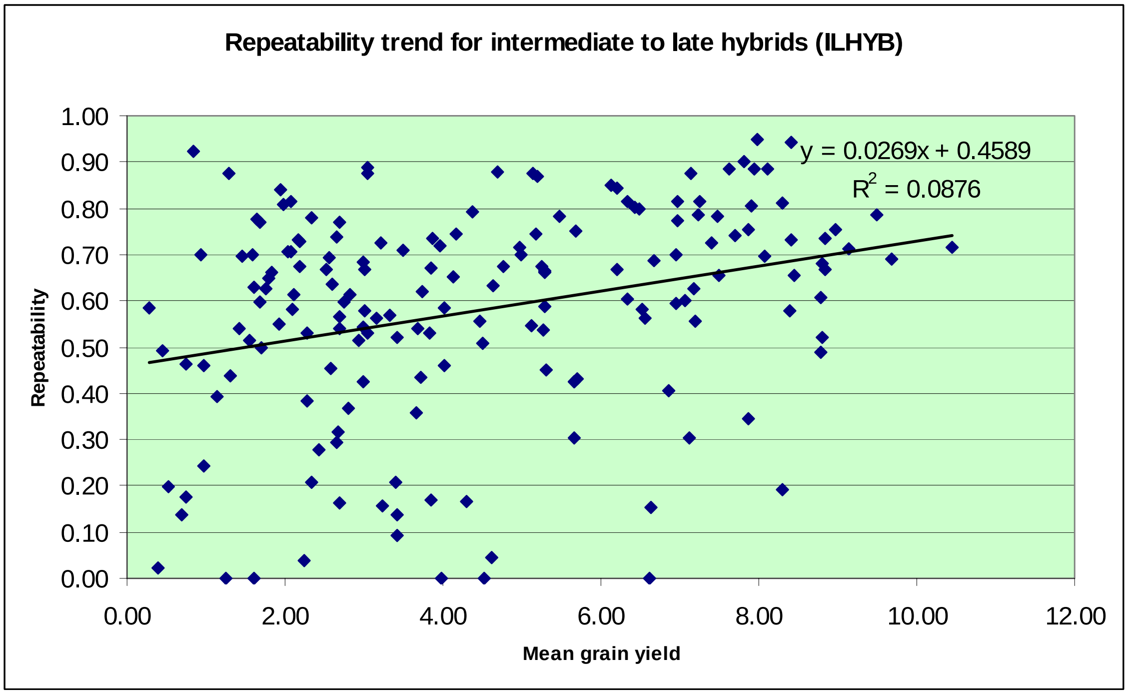

Fig. 3.28. Regression of repeatability estimates with respect to average yield per location for intermediate to late hybrids for all locations across seasons (1999-2003).

Regression of genotypic variance and residual for intermediate to late hybrids (ILHYB)

Genotypic variance and residual trends still contribute to an understanding of the partition of observed variation in various maize testing locations in eastern and southern Africa. The genotype and residual trends for ILHYB during 1999 to 2001 are shown in figures 3.29, 3.30, 3.31, 3.32, 3.33. Figure 3.34 show the trends across the five seasons. There was significant correlation between average grain yield of a specific location and genotypic and residudal variances in all seasons (Fig. 3.35). The trend that emerged was similar to that observed for EIHYB, high yielding locations showed high genotypic variability and residual. The stressed locations showed less genotypic variability and residual similar to the results observed with the early to intermediate hybrids (EIHYB).

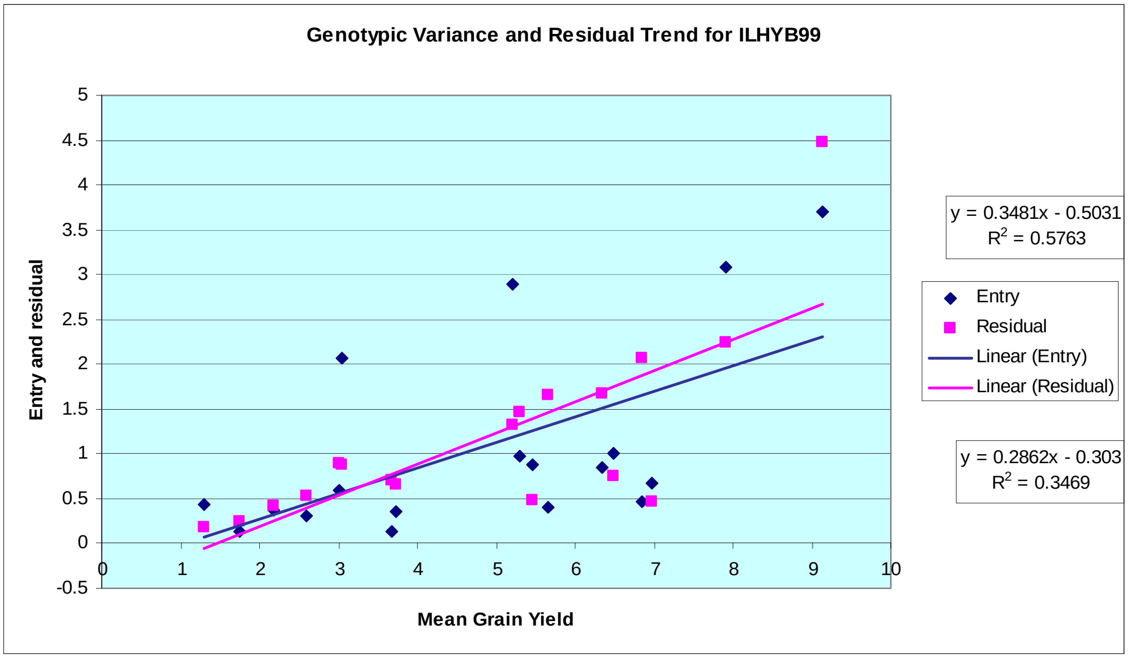

Fig 3.29. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations in 1999.

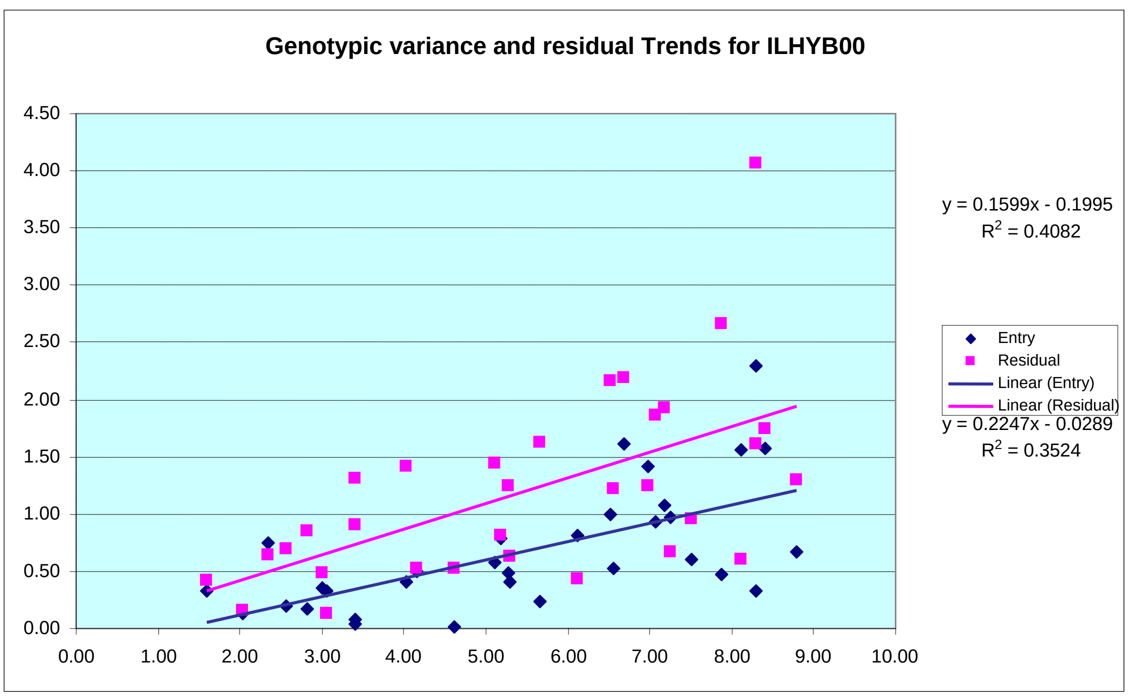

Fig 3.30. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations in 2000.

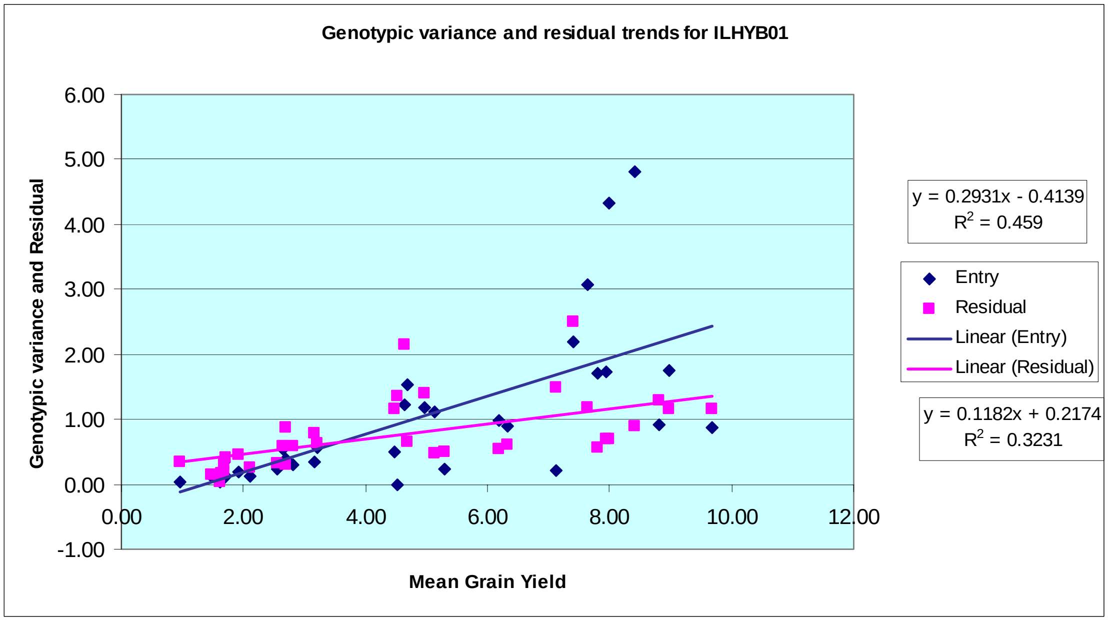

Fig 3.31. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations in 2001.

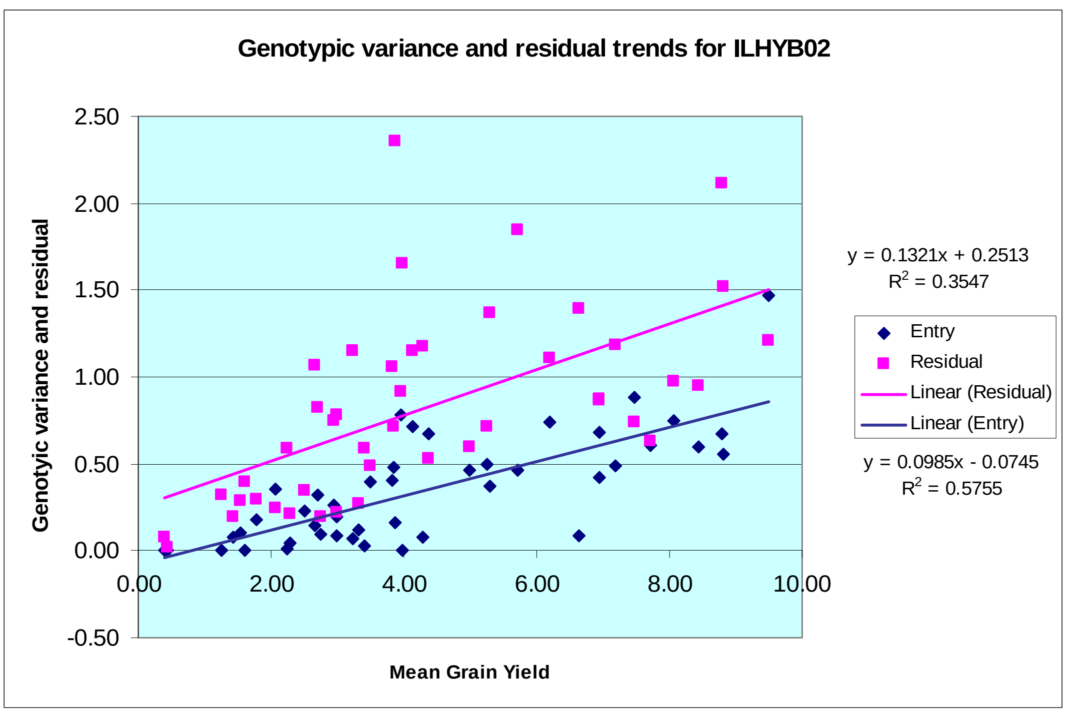

Fig 3.32. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations in 2002.

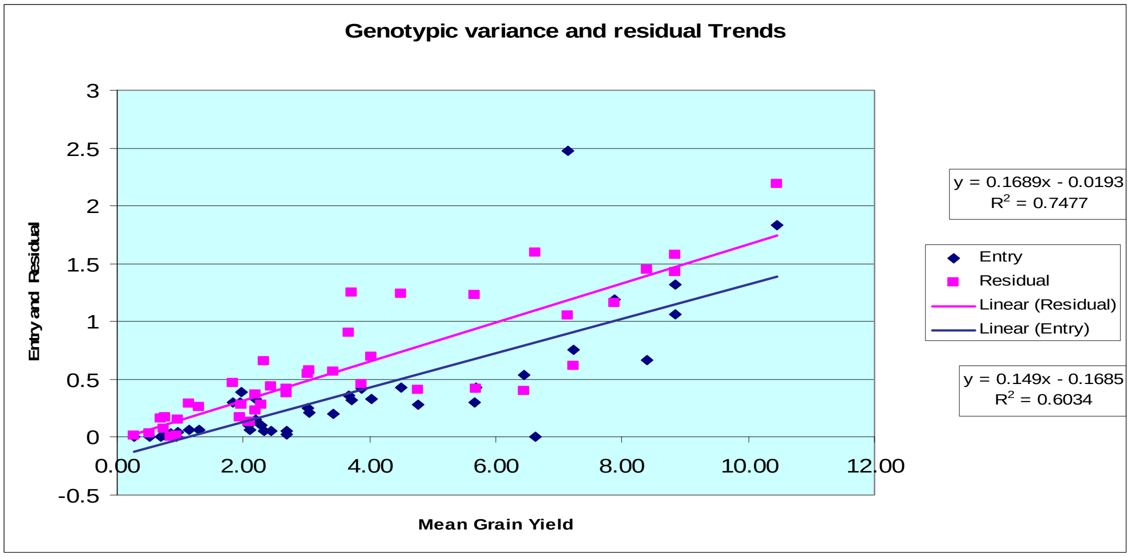

Fig 3.33. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations in 2003

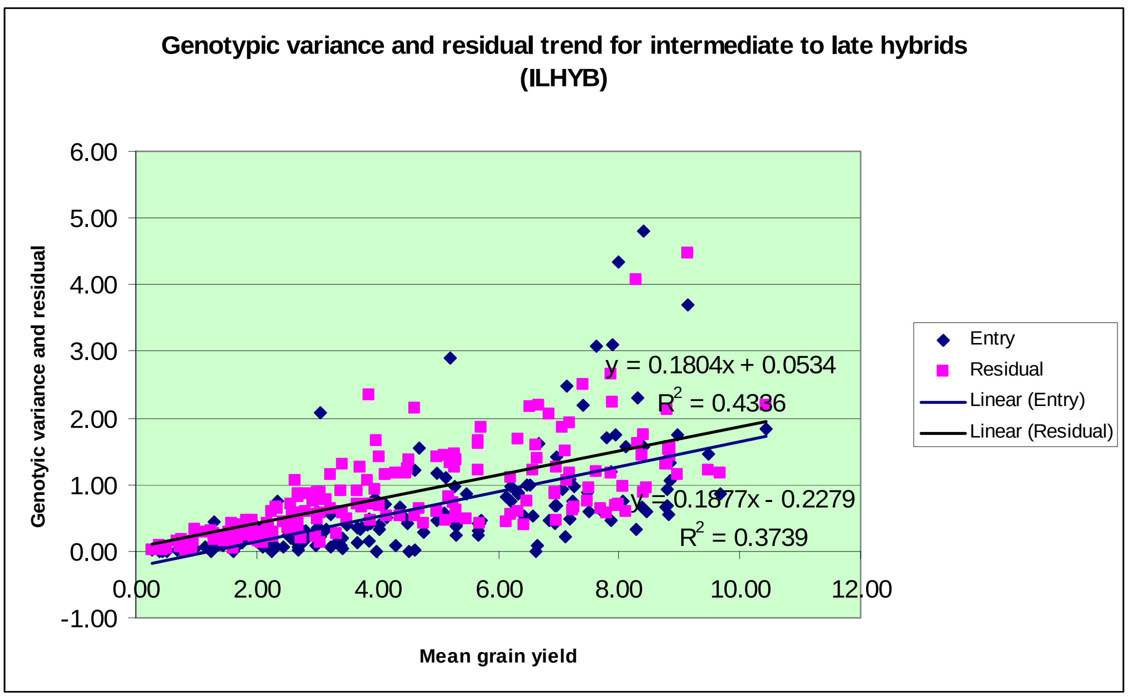

Fig 3.34. Regression of genotypic and residual variances on average yield of intermediate to late hybrids for all maize testing locations across seasons (1999-2003).

Components of variation for early populations (EPOP)

Maize hybrids that are being developed for the region are very high yielding compared to the local materials that the farmers have been using. For example, using the local materials by subsistence farmers, maize yield averages are around 1 t/ha. In contrast, using hybrids yields can average 3.5 t/ha. However, the hybrid seed cost still preclude farmers to use hybrid seed. Open pollinated varieties (OPVs) are becoming a more viable alternative for subsistence farmers. Multilocational testing of maize populations is therefore consistent with the overall developing scheme of increasing maize yields in smallholder farmers' fields. Because farmers can go in their maize crop and select seed, this reduces the major cost burden that prevents most farmers from using improved materials.

Understanding the proportion of components of total variation in multilocational testing will assist plant breeders in the region to better design breeding and testing programs that will maximize gains in selection. The components of variation of different sources (environment, replication, block, genotype, genotype x environment) for early populations in the regional maize testing program from 1999 to 2003 are shown in Tables 3.11, 3.12, 3.13, 3.14 and 3.15.

In 1999, about 60% of total variation was due to location effect, 14% to residual and 3% to genotype. Repeatability was 0.88 and 0.89 for all and optimum locations, respectively. In 2000, variation components for stress locations were added. The partition of variation across optimum and all locations is similar to that observed in 1999. Across drought locations, locations contributed 47.8% of total variation, residual 21%, and entry made no significant contribution to the total variation observed. Similar trends were observed for 2001, 2002 and 2003. In 2002, repeatability under low pH was 0.55. As observed in the hybrids, there is increased error and reduced location effects under stress for these populations together with a reduction in the effects due to the differences in the genotypes that were being evaluated. A notable observation is that the reduction of repeatabilities of population under stress was smaller that the reduction observed in hybrids. For instance, repeatability reduced from 0.97 under optimum conditions to 0.11 under low pH in hybrids (Table 3.10), but for populations it was reduced from 0.96 across all locations to 0.55 under low pH.

Table 3.11. Components of variation for grain yield across optimum and all locations for EPOP in 1999.

Source of Variation	OPT†	TV%‡	ALL	TV%
ENVIRONMENT	1.67	60.71	1.64	61.08
REP (ENV)	0.23	8.36	0.22	8.25
BLOCK (ENV*REP)	0.25	9.04	0.24	9.08
ENTRY	0.08	2.77	0.07	2.71
ENV*ENTRY	0.14	5.20	0.13	4.80
RESIDUAL	0.38	13.92	0.38	14.08
REPEATABILITY	**0.86±0.05**		**0.88±0.04**	

† OPT = Optimum locations
‡ TV% = Percentage of total variation

Table 3.12. Components of variation for grain yield across drought, low N, optimum and all locations for EPOP in 2000.

Source of Variation	**DRT†**	**TV%‡**	**LN**	**TV%**	**OPT**	**TV%**	**ALL**	**TV%**
ENVIRONMENT	1.15	47.86	1.37	71.87	2.70	60.32	2.77	61.47
REP(ENV)	0.12	5.02	0.03	1.81	0.15	3.25	0.13	2.97
BLOCK(ENV*REP)	0.39	16.39	0.21	10.81	0.14	3.03	0.14	3.21
ENTRY	0.00	0.00	0.06	3.40	0.46	10.31	0.42	9.32
ENV*ENTRY	0.21	8.91	0.04	1.99	0.32	7.10	0.37	8.19
RESIDUAL	0.53	21.82	0.19	10.13	0.72	15.98	0.67	14.84
RREPEATABILITY	**0.42±0.05**		**0.60±0.05**		**0.97±0.01**		**0.97±0.01**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.13. Components of variation for grain yieldacross drought, low N, low pH, optimum and all locations for EPOP in 2001.

Source of Variation	**DRT†**	**TV%‡**	**LN**	**TV%**	**LpH**	**TV%**	**OPT**	**TV%**	**ALL**	**TV%**
ENVIRONMENT	0.94	51.90	0.95	66.86	2.42	75.94	2.54	68.52	3.18	75.78
REP (ENV)	0.00	0.00	0.00	0.00	0.18	5.50	0.07	1.79	0.06	1.38
BLOCK(EN*RP)	0.29	16.15	0.16	11.25	0.22	6.97	0.16	4.18	0.18	4.30
ENTRY	0.04	2.41	0.05	3.52	0.02	0.58	0.23	6.21	0.14	3.43
ENV*ENTRY	0.00	0.09	0.03	1.97	0.02	0.51	0.17	4.70	0.16	3.76
RESIDUAL	0.53	29.46	0.23	16.40	0.34	10.50	0.54	14.60	0.48	11.36
Repeatability	**0.63±0.21**		**0.77±0.18**		**0.50±0.07**		**0.95±0.01**		**0.96±0.01**	

† DRT, LN, LpH and OPT = drought, low nitrogen, low pH and optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.14. Components of variation for grain yield across drought, low N, optimum and all locations for EPOP in 2002.

Source of Variation	**DRT†**	**TV%‡**	**LN**	**TV%**	**OPT**	**TV%**	**ALL**	**TV%**
ENVIRONMENT	1.74	78.30	1.47	78.20	3.86	78.14	4.08	81.72
REP (ENV)	0.07	3.32	0.11	5.62	0.09	1.79	0.09	1.81
BLOCK (ENV*REP)	0.17	7.47	0.06	3.38	0.11	2.32	0.11	2.20
ENTRY	0.03	1.51	0.02	1.00	0.12	2.41	0.08	1.70
ENV*ENTRY	0.00	0.00	0.03	1.65	0.06	1.17	0.05	1.09
RESIDUAL	0.21	9.40	0.19	10.15	0.70	14.17	0.57	11.47
REPEATABILITY	**0.71±0.11**		**0.64±0.13**		**0.90±0.03**		**0.94±0.02**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.15. Components of variation for grain yield across low pH, low N, optimum and all locations for EPOP in 2003.

Source of Variation	**LpH†**	**TV%‡**	**LN**	**TV%**	**OPT**	**TV%**	**ALL**	**TV%**
ENVIRONMENT	0.09	31.78	0.48	51.18	5.00	84.89	4.61	84.49
REP (ENV)	0.01	3.88	0.02	2.20	0.09	1.47	0.07	1.28
BLOCK (ENV*REP)	0.04	14.32	0.08	8.21	0.12	2.10	0.11	1.94
ENTRY	0.01	3.52	0.07	6.99	0.12	1.99	0.11	1.99
ENV*ENTRY	0.02	6.59	0.03	3.20	0.17	2.88	0.20	3.72
RESIDUAL	0.12	39.91	0.26	28.22	0.39	6.67	0.36	6.60
REPEATABILITY	**0.50±0.17**		**0.85±0.04**		**0.95±0.01**		**0.96±0.01**	

† LpH, LN, and OPT = low pH, low nitrogen, and optimum locations respectively
‡ TV% = Percentage of total variation

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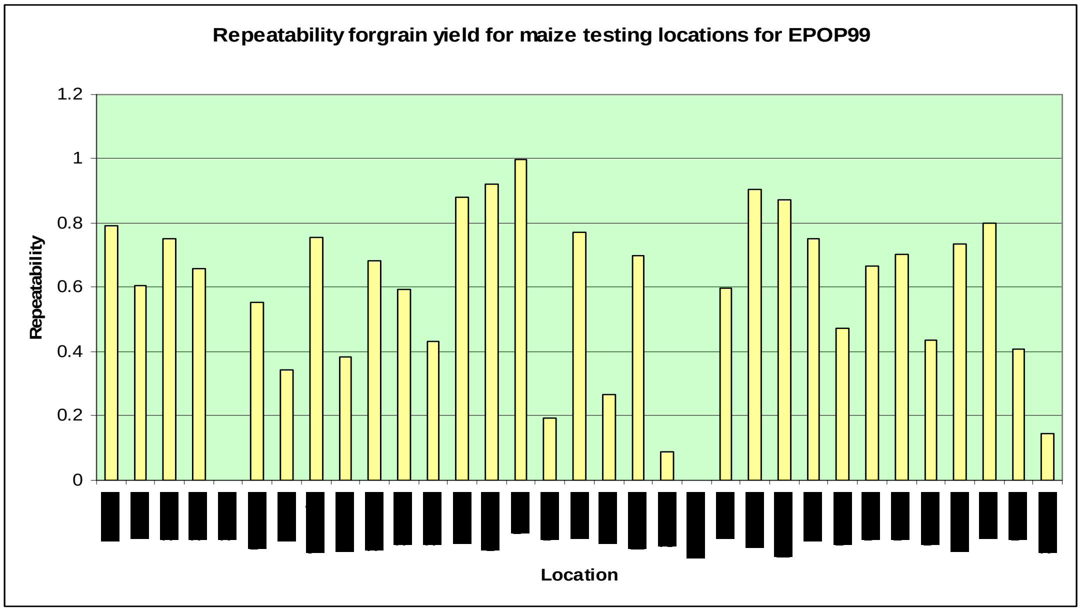

Fig. 3.35. Repeatability for grain yield for all maize testing locations for early populations in 1999.

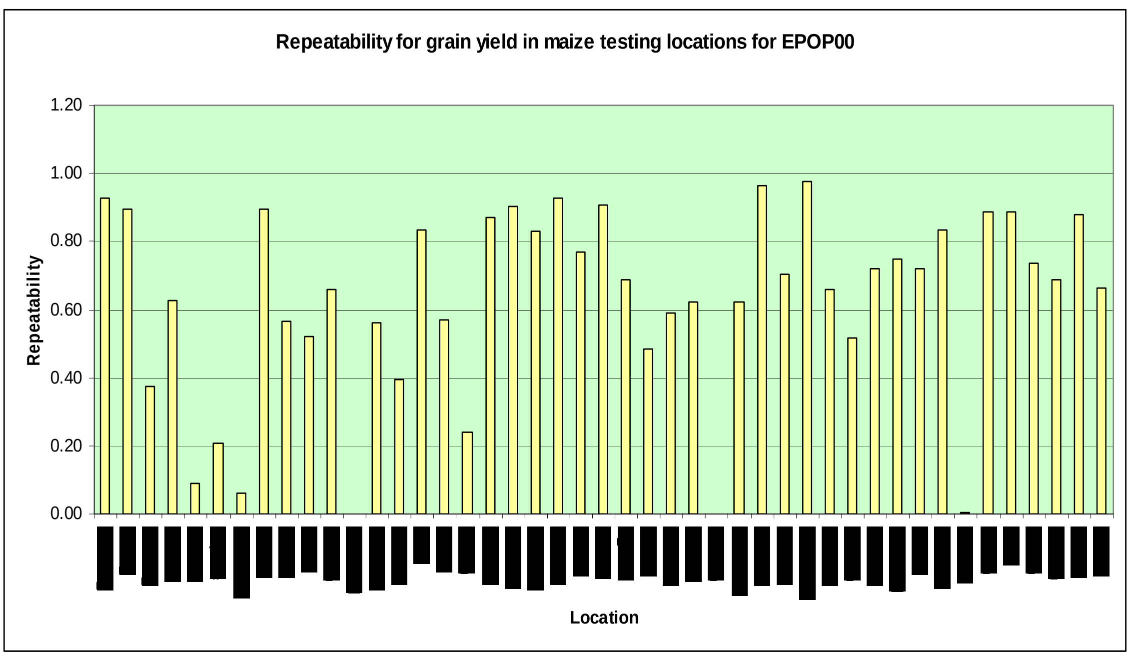

Fig. 3.36 Repeatability for grain yield for all maize testing locations for early populations in 2000.

Repeatability for grain yield for early populations (EPOP)

Repeatability estimates for early populations (EPOP) from 1999 to 2003 are shown in Fig 3.35, 3.36, 3.37, 3.38 and 3.39. In 1999, there were a total of 34 locations and repeatability of at least 0.6 was observed in 20 locations (59%). Repeatability was equal 0 in Sebele in Botswana and at low N in Mazozo, Angola. There were very high repeatability estimates for Ilonga in Tanzania (0.98) and Marondera in Zimbabwe (0.91). In 2000, the number of locations increased to 45. In 29 (64%) of these locations, repeatability estimate was at least 0.6. Repeatabilities were very low in Nanga in Zambia and reasonably high in eastern Africa and Zimbabwe.

In 2001, the number of locations increased to 53. Repeatability estimates of at least 0.6 were observed in 29 of these locations (55%). Repeatability estimates = 0 were observed in Goodhope, Botswana and again in Nanga, Zambia. In 2002, still 53 locations were used for evaluating the early population and fewer locations indicated repeatability estimates of at least 0.6. There were repeatability estimates = 0 for Ezolimo in South Africa and Mazozo in Angola. In 2003, the number of locations went up to 65 and again Mazozo, Angola and Nanga, Zambia showed repeatability estimates = 0. A total of 30 (46%) locations out of the 65 showed grain yield repeatability of at least 0.6. This type of analysis establishes the effectiveness of the entire regional maize testing program. The testing program expansion is evidenced by an increase in the number of locations from 34 in 1999 to 65 in 2005. It is desirable to achieve maximum repeatability for the various traits that are being evaluated in as many locations as possible. The analysis then cautions plant breeders and collaborators in the region to maintain and /or improve the quality of overall management or regional trials.

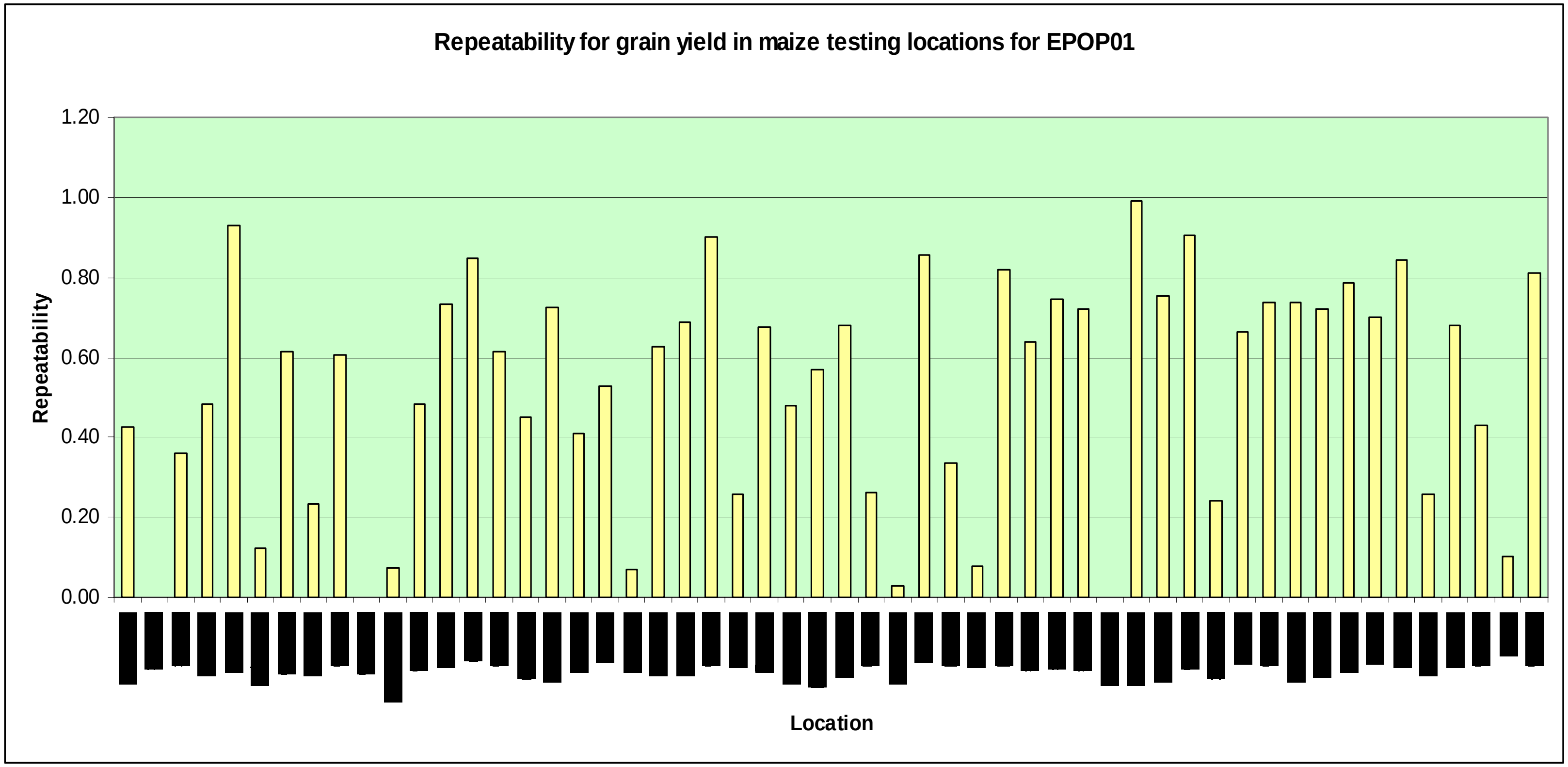

Fig. 3.37. Repeatability for grain yield for all maize testing locations for early populations in 2001.

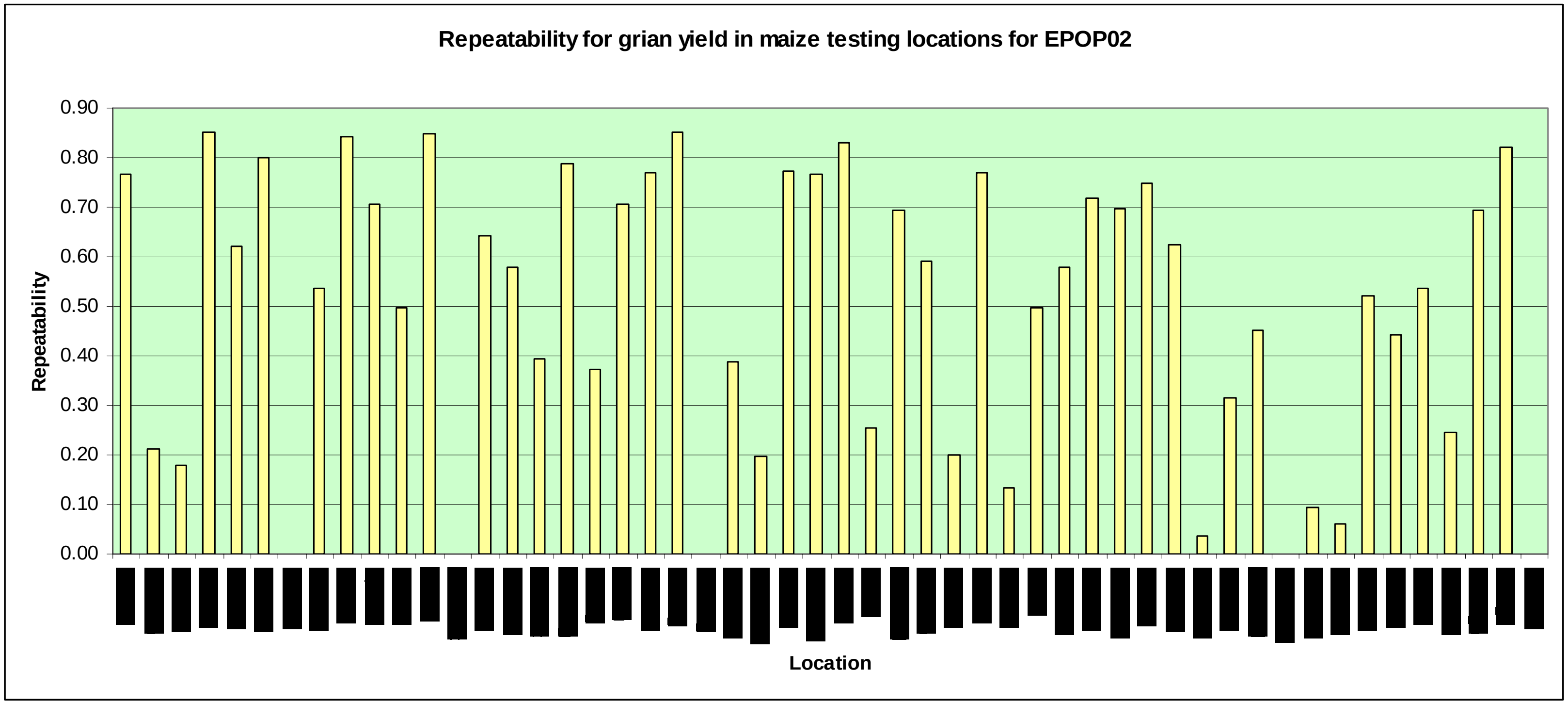

Fig. 3.38. Repeatability for grain yield for all maize testing locations for early populations in 2002.

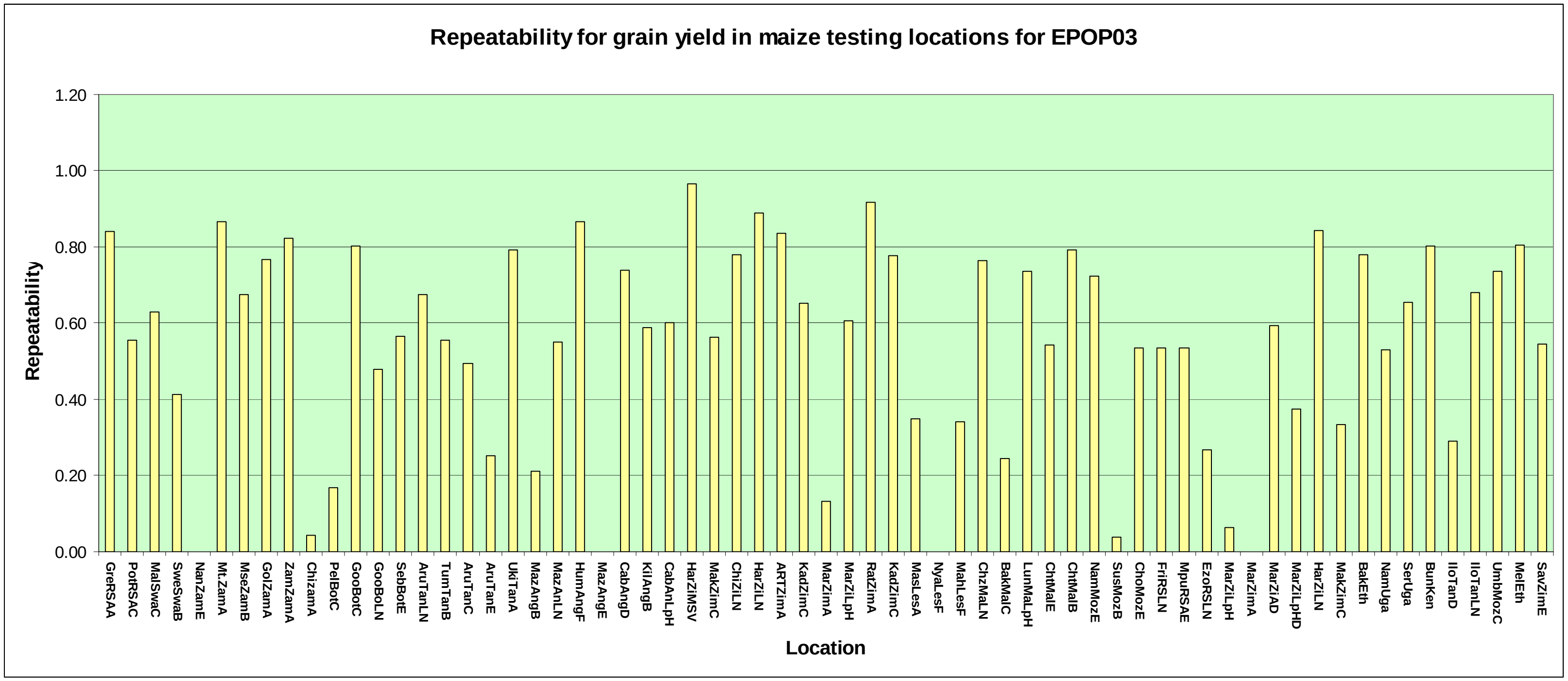

Fig. 3.39. Repeatability for grain yield for all maize testing locations for early populations in 2003.

Regression of repeatability estimates for early population (EPOP)

Repeatability trends on average grain yield of early populations are shown in figures 3.40, 3.41, 3.42, 3.43 and 3.44. Figure 3.45 shows the trend of repeatability across seasons. There was no meaningful relationship or correlation between repeatability and grain yield in all the seasons (R^2 values of 0.13, 0,25,0.08, 0.17 and 0.20 for 1999, 2000, 2001, 2002 and 2003, respectively). Across season analysis revealed similar correlation between yield and repeatability (Fig 3.45). The regression slope was consistently positive indicating that higher repeatability levels were observed in higher yielding locations and vice versa.

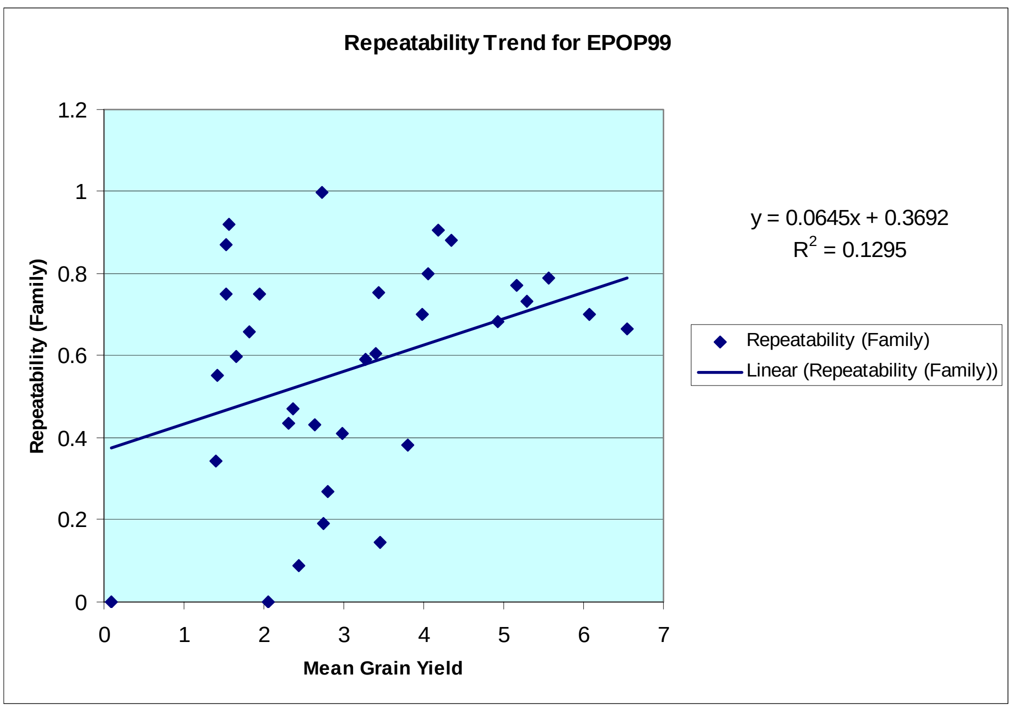

Fig. 3.40. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations in 1999.

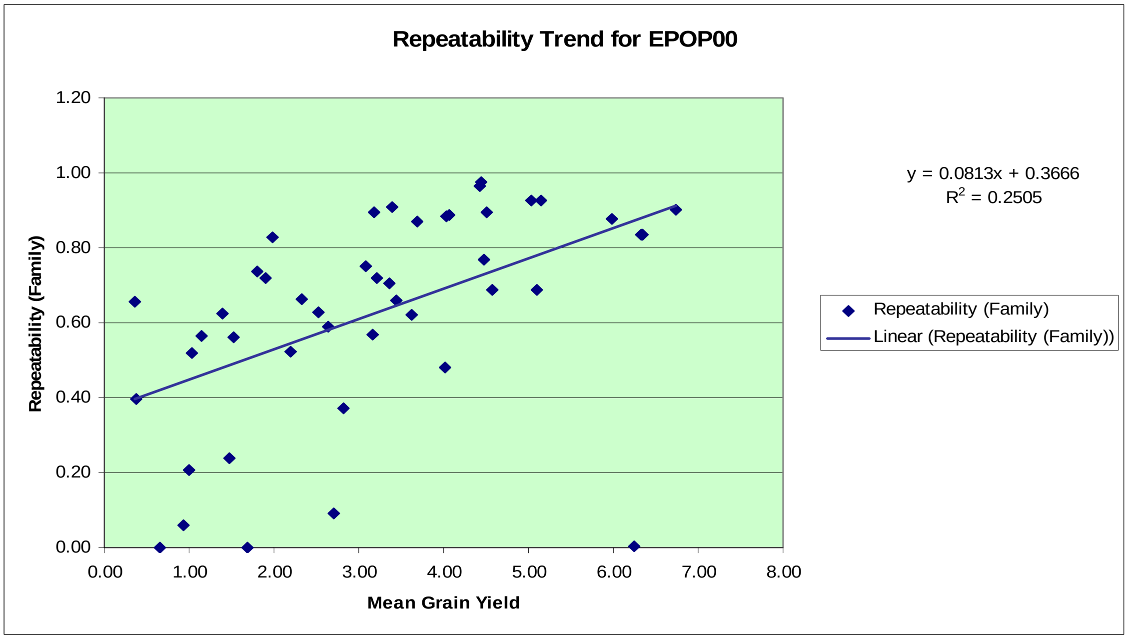

Fig. 3.41. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations in 2000.

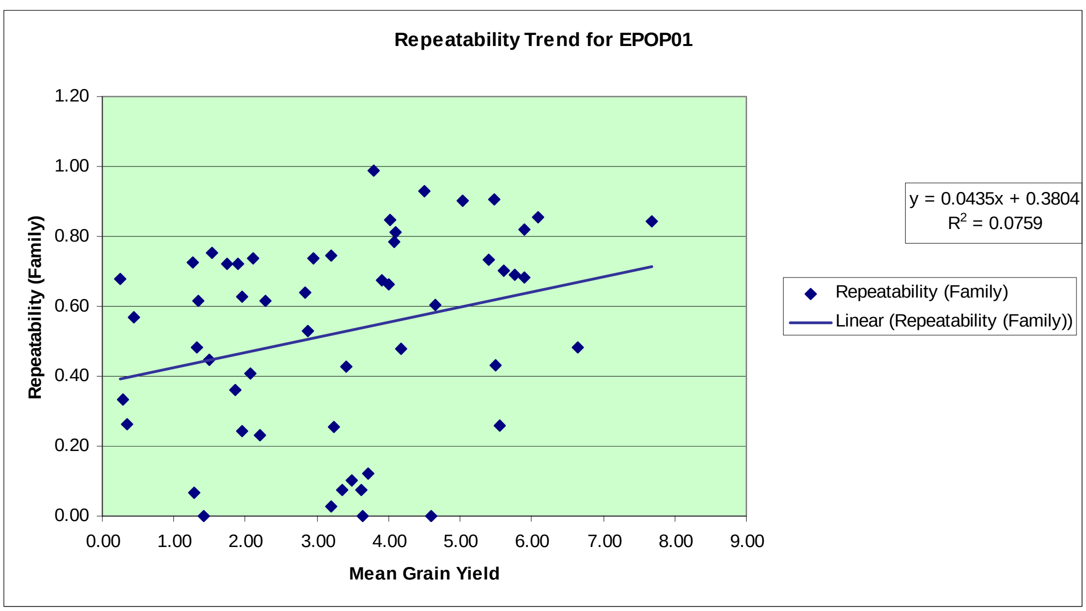

Fig. 3.42. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations in 2001.

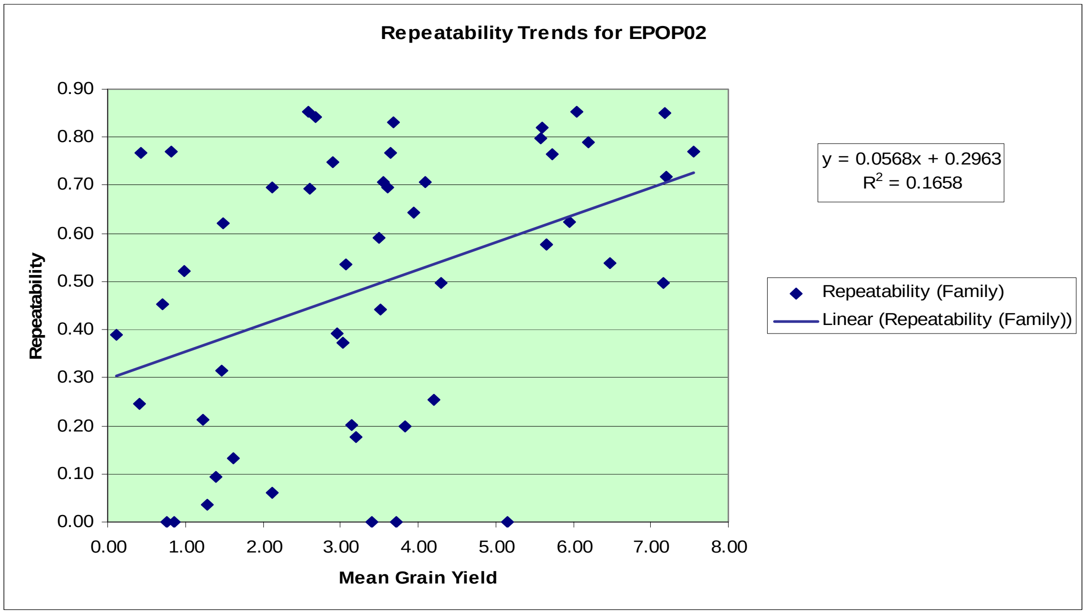

Fig. 3.43. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations in 2002.

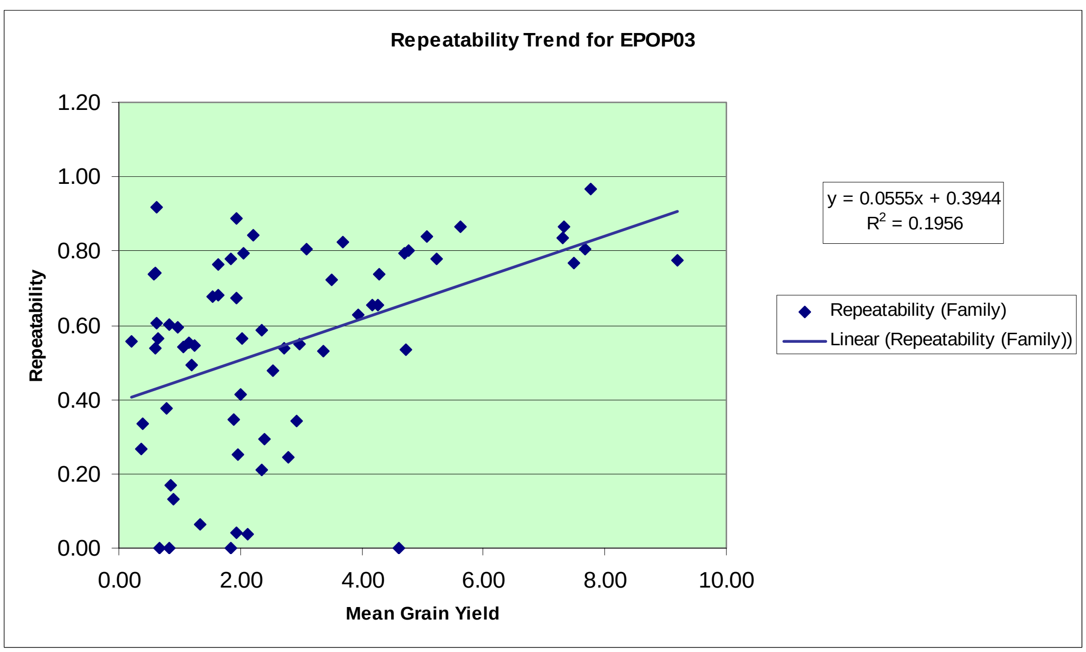

Fig. 3.44. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations in 2003.

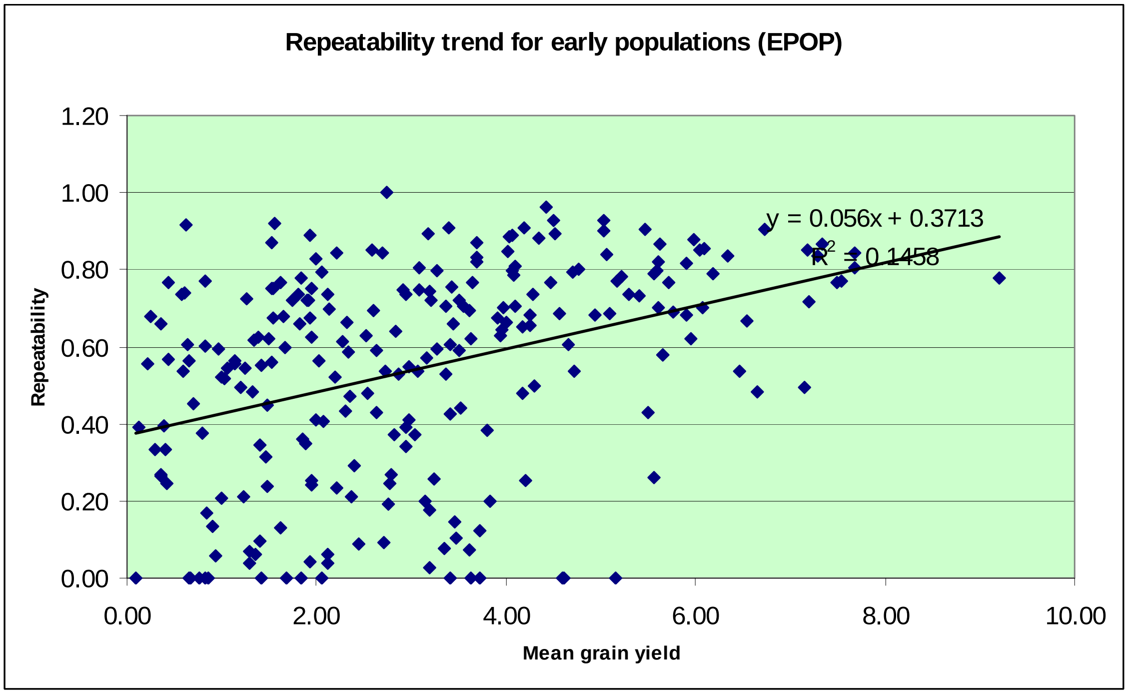

Fig. 3.45. Regression of repeatability estimates with respect to average yield of early populations for all maize testing locations across seasons (1999-2003).

Regression of genotypic variance and residual for early populations (EPOP)

Regressions of genotypic variance and residual on average grain yields for EPOP from 1999 to 2003 are shown in figures 3.46, 3.47, 3.48, 3.49 and 3.50. Figure 3.51 shows the trend across the five seasons (1999-2003). Significant relationships between average grain yield and genotypic and residual variances were observed in all the seasons. High yieldind locations showed high genotypic variability and residual. The stressed locations showed less genotypic variability and residual.

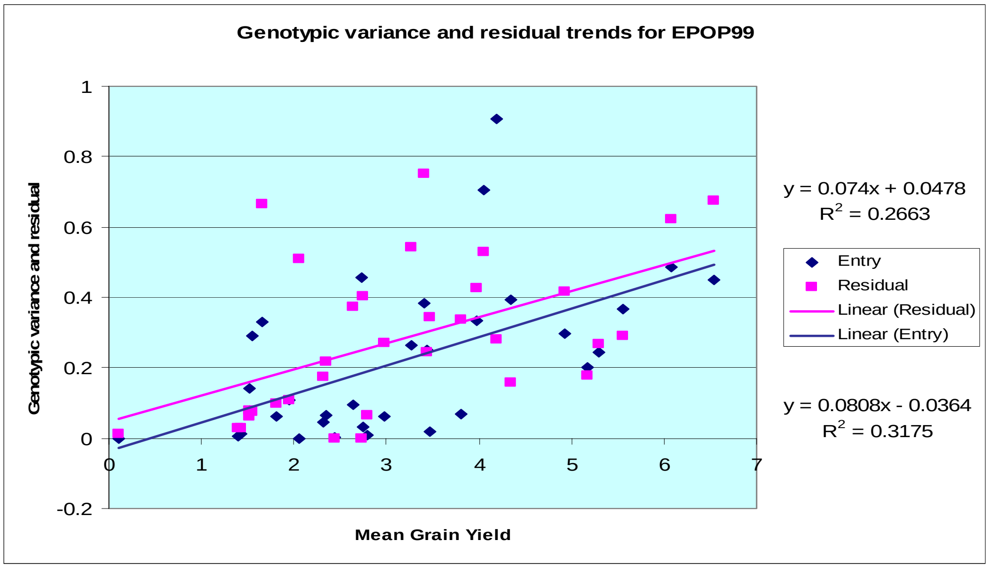

Fig 3.46. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations in 1999.

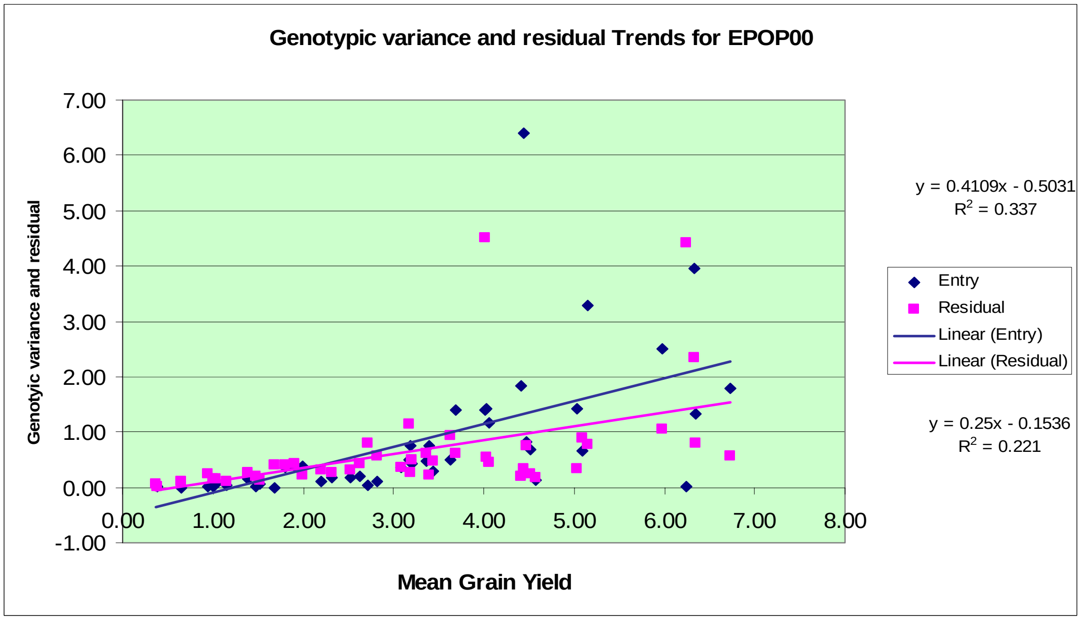

Fig. 3.47. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations in 2000.

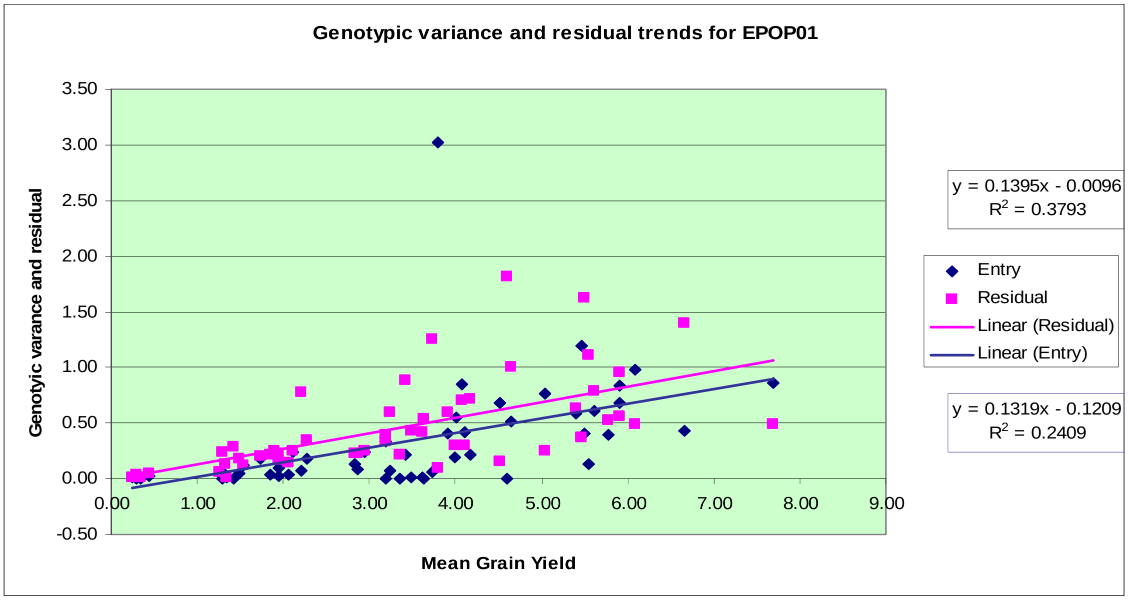

Fig. 3.48. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations in 2001.

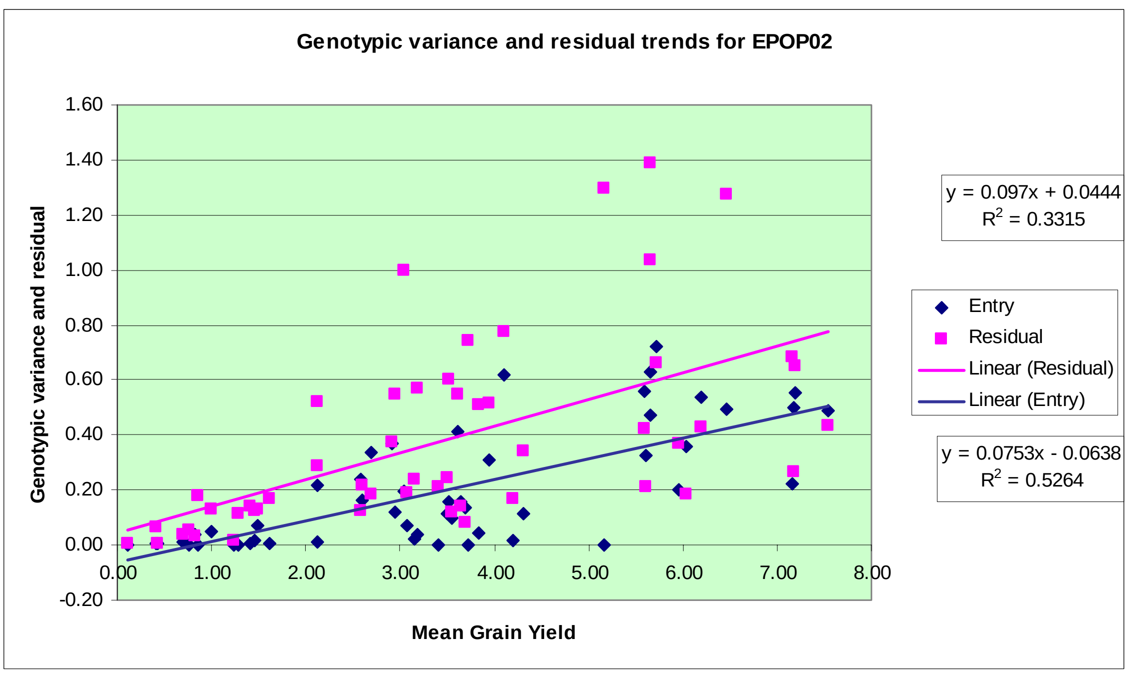

Fig. 3.49. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations in 2002.

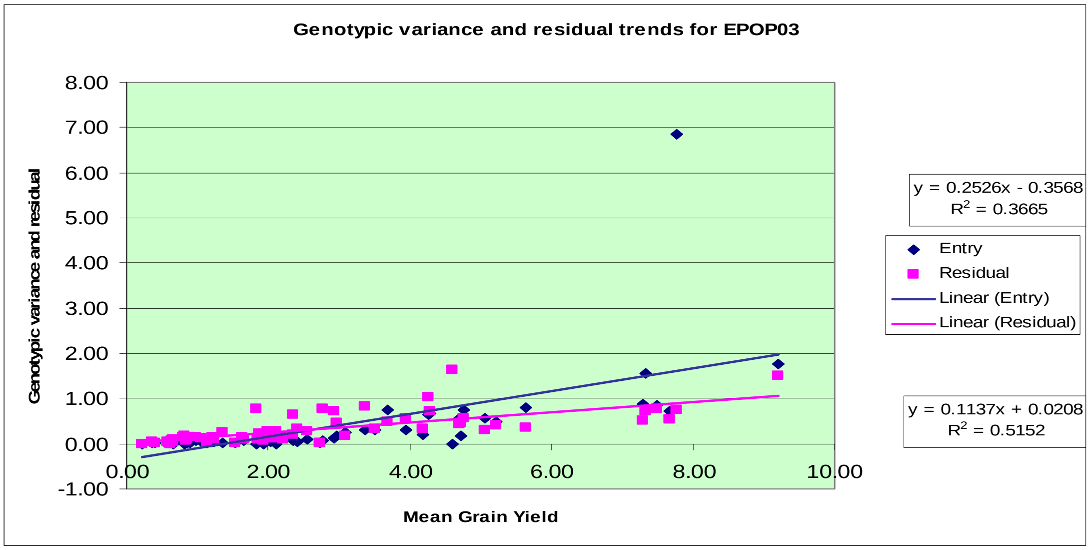

Fig. 3.50. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations in 2003.

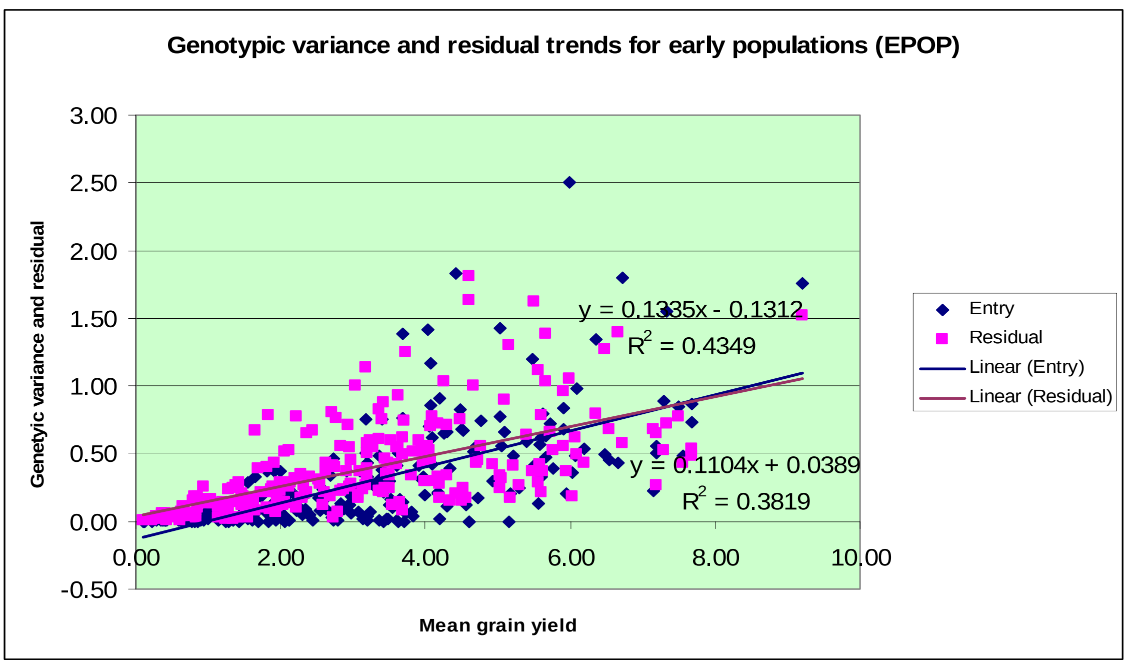

Fig. 3.51. Regression of genotypic and residual variances on average yield of early populations for all the maize testing locations across seasons 1999-2003

Components of variation for intermediate to late populations (ILPOP)

Components of variation for intermediate to late hybrids are shown in tables 3.16, 3.17, 3.18, 3.19 and 3.20 for 1999, 2000, 2001, 2002 and 2003, respectively. Most of the variation for grain yield observed in 1999 was attributed to locations (83.8% under optimum conditions and 82.6% across all locations). Under low nitrogen stress, 26.10% of total variation was attributed to locations, 6.6% due to genotypes, and 30.9% to error. There was significant increase in error variation under stress conditions. Increased error under stress would also result in reduction in heritability/repeatability. In 2000, for example, repeatability across optimum conditions was 0.87 and across all locations 0.89. On the other hand, repeatability across drought locations was 0.26, and across low N 0.19. The difference in reaction to stress between the hybrids and open pollinated varieties regarding the relative importatnce of components of variation is important element of stability of yield across locations and become an important factor as to why smallholder farmers prefer open pollinated varieties, which may not necessarily give high yield but may provide stable yields.

Table 3.16. Components of variation for grain yield across drought, low N, optimum and all locations for ILPOP in 1999.

Sources of Variation	**DRT†**	**TV%‡**	**LN**	**TV%**	**OPT**	**TV%**	**ALL**	**TV%**
ENVIRONMENT	0.24	26.10	0.24	26.10	5.03	83.83	4.40	82.58
REP(ENV)	0.19	20.21	0.19	20.21	0.08	1.41	0.09	1.63
BLOCK(ENV*REP)	0.12	13.49	0.12	13.49	0.26	4.33	0.26	4.97
ENTRY	0.06	6.58	0.06	6.58	0.10	1.72	0.10	1.79
ENV*ENTRY	0.02	2.67	0.02	2.67	0.18	3.03	0.15	2.85
RESIDUAL	0.28	30.96	0.28	30.96	0.34	5.69	0.33	6.18
REPEATABITITY	**0.50±0.26**		**0.60±0.17**		**0.87±0.04**		**0.90±0.03**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.17. Components of variation for grain yield across drought, low N, optimum and all locations for ILPOP in 2000.

Sources of Variation	DRT†	TV%‡	LN	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	1.59	47.14	0.40	36.92	3.32	70.15	3.83	72.58
REP(ENV)	0.17	4.93	0.13	12.32	0.18	3.73	0.16	3.12
BLOCK(ENV*REP)	1.18	34.87	0.16	14.86	0.19	4.00	0.27	5.20
ENTRY	0.02	0.61	0.01	1.32	0.12	2.62	0.11	2.11
ENV*ENTRY	0.05	1.55	0.09	7.95	0.23	4.93	0.27	5.16
RESIDUAL	0.37	10.90	0.29	26.62	0.69	14.57	0.63	11.84
REPEATABITITY	**0.52±0.05**		**0.19±0.19**		**0.87±0.02**		**0.89±0.02**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.18 Components of variation for grain yield across all locations for ILPOP in 2001.†

Sources of Variation	ALL	Percentage of total variation
ENVIRONMENT	3.41	72.73
REP(ENV)	0.23	4.90
BLOCK(ENV*REP)	0.24	5.17
ENTRY	0.12	2.51
ENV*ENTRY	0.18	3.80
RESIDUAL	0.51	10.90
REPEATABILITY	**0.94±0.01**	

† There was no data for stress locations

Table 3.19. Components of variation for grain yield across drought, low N, optimum and all locations for ILPOP in 2002.

Sources of Variation	DRT†	VT%‡	LN	VT%	OPT	VT%	ALL	VT%
ENVIRONMENT	1.75	78.44	1.47	77.97	3.86	79.77	4.07	82.97
REP(ENV)	0.07	3.34	0.11	6.03	0.09	1.81	0.09	1.85
BLOCK(ENV*REP)	0.17	7.40	0.06	3.28	0.17	3.57	0.15	3.11
ENTRY	0.03	1.45	0.02	0.95	0.12	2.48	0.09	1.74
ENV*ENTRY	0.00	0.03	0.03	1.63	0.14	2.81	0.11	2.33
RESIDUAL	0.21	9.35	0.19	10.15	0.46	9.55	0.39	8.01
REPEATABILITY	**0.63±0.17**		**0.70±0.12**		**0.94±0.02**		**0.95±0.02**	

† DRT, LN and OPT = drought, low nitrogen, optimum locations respectively
‡ TV% = Percentage of total variation

Table 3.20 Components variation for grain yield across low pH, low N, optimum and all locations for ILPOP in 2003

Sources of variation	LpH†	TV%‡	LN	TV%	OPT	TV%	ALL	TV%
ENVIRONMENT	0.43	59.23	0.14	15.72	4.34	82.99	4.38	83.12
REP(ENV)	0.12	17.05	0.23	25.05	0.10	1.87	0.12	2.23
BLOCK(ENV*REP)	0.05	7.08	0.13	13.61	0.11	2.11	0.11	2.03
ENTRY	0.01	0.96	0.09	10.09	0.09	1.78	0.09	1.78
ENV*ENTRY	0.02	2.23	0.02	2.28	0.12	2.21	0.13	2.45
RESIDUAL	0.10	13.44	0.31	33.27	0.47	9.03	0.44	8.38
REPEATABILITY	**0.30±0.32**		**0.84±0.06**		**0.93±0.03**		**0.94±0.02**	

† LpH, LN, and OPT = low pH, low nitrogen, and optimum locations respectively
‡ TV% = Percentage of total variation

Repeatability for grain yield of intermediate to late populations (ILPOP)

Single location repeatability estimates for intermediate to late populations (ILPOP) from 1999 to 2003 are shown in Fig 3.52, 3.53, 3.54, 3.55 and 3.56. In 1999, there were a total of 24 locations and repeatability of at least 0.6 was observed in 14 locations (58%). Repeatability was equal 0 in Umbeluzi in Mozambique and Sussundenga in Mozambique. There were very high repeatability estimates for Greytown in South Africa (0.96) and ART Farm in Zimbabwe (0.91). In 2000, the number of locations increased to 34. In 15 (44%) of these locations, repeatability estimate of at least 0.6 was observed. Repeatability equal 0 was observed in Msekera in Zambia and Morogoro in Tanzania. There were reasonably high repeatability estimates for locations in Kitale, Kenya and Harare, Zimbabwe. In 2001, the number of locations in which intermediate to late maize populations were evaluated increased further to 4. In 25 of these locations (51%), repeatability of a least 0.6 was observed. Repeatability was equal 0 in Magoye, Zambia, at a low pH location in Chianga, Angola and at a drought location in Chitala, Malawi. There were high repeatability estimates for Harare in Zimbabwe, Bvumbwe in Malawi and Kitale in Kenya. In 2002, the number of location went up further to 56 and at least 0.6 repeatability estimates were observed in 22 of these locations (39%). Repeatability estimates equal 0 were observed in Nhlangano in Swaziland, drought locations in Chitala, Malawi,Sebele in Botswana, Katrin in Tanzania, Morogoro in Tanzania, and Melkasa in Ethiopia. There were high repeatability estimates for Embu and Kakamega in Kenya. In 2003, the populations were evaluated in 48 locations, and in 22 of these locations, repeatability estimates were at least 0.6. Repeatability equal 0 were observed at Goodhope in Botswana, Mazozo in Angola, and a low pH location in

Lunyangwa, Malawi and Ilonga, Tanzania. High repeatability estimates were observed in Harare, Zimbabwe and Mazozo, Angola.

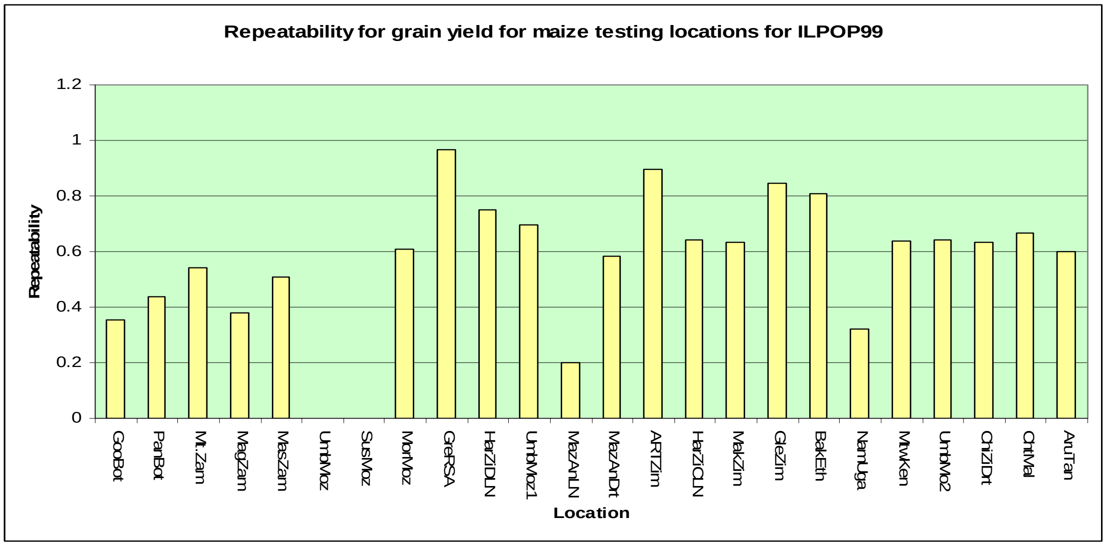

Fig. 3.52. Repeatability for grain yield of intermediate to late populations for all maize testing locations in 1999.

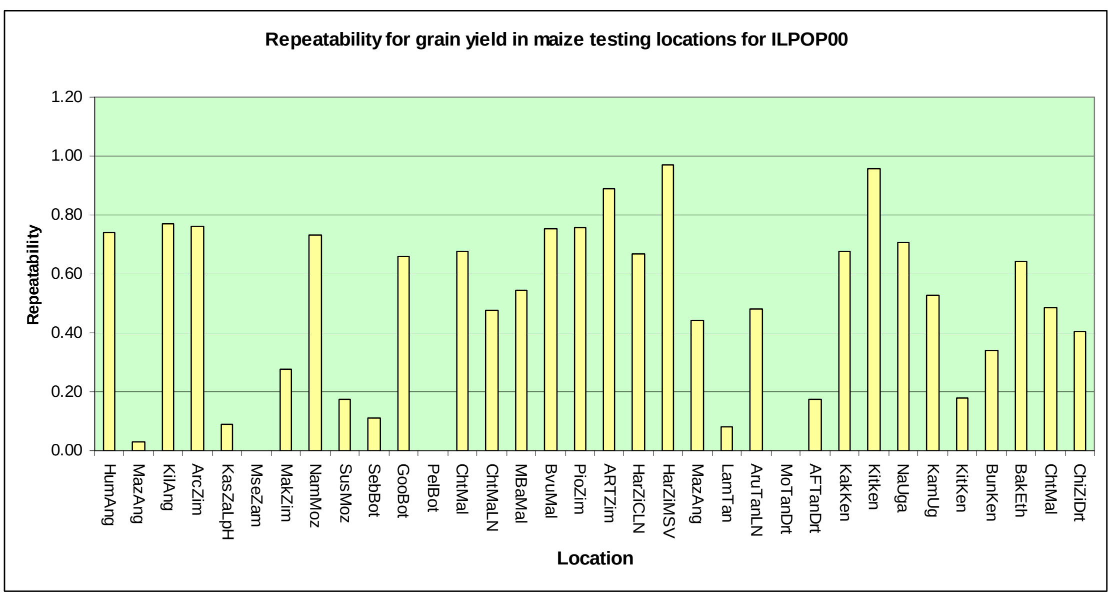

Fig. 3.53 Repeatability for grain yield of intermediate to late populations for all maize testing locations in 2000.

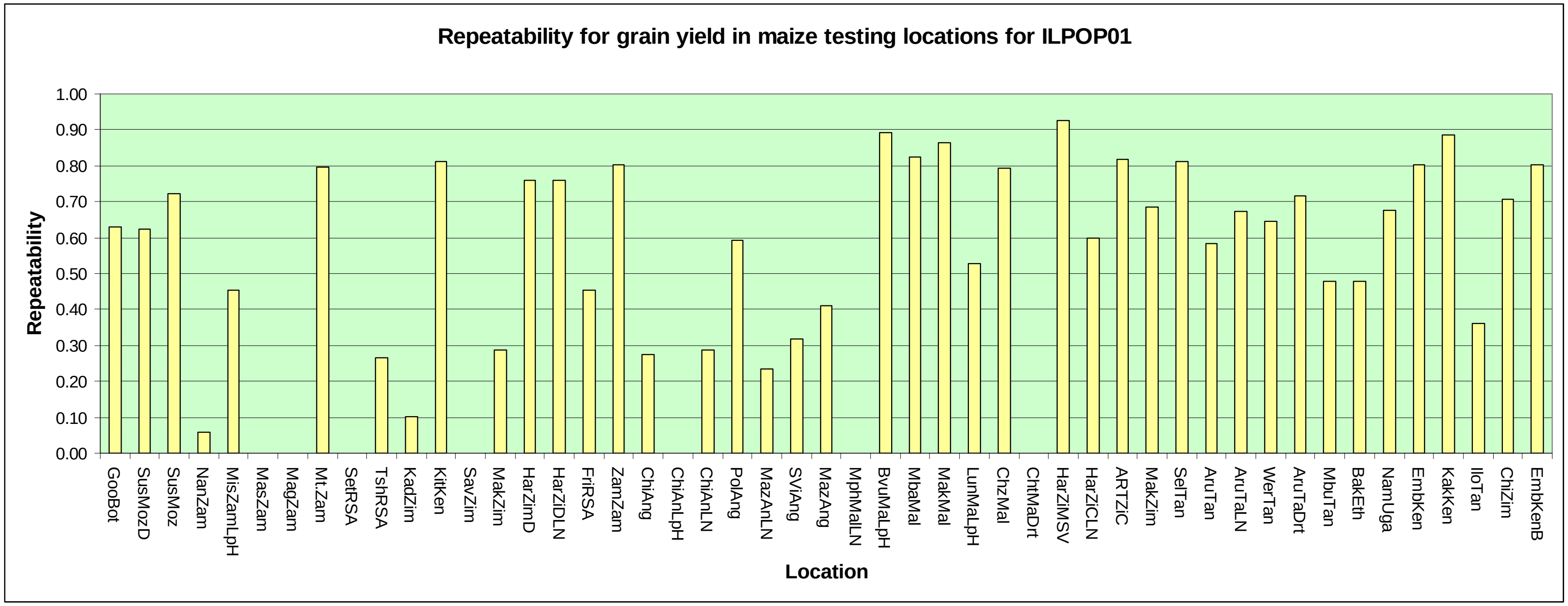

Fig. 3.54. Repeatability for grain yield of intermediate to late populations for all maize testing locations in 2001.

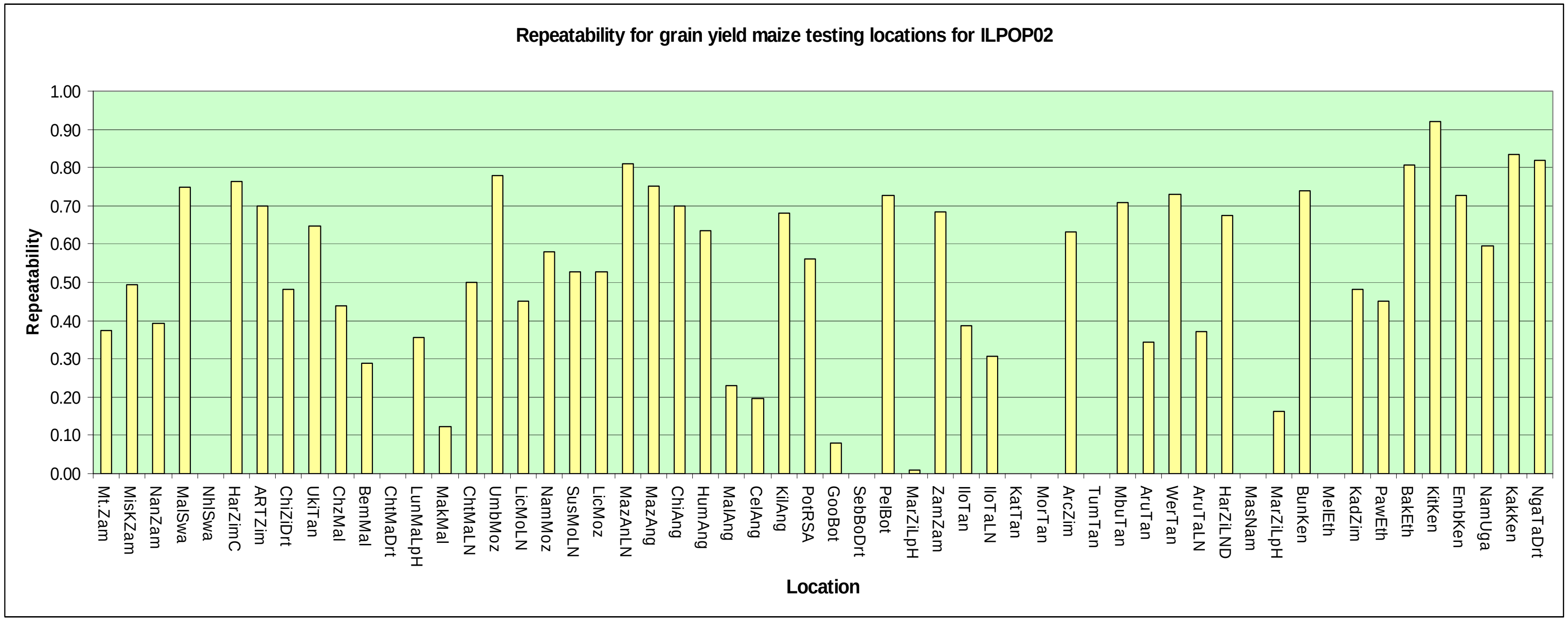

Fig. 3.55. Repeatability for grain yield of intermediate to late populations for all maize testing locations in 2002.

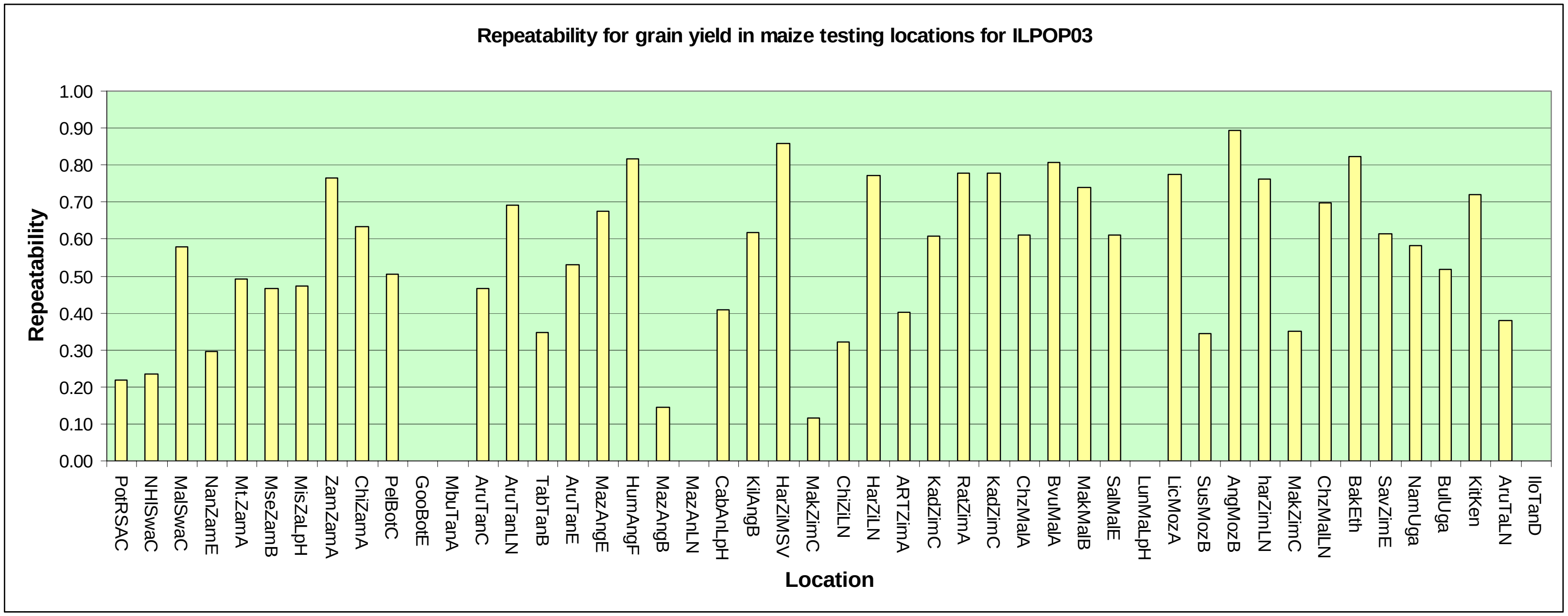

Fig. 3.56. Repeatability for grain yield of intermediate to late populations for all maize testing locations in 2003.

Regression of repeatability estimates on average grain yield per location for intermediate to late population (ILPOP).

Regression of repeatability estimates on average grain yield per location for intermediate to late population are shown in figures 3.57, 3.58, 3.59, 3.60 and 3.61. Figure 3.62 showed the regression across the seasons. There was no significant correlation between repeatability and grain yield in all the seasons (R^2 were 0.16, 0.34, 0.16, 0.11and 0.07 for 1999, 2000, 2001, 2002 and 2003, respectively). The regression slope was consistently positive, which indicated that higher repeatability levels were observed in higher yielding locations.

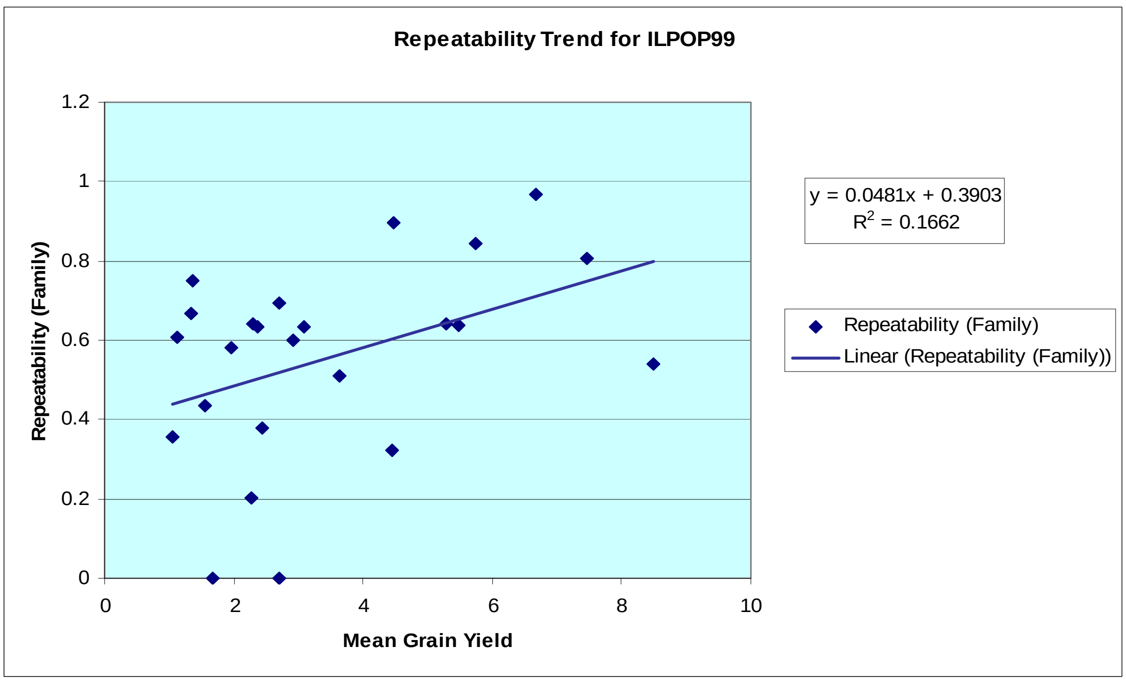

Fig. 3.57. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations in 1999.

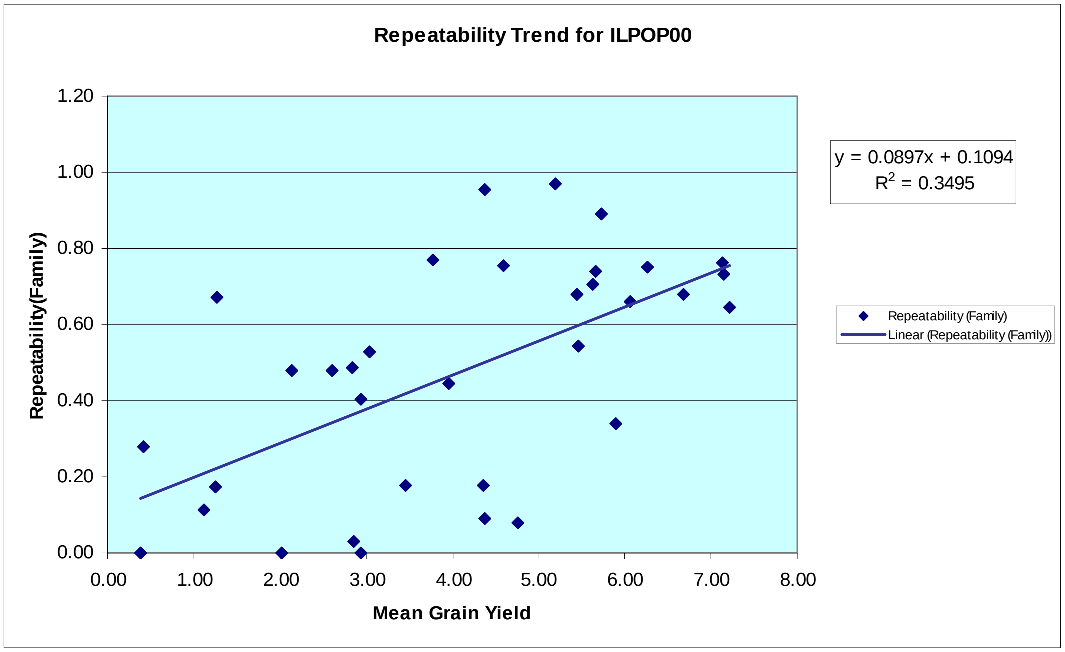

Fig. 3.58. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations in 2000.

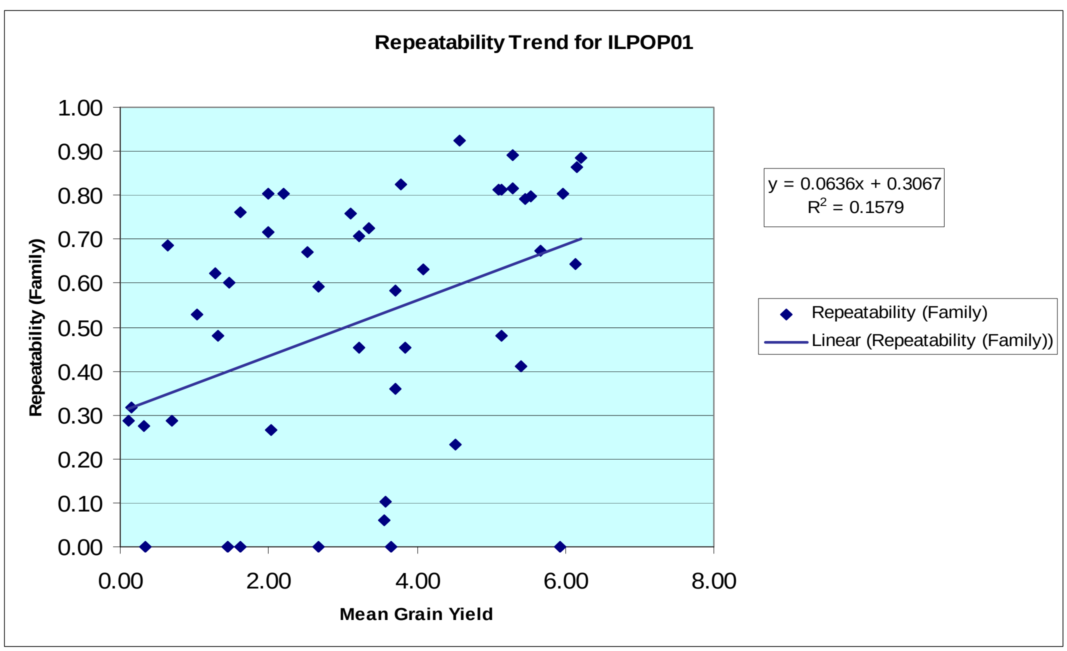

Fig. 3.59. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations in 2001.

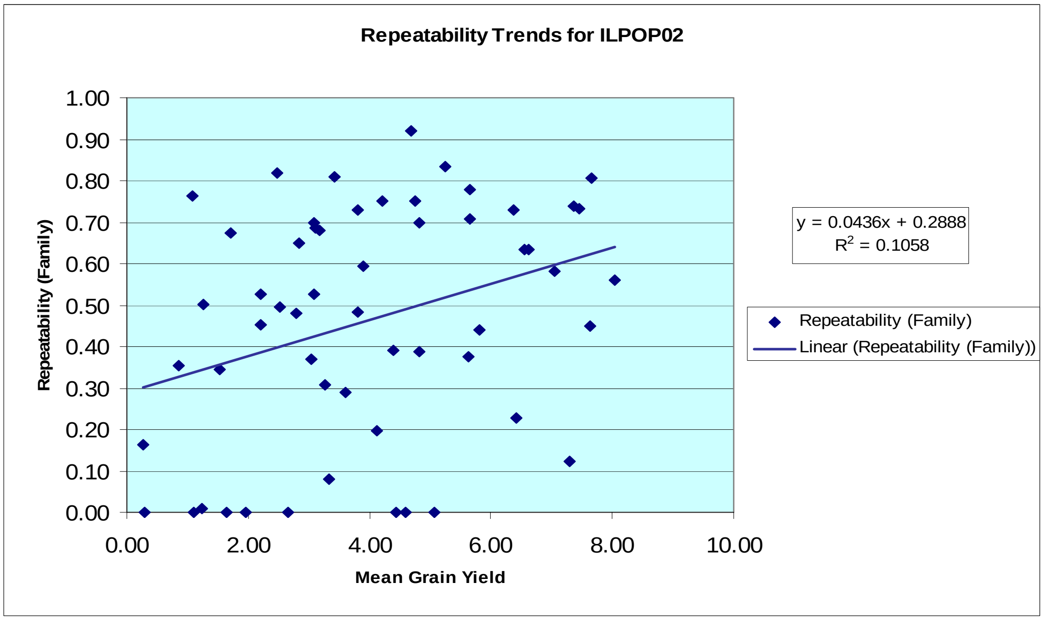

Fig. 3.60. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations in 2002.

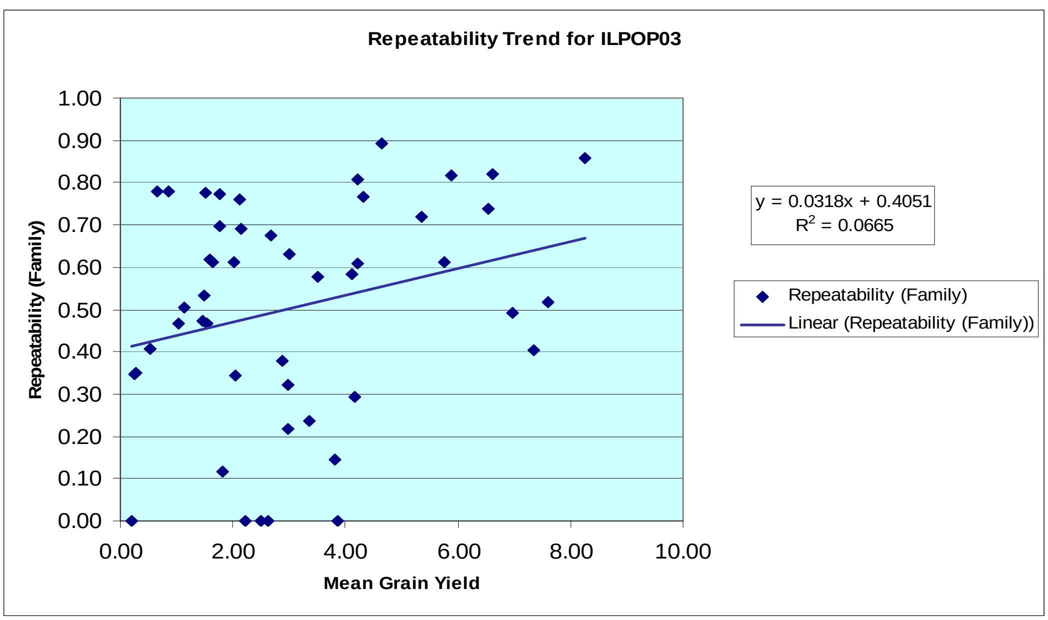

Fig. 3.61. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations in 2003.

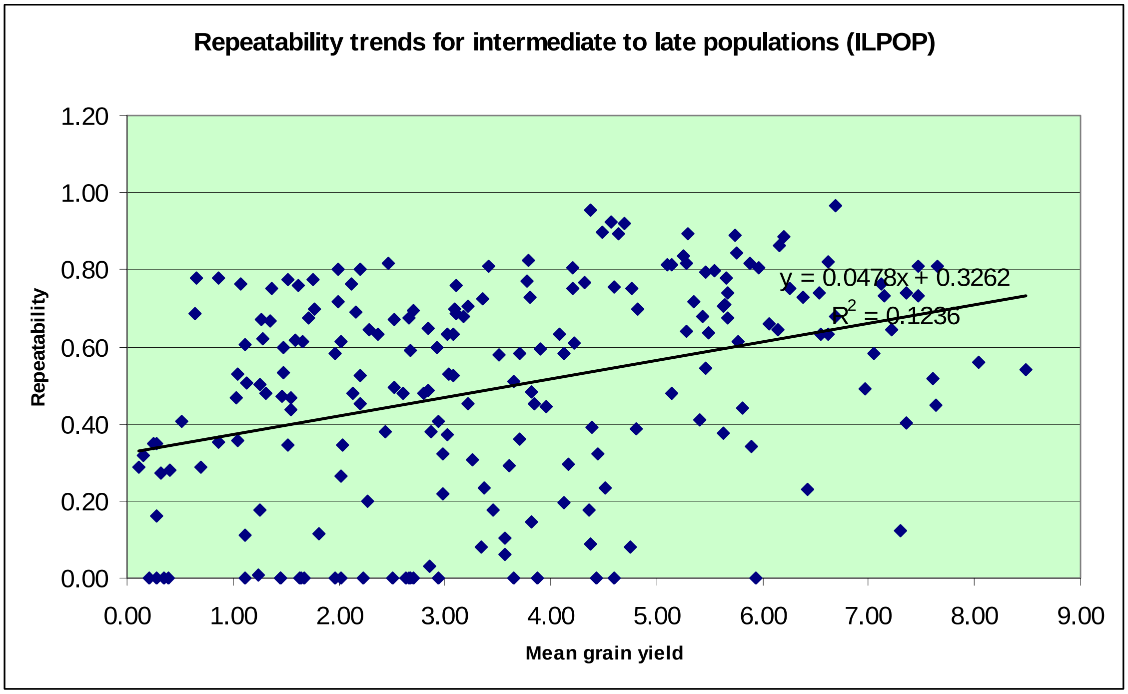

Fig. 3.62. Regression of repeatability estimates on average yield for intermediate to late populations in all maize testing locations across seasons (1999-2003).

Genotypic variance and residual trends for intermediate to late populations (ILPOP)

The regression of genotype and residual variances on average grain yield of ILPOP from 1999 to 2003 are shown in figures 3.63, 3.64, 3.65, 3.66 and 3.67. The regression across seasons is shown in Fig. 3.68. Significant relationships between average grain yield and genotypic and residual variances were observed, especially in 1999 and 2003. High yielding locations showed high genotypic and residual variances. Stressed locations had less genotypic and residual variances. The more genetic variability that can be expressed, the easier is to discriminate among genotypes and more progress would be expected in cultivar development.

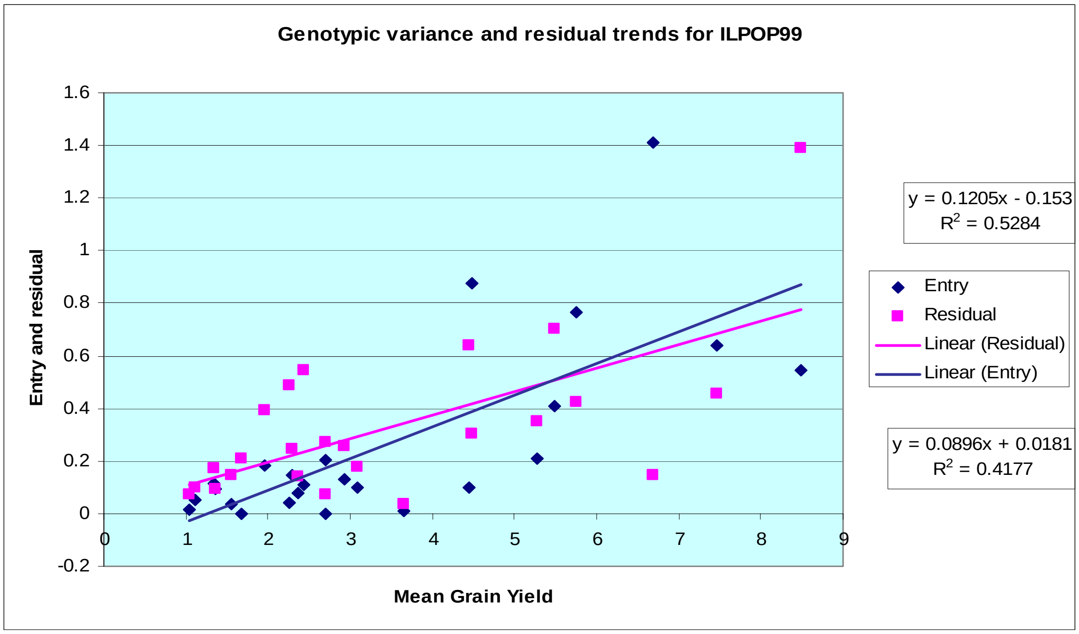

Fig. 3.63. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations in 1999.

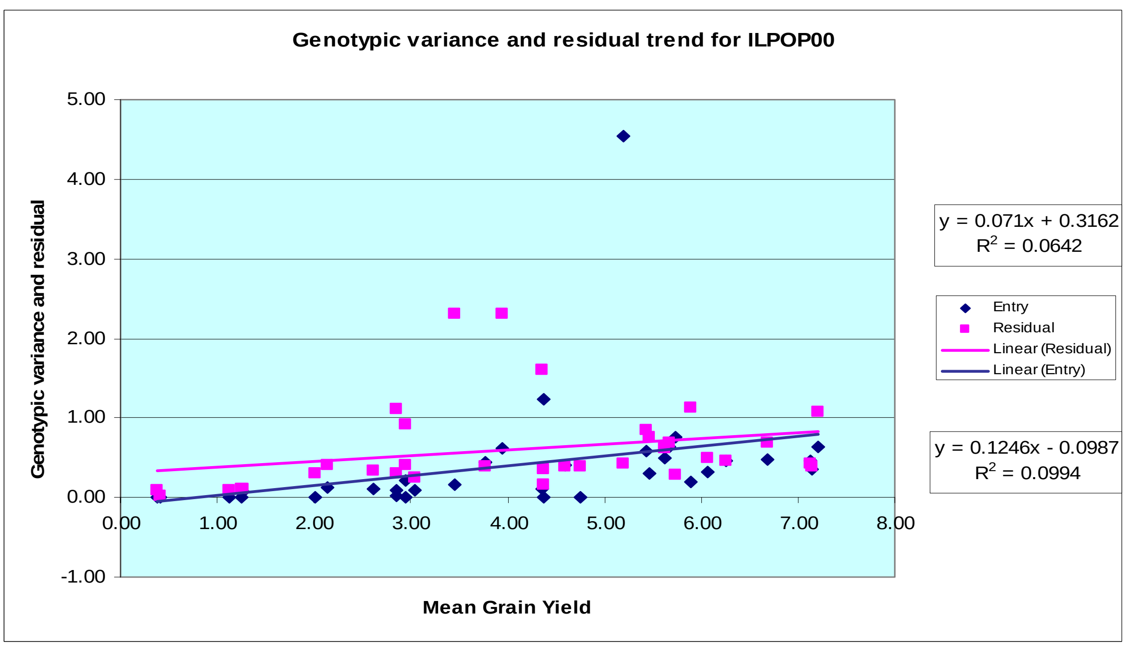

Fig. 3.64. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations in 2000.

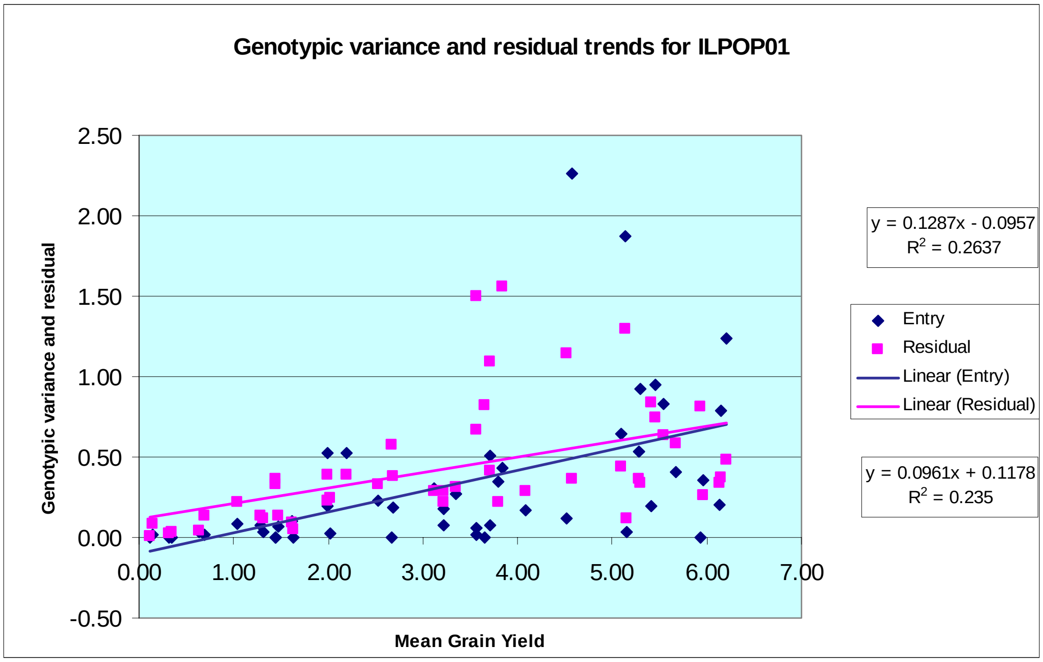

Fig. 3.65. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations in 2001.

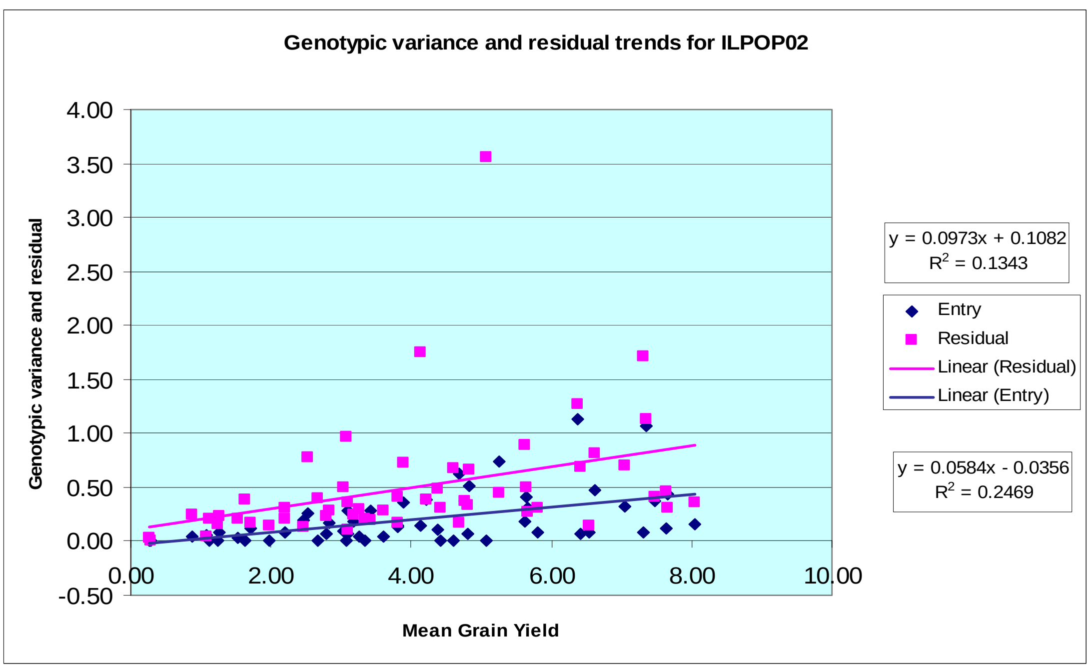

Fig. 3.66. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations in 2002.

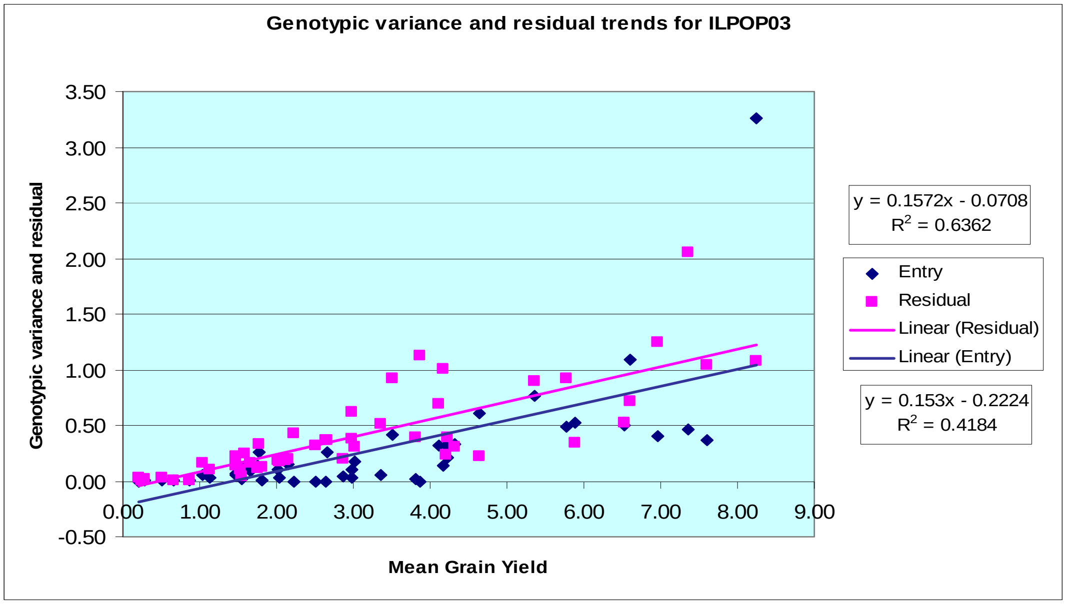

Fig. 3.67. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations in 2003.

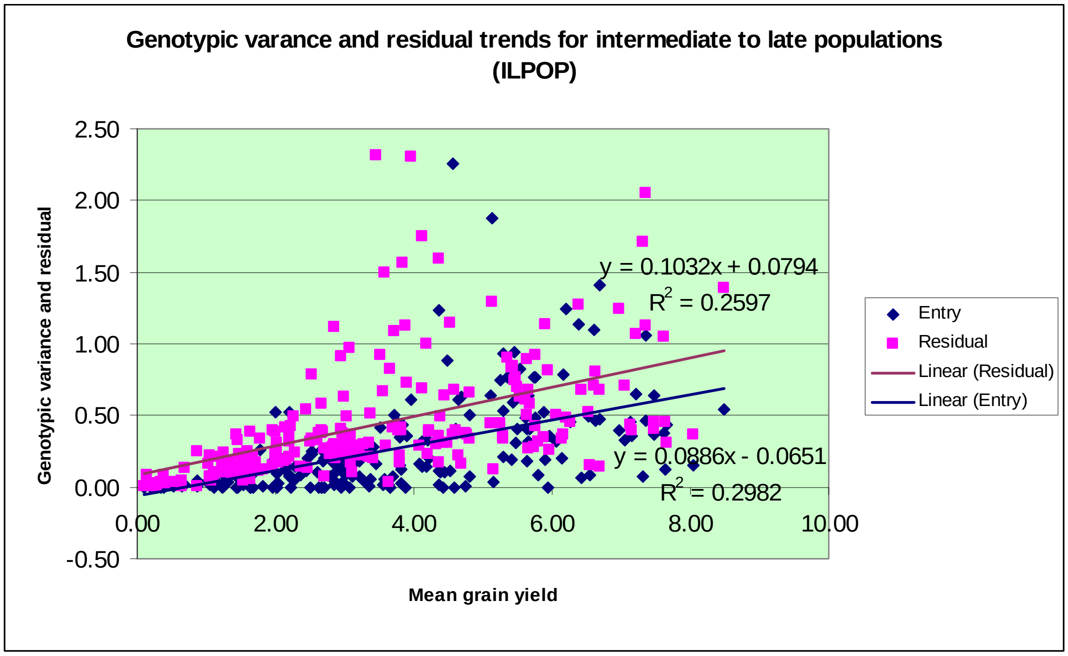

Fig. 3.68. Regression of genotypic and residual variances on average grain yield of intermediate to late populations for all maize testing locations across seasons (1999-2003).

SUMMARY

Multilocational testing remains a very important tool for regional cultivar development in eastern and southern Africa. The results of this study have shown that the effect due to differences in location is very important in determining the phenotypic expression of the materials that were being evaluated. An analysis of components of variation has shown that location contributed over 60% and sometimes up to 85% of total phenotypic variation. The high proportion of variation due to environment and significant genotype by location interation emphasize the need for multilocation testing for testing to identify high yielding, nitrogen efficient, drought tolerant and low pH tolerant cultivars in the region.

The variation attributed to location is reduced under stress locations compared with optimal conditions. The relative proportion of variation components also change under stress. Reduced genotypic variance creates a reduction in repeatability under stress conditions. This finding is consistent with those by Ud-din et al. (1992), Calhoun et al. (1994), Bänziger et al. (1997), Bertin and Gallais (2000), and Sinebo et al. (2002) who stated that heritabilities are generally lower under lower input level or in stressed conditions than under optimum or high input conditions. Among the three abiotic stresses considered, low pH resulted in significant reduction in repeatability for grain yield. Low nitrogen and drought remain to be the most important stress factors affecting maize production in the region.

Repeatability and repeatability regressions on average grain yields showed that there is more variation under optimum conditions compared to stress conditions. Therefore the efficiency of indirect selection where selections for grain yield are conducted under optimal conditions to improve tolerance to drought or low N will depend on the genetic correlation among stress and non stress environments, the type of trait (quantitative vs. qualitative), and the quality of results form evaluation (affected by trial design and management).

CHAPTER IV
RELATIONSHIPS AMONG TRAITS IN MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

INTRODUCTION

Maize (*Zea mays* L.) is a very important cereal crop for eastern and southern Africa. It is the staple food in many countries of the region. Most of the maize in the region is produced by smallholder farmers, others practiced mixed cropping in an area under a hectare. The maize crop is also exposed to mid-season and terminal water stress (Chapman and Edmeades, 1999) and a considerable proportion is produced under low nitrogen conditions (Bänziger and Lafitte, 1997). Most maize in eastern and southern African countries is produced under low N conditions (McCown et al., 1992; Oikeh and Horst, 2001) because of low N status of tropical soils, low N use efficiency in drought-prone environments, high price ratios between fertilizer and grain, limited availability of fertilizer, and low purchasing power of farmers (Bänziger et al., 1997). General manifestations of poverty which result in late planting and poor weed and pest control makes low N and to some extent moisture deficit common characteristics of maize growing environments in the region. The crop is grown under water stress because farmers cannot afford an investment in irrigation facilities and because of high population growth, more and more farmers are forced to grow crops in marginal areas, and in recent years, the region has experienced frequent dry spells and drought.

This has resulted in the need for plant breeders and physiologists to decide appropriate conditions for testing and selection that will maximize gains, because the crop is produced under a wide range of mostly unpredictable conditions. Plant breeders have looked at the following strategies for obtaining such broadly adapted maize cultivars. Selection may be done under favorable conditions of adequate fertilization, adequate water availability through irrigation or through adequate and well distributed precipitation. These conditions are experienced in most agricultural research stations, and in some areas in eastern and southern Africa, which very rarely experience long dry spells or drought, and therefore selection may be planned and conducted in those locations. Johnson and Gaedelmann (1989) reported that yield gains from selection under irrigation were equal to those from selection under drought stress when evaluated in stress conditions, and that such gains were superior when evaluated under favorable conditions. Arboleda-Rivera and Compton (1974), however found that progress from selection for high yield under well-watered conditions was reduced under crop water deficit. With increasing N-stress intensity in most maize growing areas, selection under low nitrogen becomes more efficient selection strategy for producing broadly adapted tropical maize under high nitrogen conditions (Bänziger et al., 1997).

Selection could be conducted only under stress conditions, which may be either under water deficit or under low nitrogen conditions or sometime a combination of both stress conditions, which is not uncommon in maize growing locations in the region. The problem with this approach is that some traits that contribute to productivity and survival may reduce productivity under favorable conditions (Blum, 1988), the other limitation may be that heritability for grain yield and thus effectiveness, and progress in cultivar development and improvement are reduced under stress conditions (Blum, 1988). Arboleda-Rivera and Compton (1974) however employed this selection strategy, with considerable success, and they reported an increase in yield in both stressed and unstressed maize growing environments. The last selection strategy is selecting in a combination of stressed and unstressed environments. This is particularly relevant in this study because the selection strategy is the intrinsic goal of multilocation testing schemes, like the regional maize trials network for eastern and southern Africa, which is conducted by CIMMYT with collaboration with the national agricultural research programs, and the private sector in the region. This is very practical and direct way of obtaining broadly adapted cultivars because the materials are exposed to both stressed and unstressed environment in the same set of evaluation.

Yield gains during cultivar development and improvement and improvement selection for drought tolerance were associated with increased ear per plant and shortened anthesis silking interval (ASI) (Bolaños et al., 1993; Edmeades et al., 1999) as these are indicators of general plant vigor, which determines the extent of source sink relationships in photosyntate partitioning. The consideration of secondary trait could improve selection efficiency (Bänziger and Lafitte, 1997). Theoretically, indirect selection for single secondary trait results in greater progress for grain yield than direct selection for grain yield when $h_{GY} < |r_G h_{ST}|$, where h_{GY} and h_{ST} are square roots of the heritabilities/repeatabilities of grain yield and the secondary trait respectively and r_G is the genetic correlation between grain yield and the secondary trait (Falconer, 1989). The genetic correlation and the trait relationships confirm the experience that indirect selection is generally less efficient than direct selection in high yielding environments where heritabilities of grain yield are high (Smith and Nelson, 1986) but it might prove more useful in stress environments where heritabilties of grain yield are low. Selection for one trait will cause a correlated response to selection in a second trait if genetic correlation exists between the two traits. An association has been reported between ASI and grain yield (Edmeades et al., 1993). Although ASI had shown to be an effective predictor of grain yield under stress conditions (Bolaños and Edmeades, 1993), additional secondary traits may be evaluated to improve selection efficiency under stress. The objective of this study was to assess and evaluate relationships among traits in maize regional trials in eastern and eastern Africa. The results can provide information to asses the relative value of stress adaptive traits, and thus improve current maize breeding strategies for abiotic stress tolerance in the region.

REVIEW OF LITERATURE

A phenotypic correlation exist when the phenotypic values for multiple traits are correlated due to genetic and non-genetic causes and the genetic correlation is the linear association between the breeding values of individuals for multiple traits (Bernardo, 2002). According to Bernardo (2002), a non-zero genetic correlation occurs by two ways. Linkage causes a genetic correlation if the loci found close together on the same chromosome control different traits. If dominant alleles cause higher values for each trait, then coupling linkage would cause a positive genetic correlation where as repulsion linkage caused negative correlation, the strength of correlation depends on the tightness of the linkage between the loci, and this type of correlation may be dissipated by repeated meiosis, which may be effected by random mating or selfing. Pleiotropy, which occurs when two traits are controlled by the same loci, naturally leads to a genetic correlation between the two traits, and this correlation has a physiological basis, cannot be dissipated by repeated meiosis and is thus more permanent that correlations due to linkage.

Plants breeders' main objective for cultivar development is grain yield. During selection, testing and evaluation especially for drought and low N tolerance in maize, secondary traits improve the precision with which drought or low N tolerant genotypes are identified, compared to measuring only grain yield under drought or low N stress. This is because under stress the heritability of grain yield usually decreases, whereas the heritability of some secondary traits remains high and the genetic correlation between grain yield and those traits increases sharply (Bänziger and Lafitte, 1997; Bolaños and Edmeades, 1996). They also demonstrate the degree to which drought or low N stressed a crop. If observed before or at flowering, they can be used for selecting desirable parents for crossing.

Chapman and Edmeades (1999) looked at selection for drought tolerance in tropical maize populations; particularly they were concerned with direct and correlated responses among secondary traits. Maize populations were selected with an index of traits that included the primary trait, grain yield. Relative contribution to the index of grain yield (GY) was twice that for anthesis silking interval (ASI), ears per plant (EPP), and anthesis date (AD) and three to four times that for other secondary traits. Secondary traits chosen for the index were thought to improve performance in water-limited environments. They pointed out that an ideal secondary trait should be genetically associated with grain yield under stress, carry no yield penalty under favorable conditions, be heritable, cheap and rapid to measure, stable over the measurement period, and be able to be observed at or before flowering so that undesirable parents are not crossed . The use of secondary traits with GY, rather than selection for GY alone, has been shown to increase selection efficiency by about 20% in maize grown under stress induced by low nitrogen status (Bänziger and Lafitte, 1997). Progress due to selection was evaluated in 10 environments that differed mainly in available water, and ranged in yield from 1.01 to 10.40 Mg ha^{-1}. Sixteen entries, comprised of cycles of selection and checks, were included in each environment. In five well-watered (WW) trials, irrigation was applied every 10 d if rain was insufficient. The five water-deficit trials were managed by withdrawing or delaying irrigation during flowering and grain filling. They reported that under water deficit, changes per cycle with selection ($P < 0.05$) were as follows: GY 12.6%, fertile ears per plant (EPP) 8.9%, grains per fertile ear (GPE) 6.3%, grain number per square meter 12.2%. 1000 grain weight did not change, anthesis-silking interval (ASI) -22.0%, days from sowing to 50% anthesis -0.7%, plant height -2.0%, primary tassel branch number -5.9%, and senesced leaf area 2.7%. Responses under well-watered conditions were smaller but generally of the same sign. Grain yield was strongly associated with grain number per square meter in both water-stressed and well-watered environments (r =0.96; r = 0.87 P < 0.001). Grain yield, EPP, and GPE were strongly correlated with ASI under drought (r = -0.89,-0.93, 0.90; P <0.001), though not when water was plentiful. They endorsed the use of managed stress environments that consistently reveal genetic variation for these traits at specific times during crop development for selection purposes.

Bolaños and Edmeades (1996) looked at the importance of the anthesis-silking interval and other secondary traits in breeding for drought tolerance in tropical maize. They reported on six elite maize populations adapted to lowland tropics, varying in maturity, grain color and texture. They analized data from a total of 50 trials, comprising 11 sets of S1 progenies (166 to 250 each for a total of 2489 Sl's), five sets of S2 progenies (64 to 164 each for a total of 623 S2's) and four sets of S3 progenies (46 to 135 each for a total of 397 S 3's). These were evaluated under two to three water regimes in the course of routine breeding for adaptation to drought at CIMMYT. They reported genetic correlations (r_g) between GY under severe drought stress and secondary traits. They showed a strong dependence of grain yield on (EPP) $r_g = 0.90$ and grains per ear (GPE) $r_g = 0.70$. Correlation between (GY) and weight per grain (WPG) was weak ($r_g = 0.14$). A moderately strong correlation $r_g = -0.60$ was reported between GY and ASI, while genetic correlations between GY and plant height was generally less than |0.20|. Guei and Wassom (1992) reported similar results for two of these populations and pointed out that that EPP was a measure of barrenness rather than of prolificacy.

Betrán et al. (2003) reported on secondary traits in parental inbreds and hybrids under stress and non-stress environments in tropical maize. Their objective was to estimate the general combining abilities for secondary traits and their relationship with grain in a group of tropical white inbred lines and their hybrids under stress and non-stress environments. The secondary traits measured and analyzed included, anthesis, silking ASI, plant height, ear height, root lodging, stalk lodging ears per plant, drain moisture, shelling percentage, tassel size, erect leaves, leaf rolling, senescence, chlorophyll content, root capitance, *E.turcicum* and husk cover. In terms of combining ability, they reported that general combining ability (GCA) was significant for all the secondary traits except stalk lodging. Specific combining ability (SCA) was significant for male and female flowering, ASI, plant and ear height, tassel size and erect leaves. With respect to correlation between GY and secondary traits, they showed that genetic correlations between GY and male and female flowering dates were negative in both inbreds and hybrids. ASI was also negatively correlated with GY in hybrids and inbreds across environments. Negative correlations between ASI and GY have also been found consistently in progeny evaluation trials of tropical maize under drought (Bolaños and Edmeades, 1996) and low N (Lafitte and Edmeades, 1995). This relationship maybe mediated through reduced kernel set in genotypes exhibiting delayed silk emergence. EPP was strongly correlated with GY in all the environments especially under drought stress (*r* = +0.86). Shelling percentage was positively correlated with GY both in stress and non-stress environments.

MATERIALS AND METHODS

Maize germplasm, trial management and locations

Hybrids and populations of diffetent matutities (EIHYB, ILHYB, EPOP, and ILPOP) were evaluated across a range of environments including managed stress environments in eastern and southern Africa from 1999 to 2003. Details about the maize germplasm and trial locations and management are presented in previous chapters.

Trait measured

Traits measured in this evaluation were grain yield (Mg/ha), plant height (cm), ear height (cm), anthesis-silking interval (days), ear position (cm), stalk lodging (%), and ears per plant (number). Grain yield was measured as shelled hand harvested ears and was adjusted to 12.5% moisture content. Plant height was measured in cm from the base of the plant to the top of the tassel, ear position is the distance from the base of the maize plant to the main ear bearing node. Stalk lodging is measured as number of plants which broke along the stalk divided by the total number of plants in the plot multiplied by 100.

Statistical analysis (singular value decomposition)

The relationships among traits were estimated by singular value decomposition using BIPLOT 1.1 (an Excel add-in by Lipkovich and Smith, 2002) and the results displayed in biplots (Gabriel, 1971). Small angles among vectors representing the traits indicate positive correlation and wide angles among them negative correlations. The variables were previously standardized to remove the unit effects. Data from each set of plant materials (ILPOP, EPOP, ILHYB, and EIHYB) from 2000 to 2003 were used in the analysis. This analysis was conducted across all locations for a set in a particular season, and in addition for a set across specific managed stress locations (drought, low nitrogen and low pH). Linear regression was also conducted to illustrate and confirm the relationship among traits.

RESULTS

Relationship between grain yield and anthesis-silking interval

Plant breeders and physiologists have advocated judicious incorporation of secondary traits within plant breeding programs (Blum, 1988), but very few have shown notable and useful responses under stress. ASI is one trait that that has shown significant responses under stress, especially drought and has proven to be a useful trait in selection for tolerance to stress in tropical maize. Bolaños and Edmeades (1996) reported that the only trait that registered significant change from selection was reduction in ASI under drought associated with an increased ears and kernels per plant while there was no progress was recorded in other drought adaptive traits. Figures 4.1, 4.2, 4.3 and 4.4 show the relationship between anthesis silking interval (ASI) and grain yield for early to intermediate hybrids (EIHYB), intermediate to late hybrid (ILHYB), early population (EPOP) and intermediate to late population (ILPOP) across CIMMYT regional maize trials and testing locations in eastern and southern Africa.

The results show that locations with high grain yield showed shorter ASI. Stressed locations therefore showed longer ASI. This confirms the importance of ASI as an important trait in breeding for stress tolerance and is also consistent with results reported by Betrán et al. (2003), who observed negative correlation between GY and ASI especially in stress environments. Negative correlation between ASI and GY has also been reported consistently in evaluation trials under limited water stress (Bolaños and Edmeades, 1996) and low nitrogen (Lafitte and Edmeades, 1995; and Mugo et al, 1998).

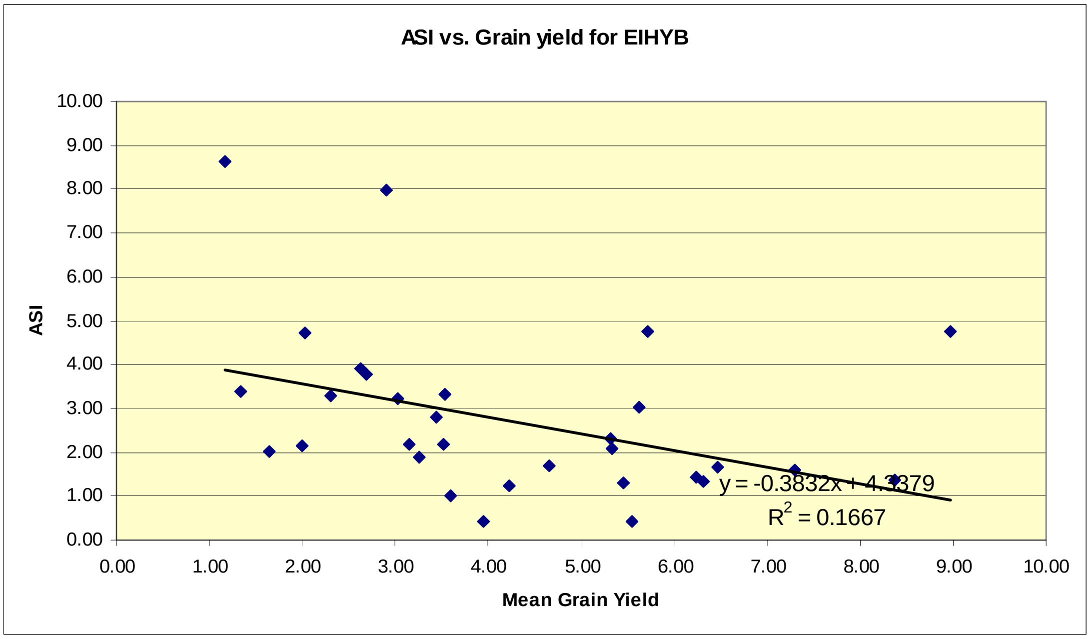

Fig. 4.1. Relationship between anthesis silking interval and grain yield in early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2001 to 2003.

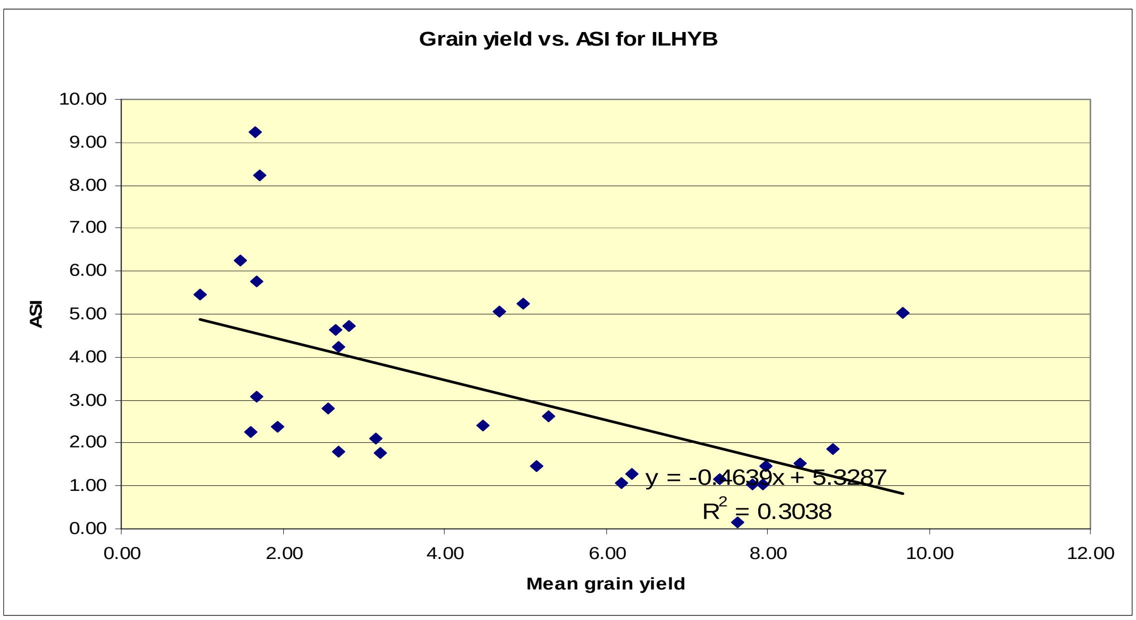

Fig. 4.2. Relationship between anthesis silking interval and grain yield in intermediate to late hybrids (ILHYB) across locations in eastern and southern Africa in 2001 to 2003.

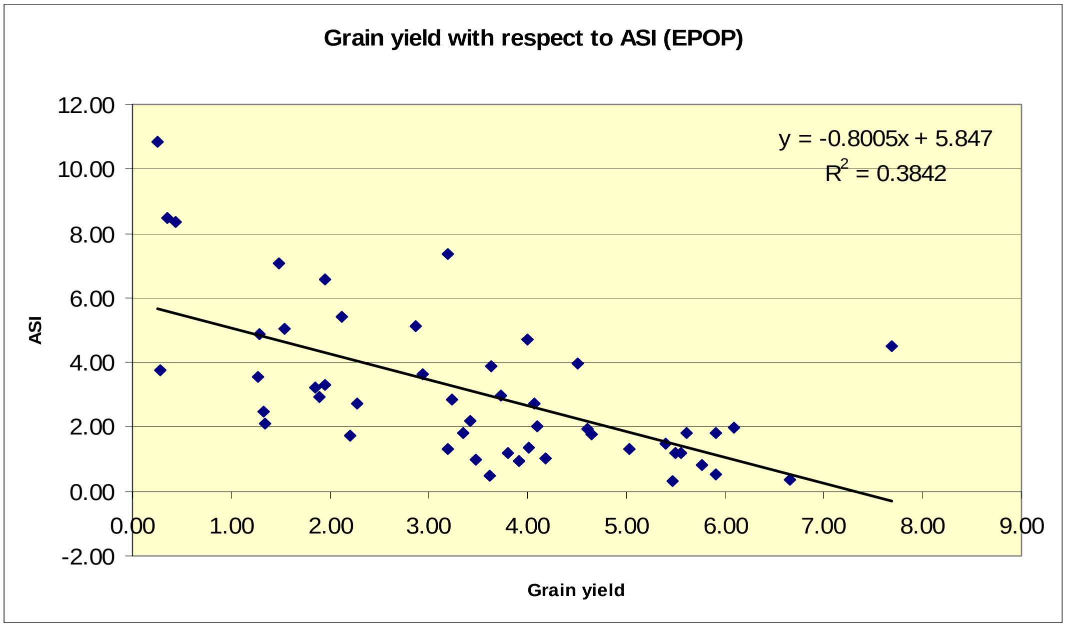

Fig. 4.3. Relationship between anthesis silking interval and grain yield in early populations (EPOP) across locations in eastern and southern Africa in 2001 to 2003.

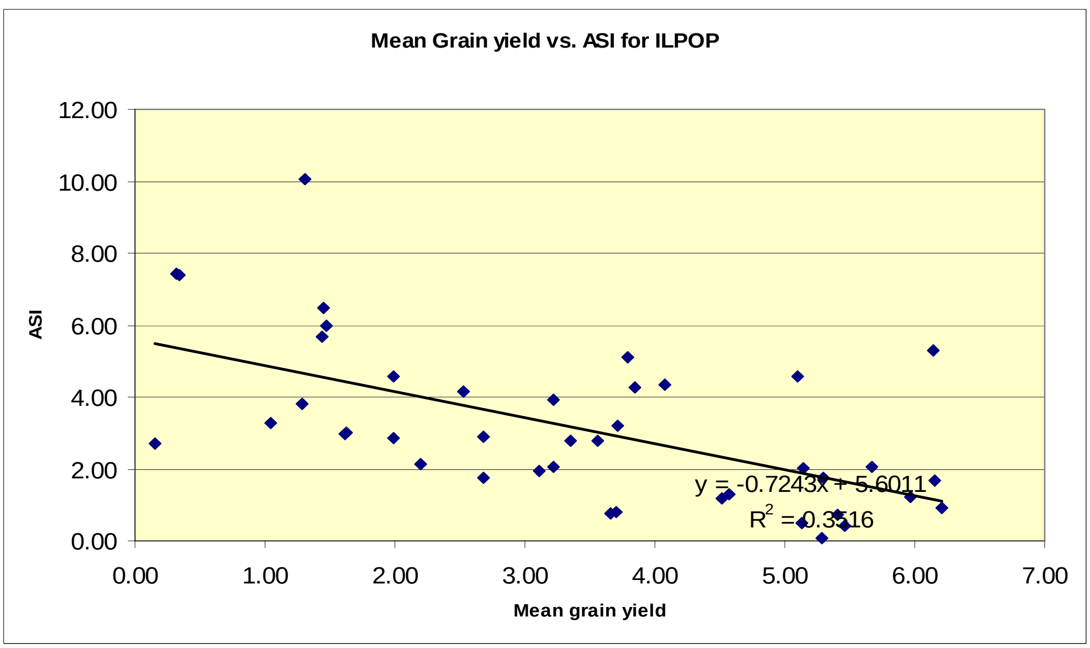

Fig. 4.4. Relationship between anthesis silking interval and grain yield in intermediate to late populations (ILPOP) across locations in eastern and southern Africa in 2001 to 2003.

Mugo et al. (1998) reported that low grain yield was associated with a large anthesis-silking interval (ASI) of 28 d in Katumani compared to an average of 18 d for all the entries in the trial. They further observed that under severe stress, time to silking were considerably increased, thus significantly increasing ASI.

The relationship of nitrogen stress and ASI was further confirmed by Singh et al. (1999). He used the average N stress effect over the reproductive period (tassel initiation to silking) in a model to modify ASI, which in turn determines the number of grains per ear. The days to silking increased from 78 to 108 as N deficiency in the plant increased, and the resultant delayed silking resulted in an increase in ASI.

Correlation between grain yield and other traits

The results showing the relationship among grain yield (GY), plant height (PH), ears per plant (EPP) ear position (EPO), anthesis silking interval (ASI) and stalk lodging (SL) are shown as biplots resulted from singular value decomposition of standardized variables. Figures 4.5, 4.6 and 4.7 show the relationship among traits across all locations within a year for early to intermediate hybrids (EIHYB) in 2000, 2001 and 2002, respectively. In 2000, there was positive and close correlation between grain yield and ears per plant (Figure 4.5). There was positive correlation between plant height and ear position. Stalk lodging was negatively correlated with plant height. Most of stalk lodging is caused by wind and the taller the maize plants the more susceptible they were to stalk lodging. Ears per plant and grain yield were negatively correlated with anthesis silking interval.

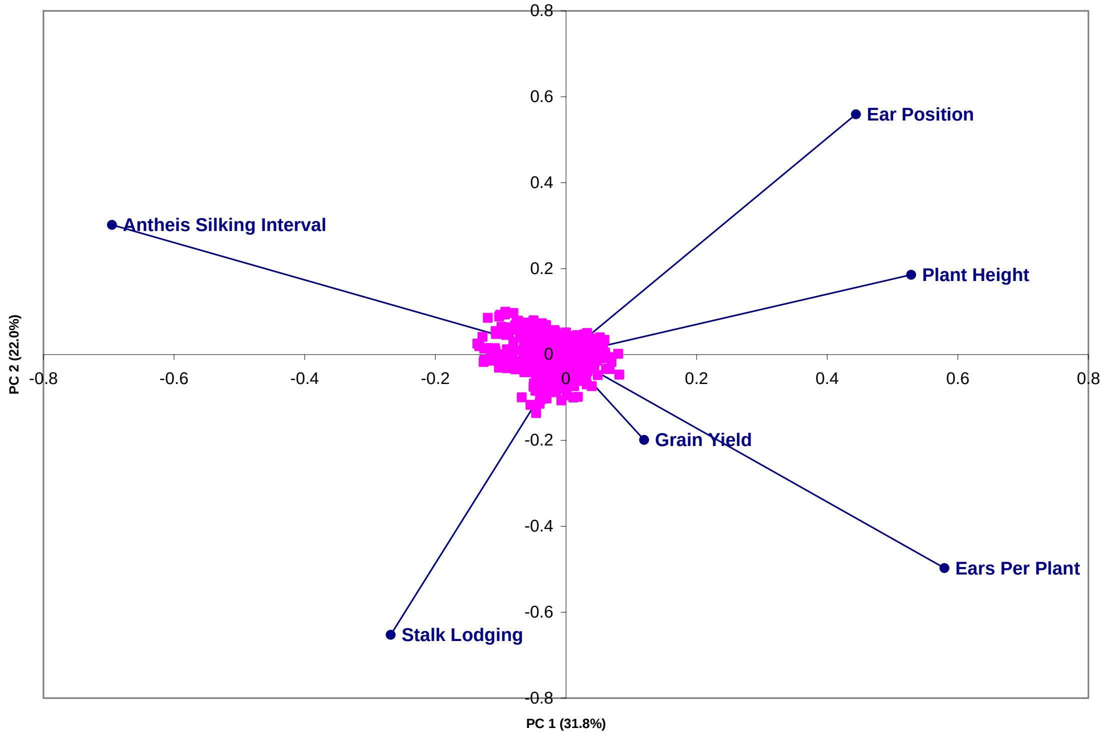

Fig. 4.5. Biplot showing the relationships among maize traits for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2000.

Correlation among traits for early to intermediate hybrids (EIHYB) in 2001 and 2002 showed identical results (Figs. 4.6 and 4.7). There was close and positive correlation among ears per plant, grain yield plant height and ear position. Anthesis silking interval was negatively correlated to ears per plant, grain yield, plant height and ear position. There was no clear relationship between stalk lodging and the rest of the traits. The traits have equidistant vectors on the biplot and this suggested that the traits had equal influences on the relationships on the biplot.

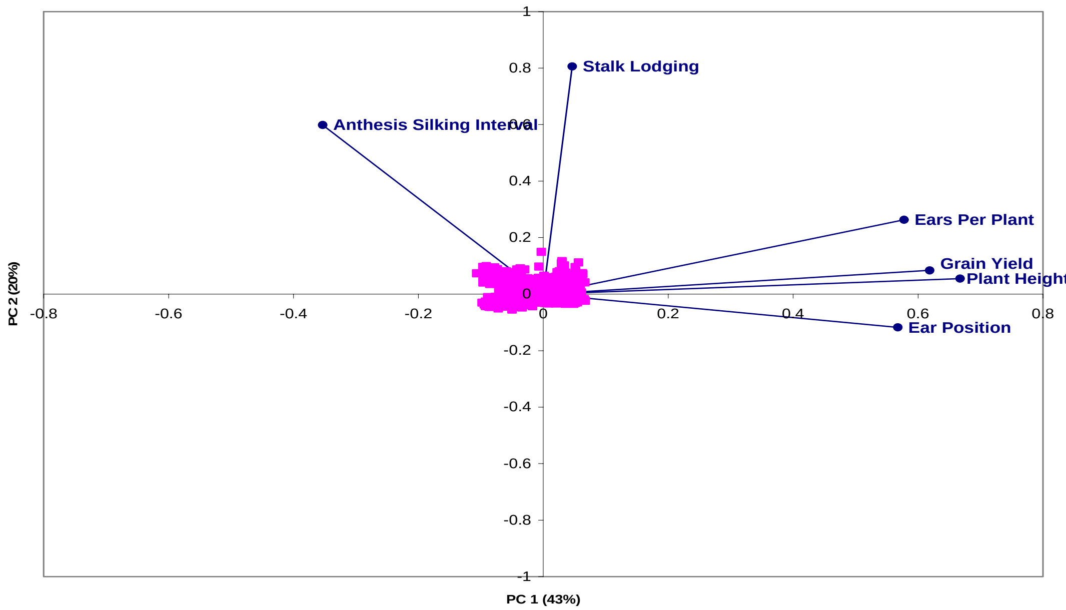

Fig. 4.6. Biplot showing the relationships among maize traits for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2001.

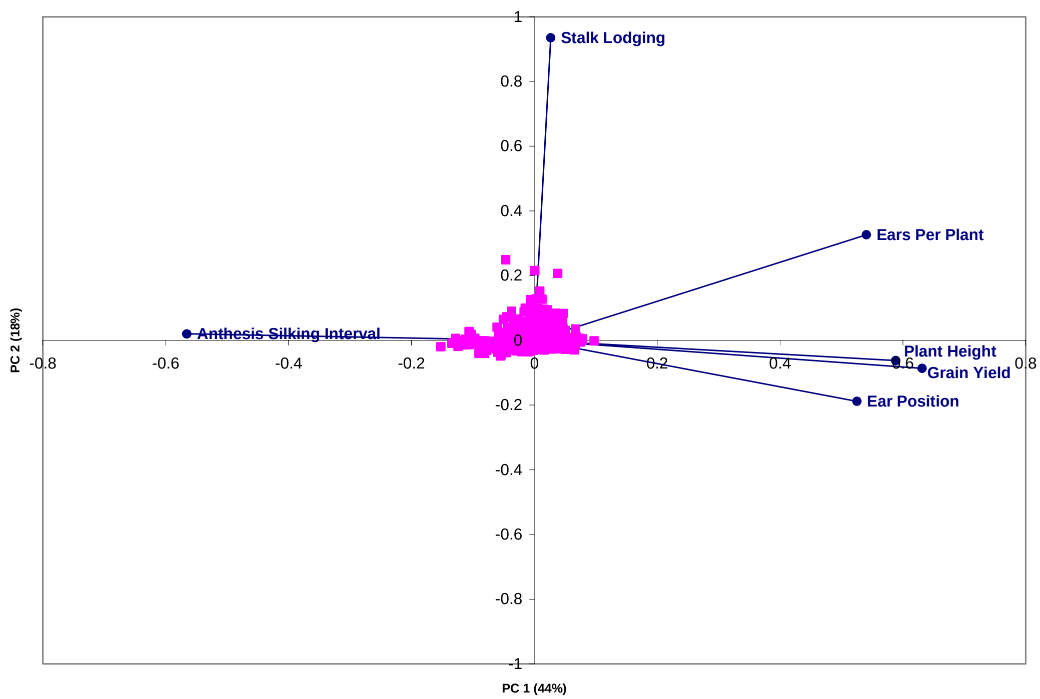

Fig. 4.7. Biplot showing the relationships among maize traits for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2002.

Relationships among traits in early to intermediate hybrids (EIHYB) under drought, low N and low pH.

The relationships among traits under stress conditions for EIHYB are presented in figures 4.8, 4.9 and 4.10 across drought, low N and low pH conditions, respectively. Under drought, there was a negative correlation between plant height and stalk lodging, although plant height had a shorter vector on the biplot (Fig 4.8). There was also a negative correlation between ears per plant and anthesis silking interval. There was positive correlation grain yield and plant height.

Under low N, there was positive correlation between grain yield, ears per plant and between plant height and ear position (Fig. 4.9). The positive correlation between stalk lodging and grain yield was surprising. There also was a negative correlation between the plant height and anthesis silking interval.

Across low pH stress locations for EIHYB, there was positive correlation among plant height, ears per plant and grain yield (Fig 4.10). Ear position was negatively correlated to anthesis silking interval.

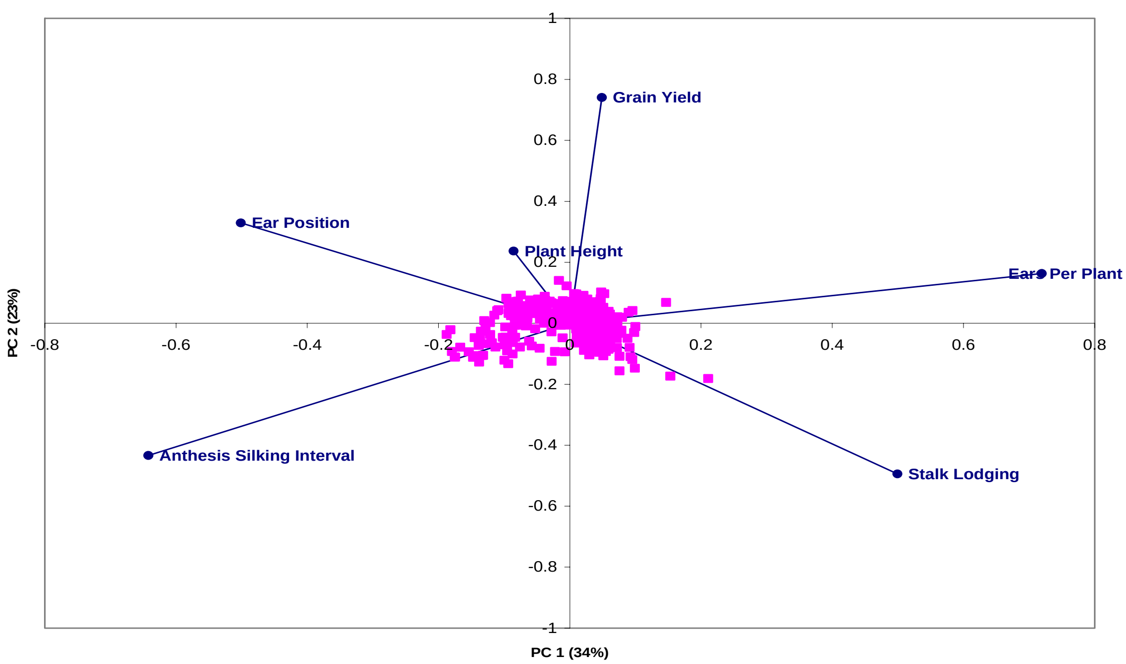

Fig. 4.8. Biplot showing the relationships among maize traits for drought locations for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2001 to 2003.

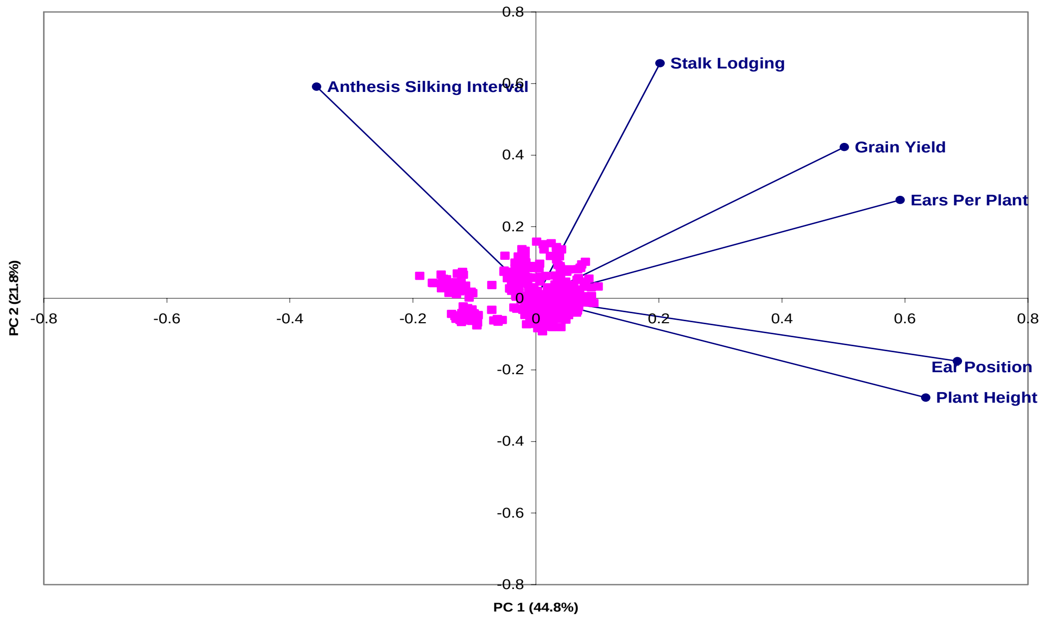

Fig. 4.9. Biplot showing the relationships among maize traits for low N locations for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2001 to 2003.

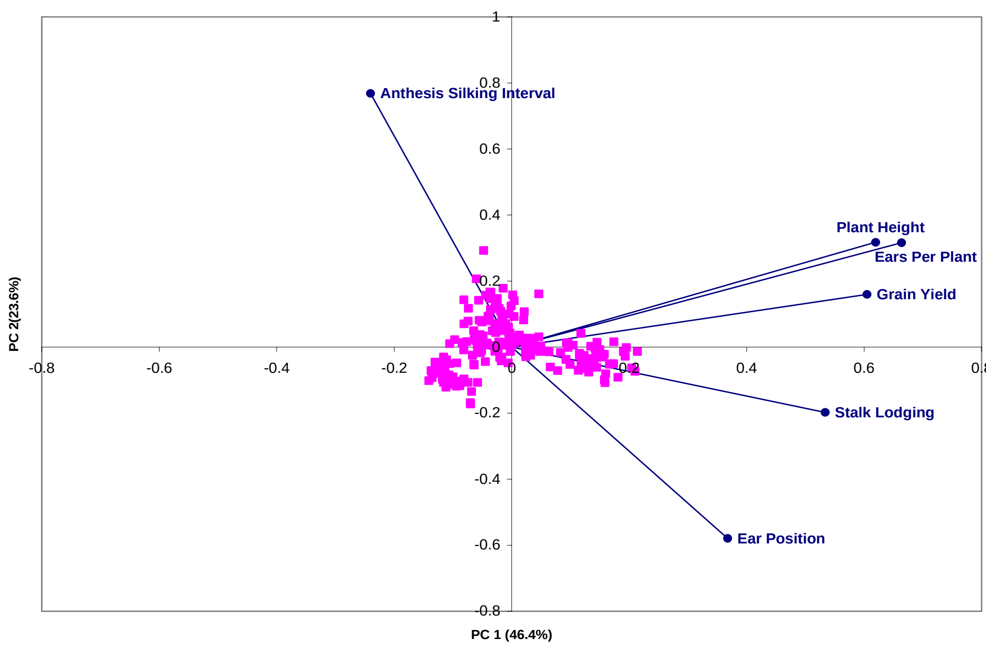

Fig. 4.10. Biplot showing the relationships among maize traits for low pH locations for early to intermediate hybrids (EIHYB) across locations in eastern and southern Africa in 2001 to 2003.

Trait relationships among intermediate to late hybrids (ILHYB)

The relationships among traits for intermediate to late hybrids (ILHYB) are presented in figures 4.11, 4.12 and 4.13 for 2000, 2001 and 2002, respectively. The analysis was across optimum locations. In 2000, anthesis-silking interval was negatively correlated to ears per plant (Fig. 4.11). There was negative correlation between stalk lodging and grain yield and positive correlation between plant height, ear position and ears per plant. In 2001, anthesis silking interval was negatively correlated to grain yield, and stalk lodging was negatively correlated with plant height (Fig. 4.12). In 2002, the trait relationships were identical to those observed in 2001 (Fig 4.13).

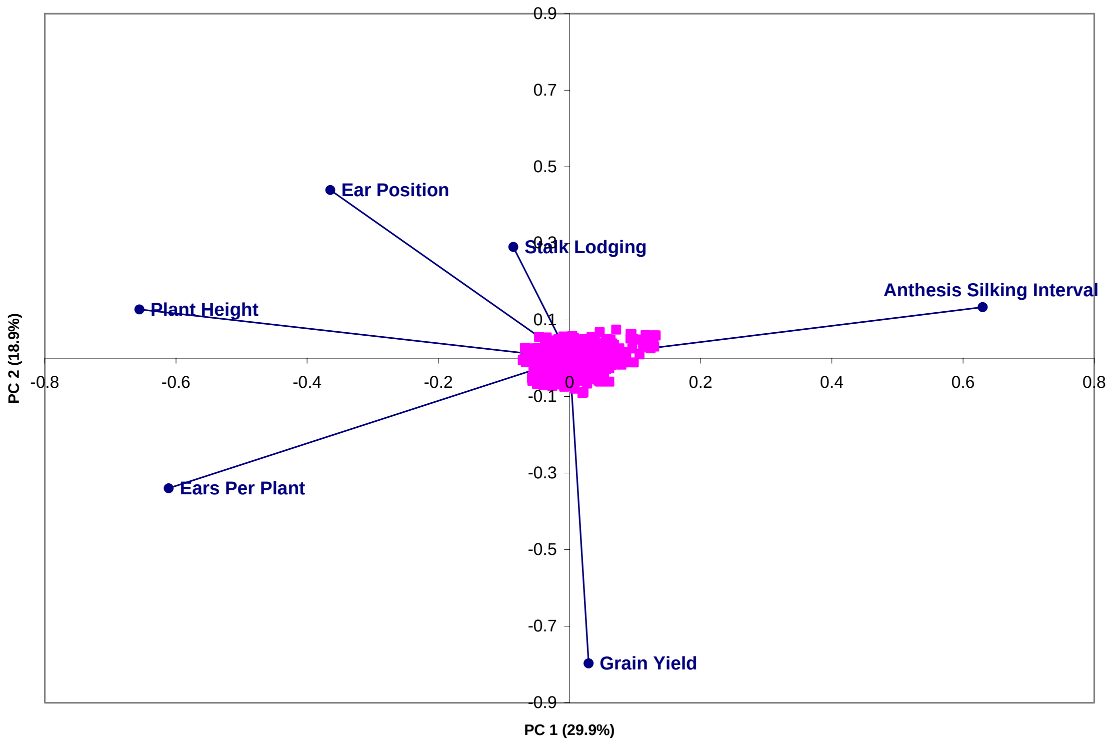

Fig. 4.11. Biplot showing the relationships among maize traits for intermediate to late hybrids (ILHYB) across optimal locations in eastern and southern Africa in 2000.

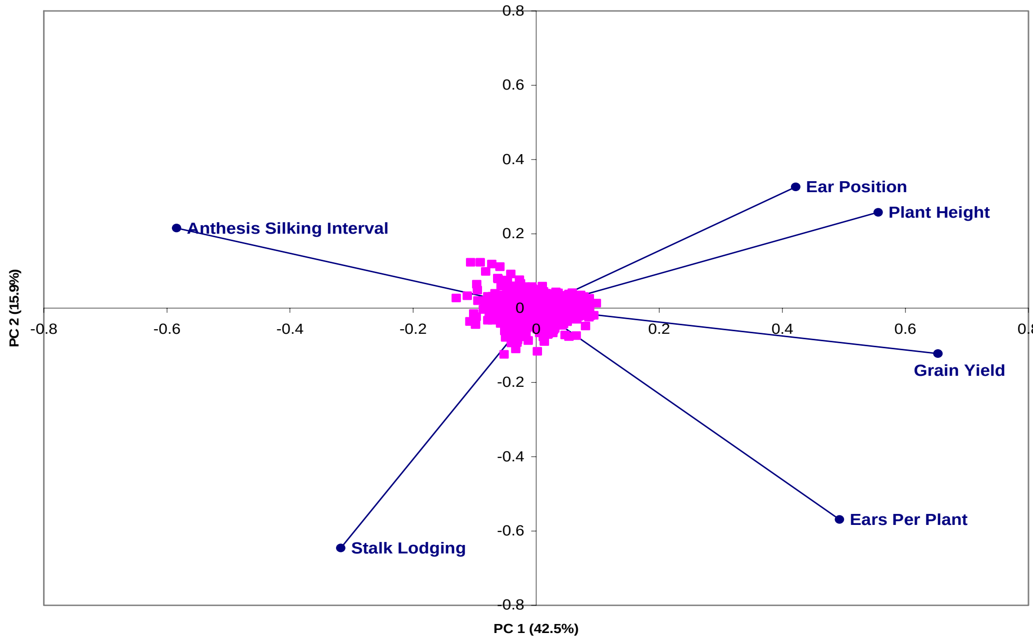

Fig. 4.12. Biplot showing the relationships among maize traits for intermediate to late hybrids (ILHYB) across optimal locations in eastern and southern Africa in 2001.

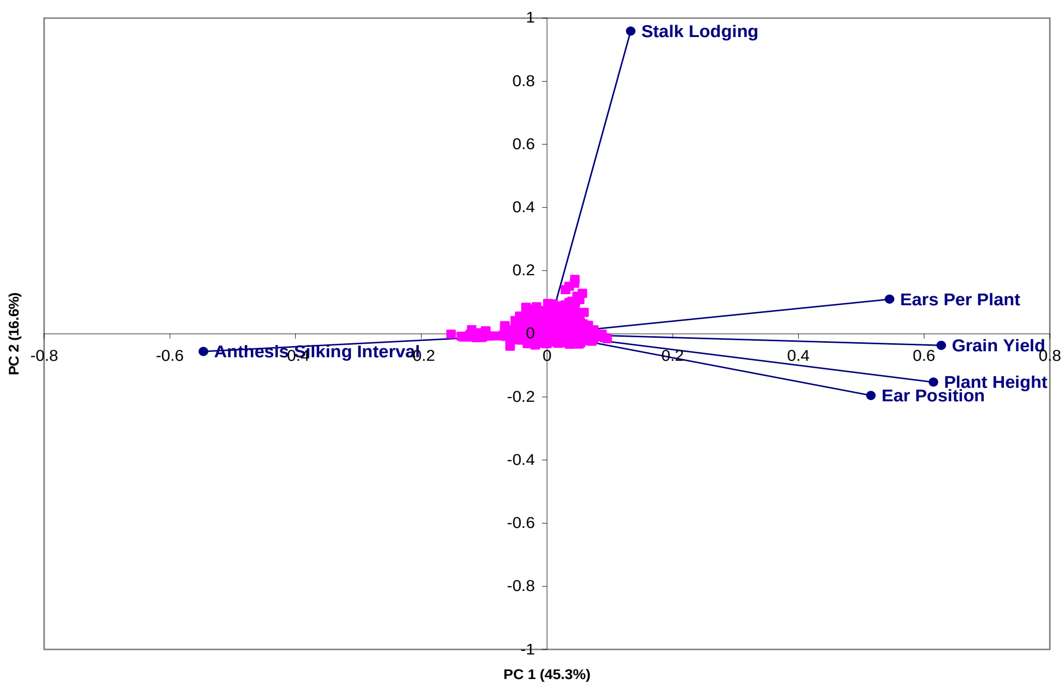

Fig. 4.13. Biplot showing the relationships among maize traits for intermediate to late hybrids (ILHYB) across optimal locations in eastern and southern Africa in 2002.

Relationships among traits in intermediate to late hybrids (ILHYB) drought, low N and low pH stress conditions.

Relationships among traits in intermediate to late hybrids (ILHYB) under stress conditions are shown in figures 4.14, 4.15 and 4.16. Across drought locations, anthesis silking interval was negatively correlated with grain yield. Stalk lodging was negatively correlated with plant height (Fig 4.14). There was a positive correlation between grain yield and ear position. Across low N and low pH conditions, there were positive correlations among plant height, ear position, grain yield and ears per plant (Fig. 4.15 and 4.16). Anthesis-silking interval was negatively correlated with grain yield, ears per plant and plant height. Stalk lodging has no specific relationship with the rest of the traits.

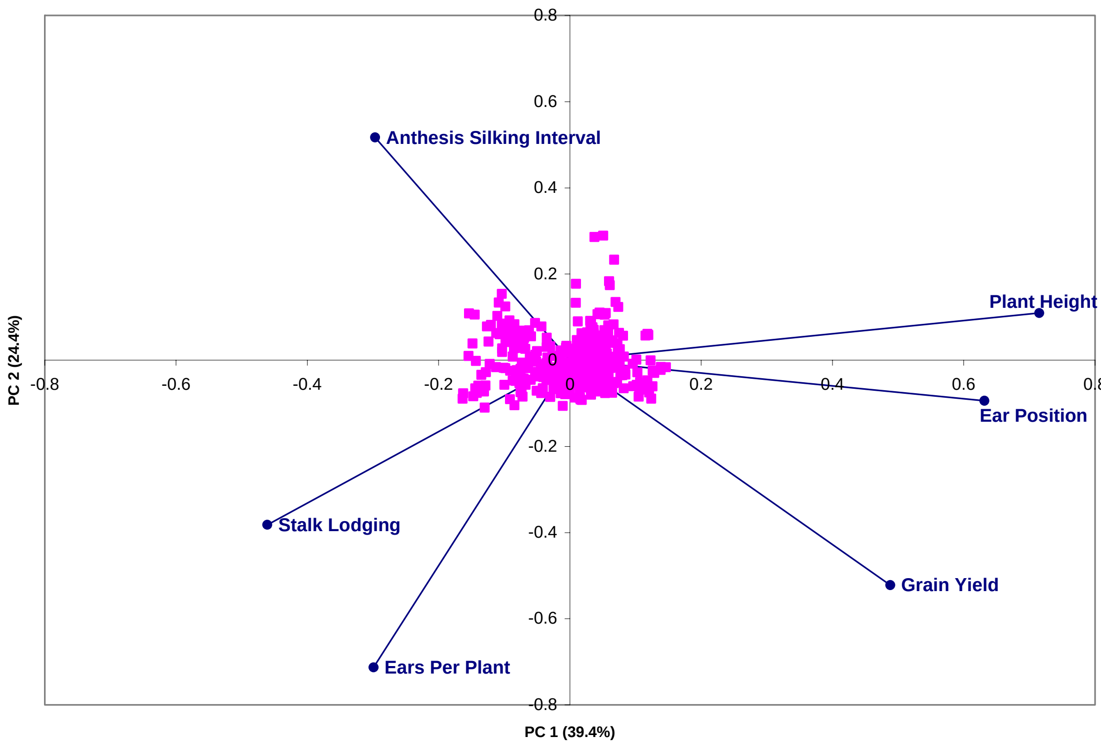

Fig. 4.14. Biplot showing the relationships among maize traits for drought locations for intermediate to late hybrids (ILHYB) in eastern and southern Africa from 2000 to 2002.

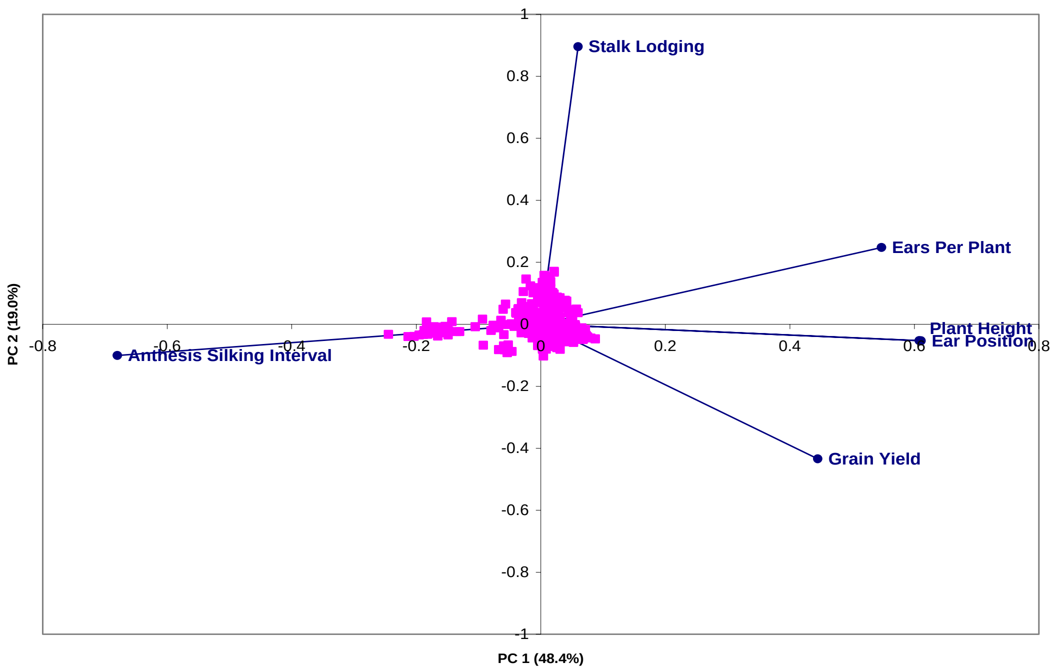

Fig. 4.15 Biplot showing the relationships among maize traits for low N locations for intermediate to late hybrids (ILHYB) in eastern and southern Africa from 2000 to 2002.

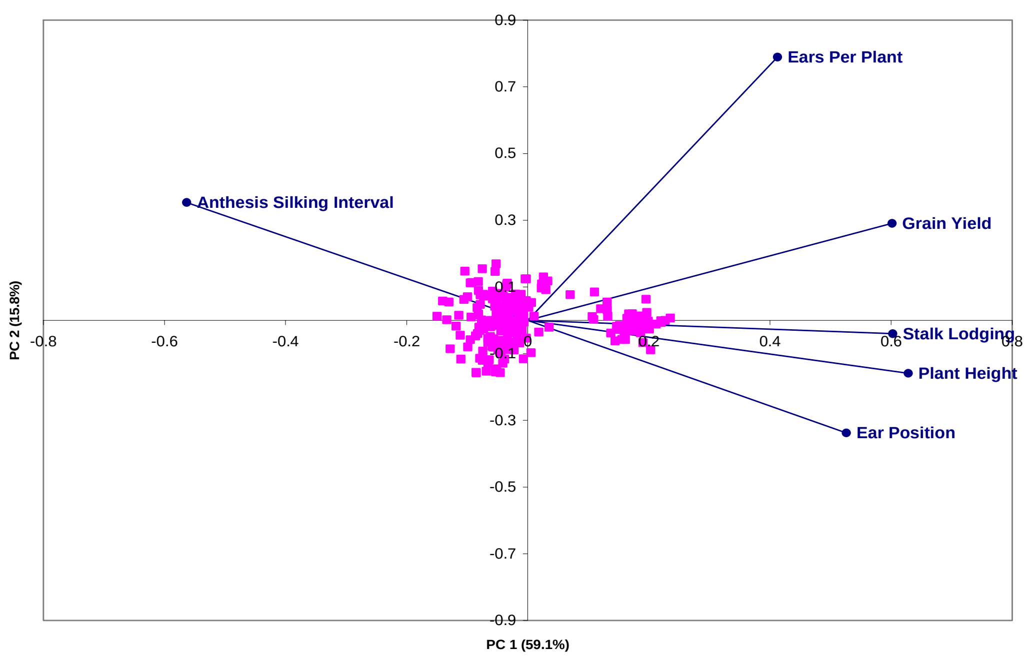

Fig. 4.16. Biplot showing the relationships among maize traits for low pH locations for intermediate to late hybrids (ILHYB) in eastern and southern Africa from 2000 to 2002.

Trait relationships in optimal locations for early populations (EPOP)

Maize trait relationships among optimum locations for early populations (EPOP) for 2000, 2001 and 2002 are shown in figures 4.17, 4.18 and 4.19. In 2000, a very short vector was observed for grain yield (Fig 4.17). This meant that grain yield had less influence on the biplot. There was positive correlation between stalk lodging, grain yield and ears per plant. Stalk lodging was negatively correlated with plant height. Anthesis-silking interval was negatively correlated with grain yield. In 2001 and 2002, the relationships among traits were identical (Figs. 4.18 and 4.19). There was strong and positive correlations between ears per plant, grain yield, plant height and ear position, and all these were negatively correlated with anthesis-silking interval. Stalk lodging was independent from all the other traits.

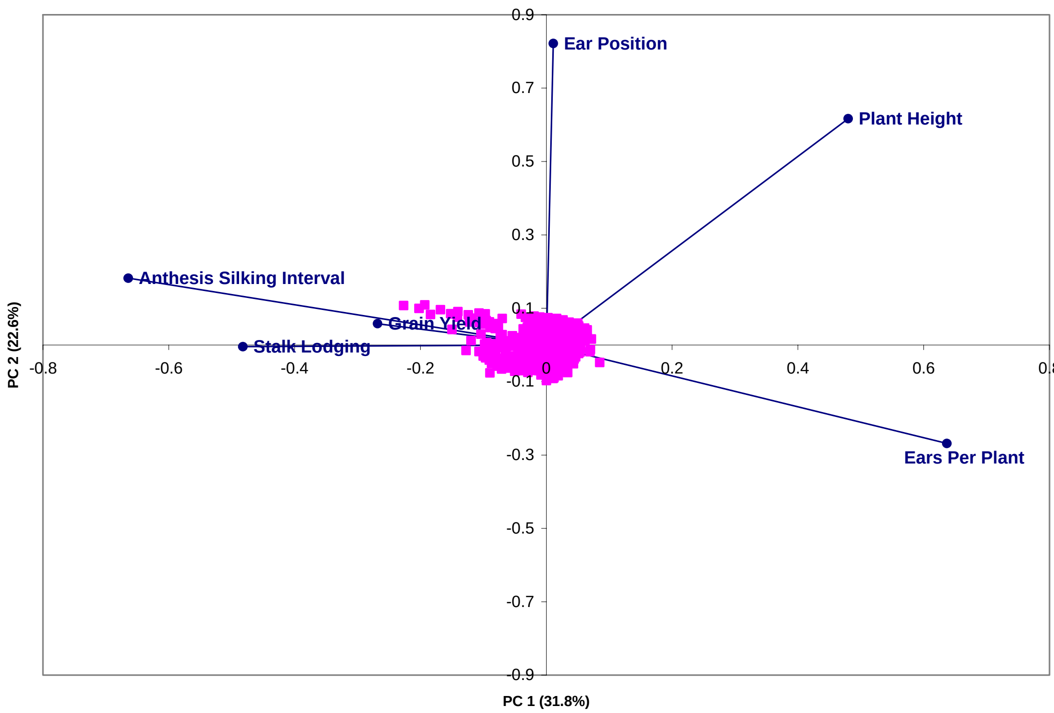

Fig. 4.17. Biplot showing the relationships among maize traits for early populations (EPOP) across optimal locations in eastern and southern Africa in 2000.

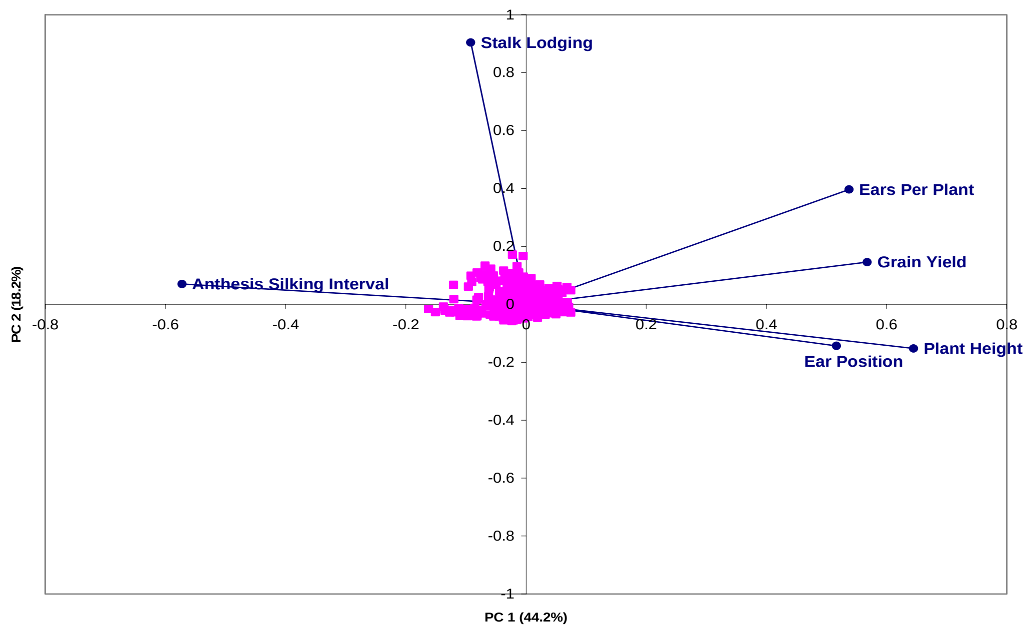

Fig. 4.18. Biplot showing the relationships among maize traits for early populations (EPOP) across optimal locations in eastern and southern Africa in 2001.

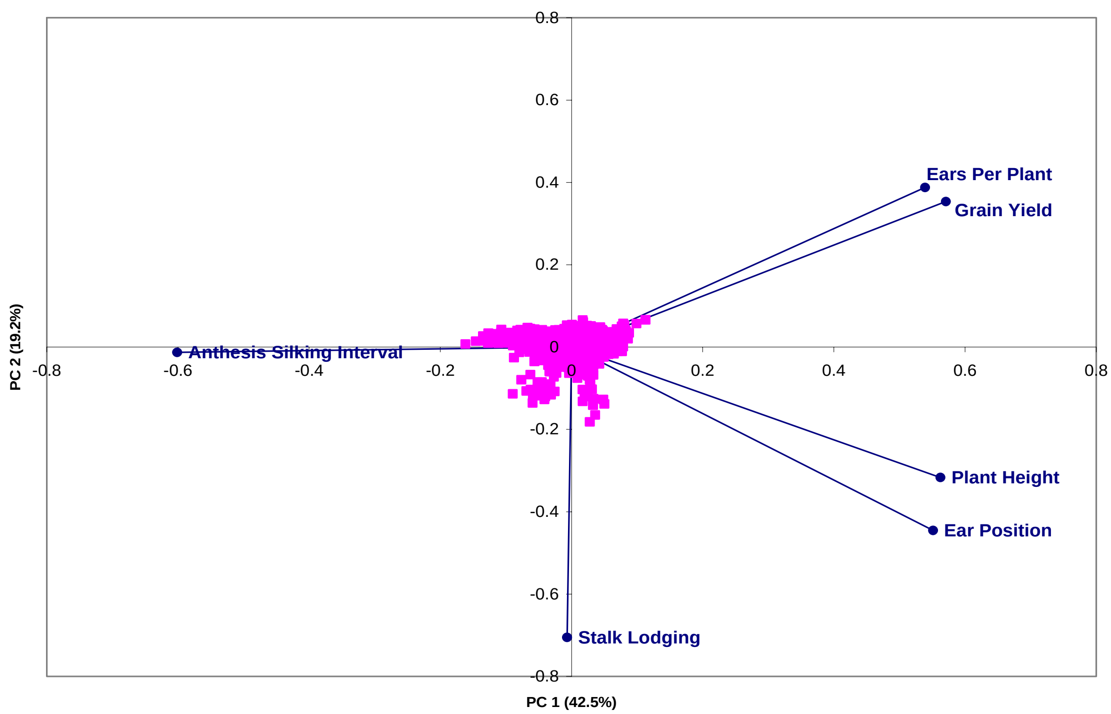

Fig. 4.19. Biplot showing the relationships among maize traits for early populations (EPOP) across optimal locations in eastern and southern Africa in 2002.

Relationships among traits in early populations (EPOP) under stress conditions

Maize trait relationships in early populations (EPOP) under stress locations are presented in figures 4.20, 4.21 and 4.22 for drought, low N and low pH, respectively. Across drought locations, there was positive correlations between ears per plant, grain yield, plant height and ear position, and all these were negatively correlated with anthesis-silking interval. Stalk lodging was negatively correlated to plant height and ear position. (Fig.4.20). Under low N conditions, there were positive correlations between ears per plant, plant height, grain yield and ear position. All these traits were negatively correlated to anthesis-silking interval. Stalk lodging was not correlated to the other traits (Fig 4.21). These results were identical to those obtained for EPOP across low pH locations (Fig. 4.22).

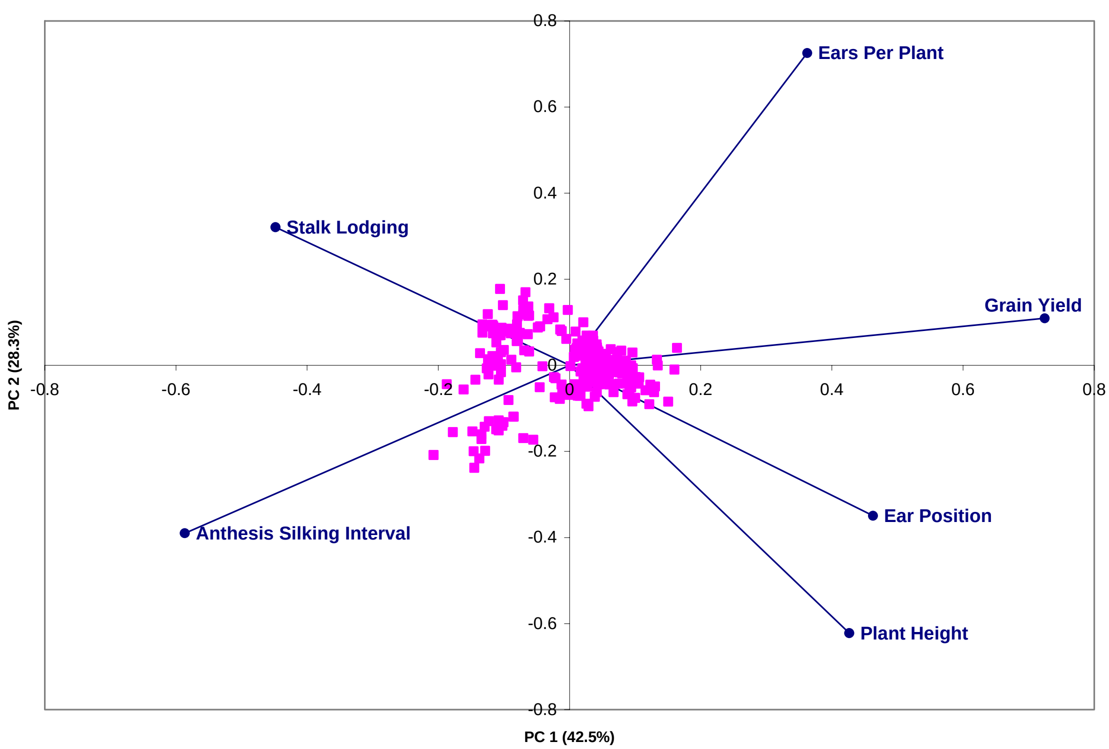

Fig. 4.20. Biplot showing the relationships among maize traits under drought locations in eastern and southern Africa for early populations (EPOP) in from 2000 to 2002.

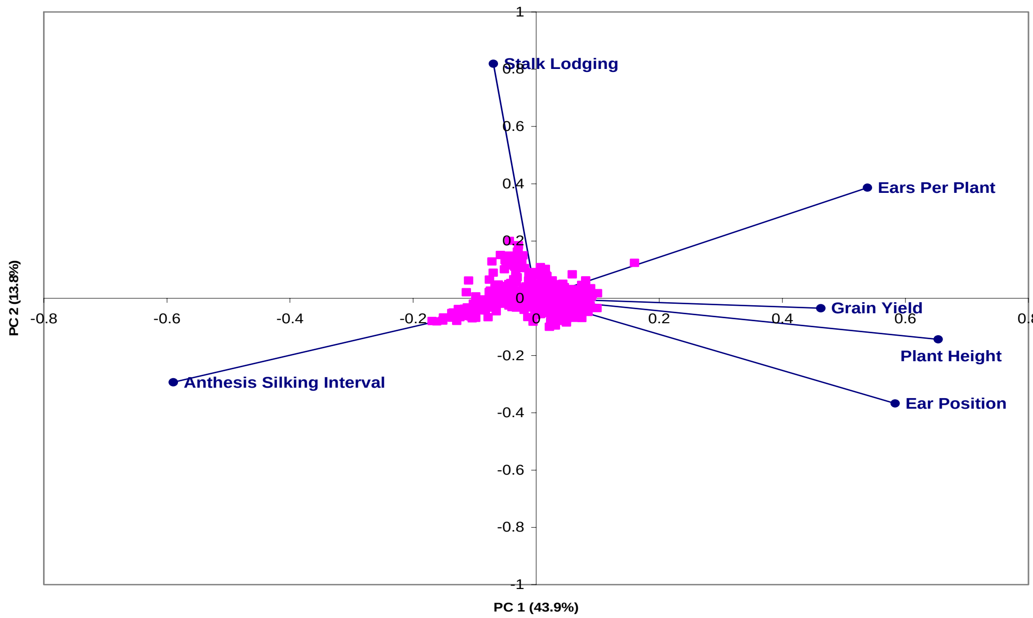

Fig. 4.21. Biplot showing the relationships among maize traits under low N locations in eastern and southern Africa for early populations (EPOP) in from 2000 to 2002.

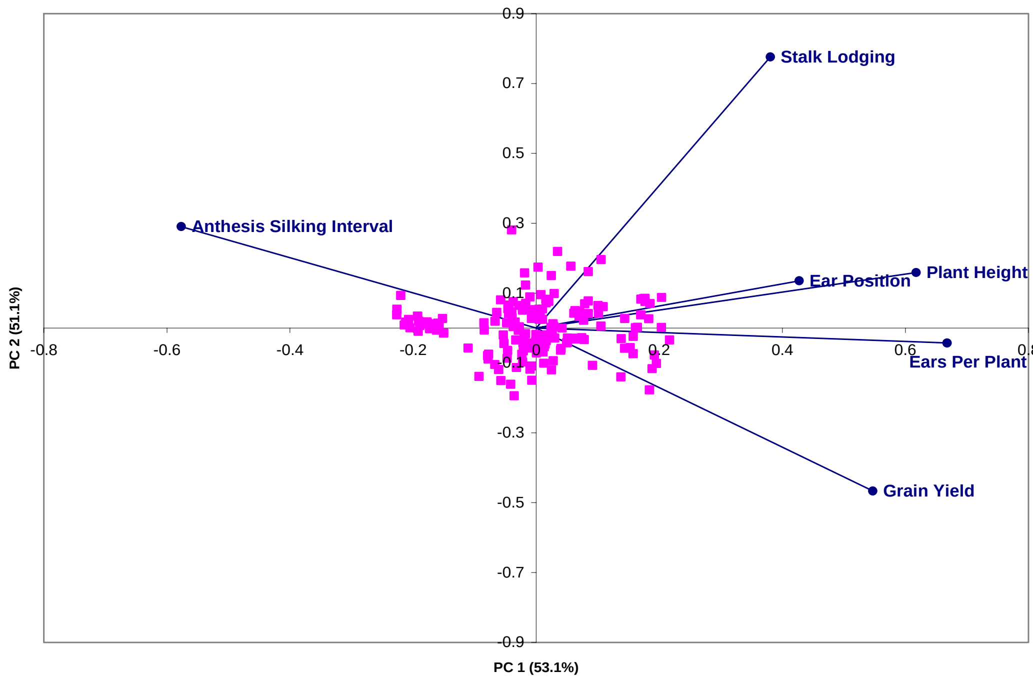

Fig. 4.22. Biplot showing the relationships among maize traits under low pH locations in eastern and southern Africa for early populations (EPOP) in from 2000 to 2002.

Trait relationships in optimal locations for intermediate to late populations (ILPOP)

Maize trait relationships in optimal locations for intermediate to late populations (EPOP) are presented in figures 4.23, 4.24 and 4.25 for 2000, 2001 and 2002, respectively. In 2000, plant height was negatively correlated with stalk lodging (Fig 4.24). Grain yield was positively correlated to ear position, but these were negatively correlated to ears per plant. The results were identical for ILPOP across optimum locations for 2001 and 2002 (Figs. 4.24 and 4.25). There was positive correlation between ears per plant, plant height, and grain yield and ear position, with EPP correlated positively to grain yield and ear position positively correlated to plant height. All these traits were negatively correlated to anthesis-silking interval.

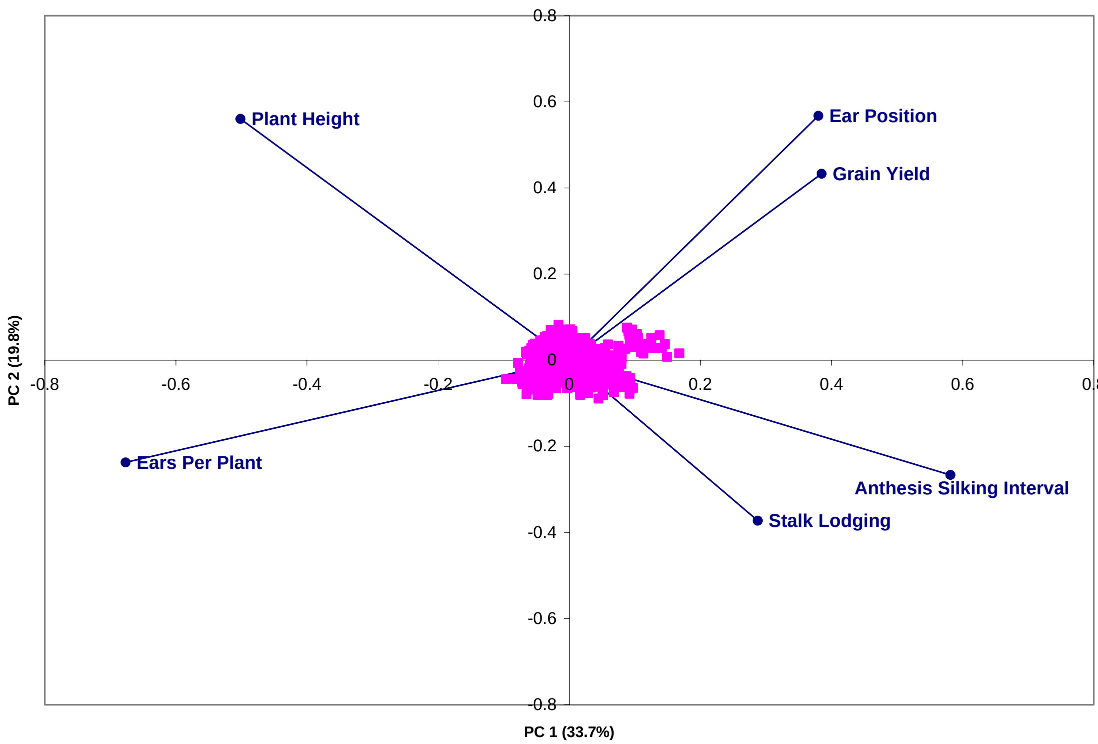

Fig. 4.23. Biplot showing the relationships among maize traits for intermediate to late population (ILPOP) under optimal locations in eastern and southern Africa in 2000.

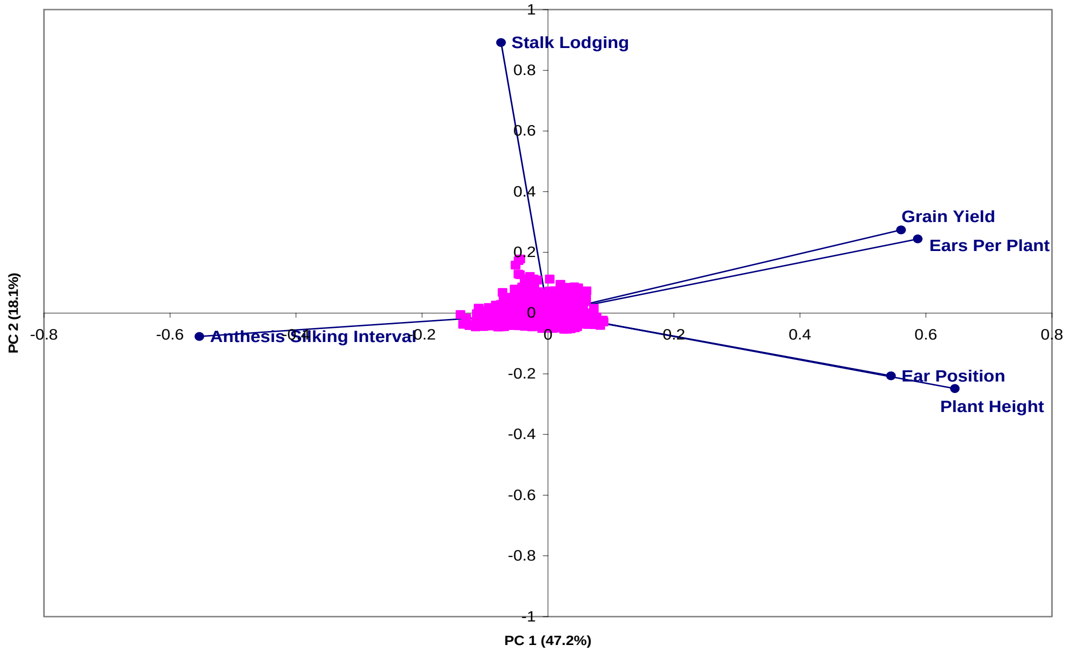

Fig. 4.24. Biplot showing the relationships among maize traits for intermediate to late population (ILPOP) under optimal locations in eastern and southern Africa in 2001.

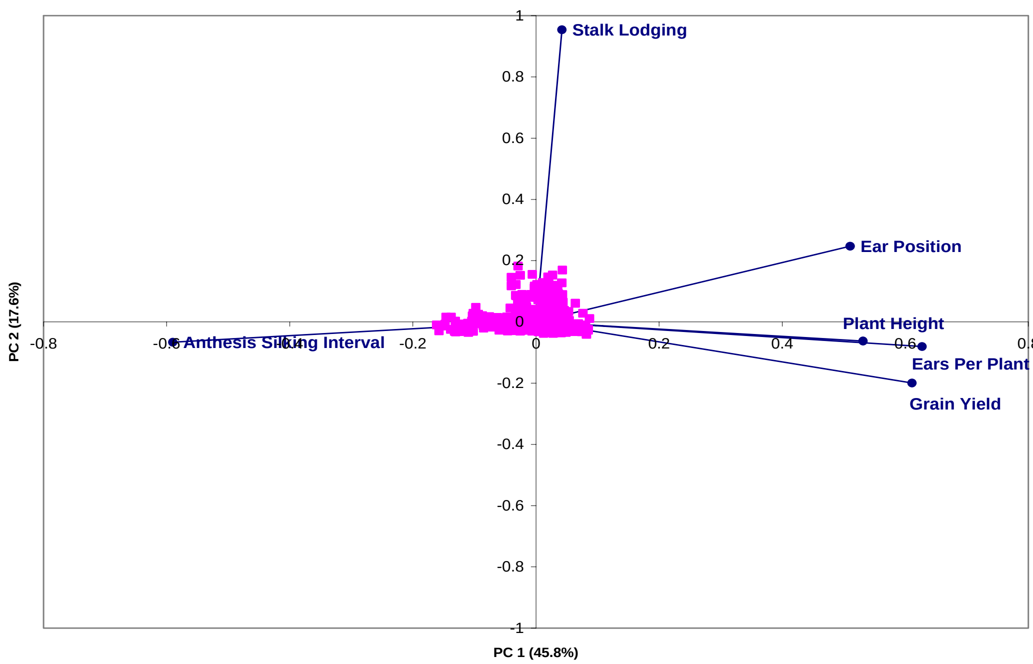

Fig. 4.25. Biplot showing the relationships among maize traits for intermediate to late population (ILPOP) under optimal locations in eastern and southern Africa in 2002.

Relationships among traits in intermediate to late populations (ILPOP) under drought, low N and low pH conditions

Maize traits relationships in intermediate to late populations (ILPOP) under stress conditions are presented in figures 4.26, 4.27 and 4.26 for drought, low N and low pH, respectively. Across drought locations, ears per plant was negatively correlated with anthesis-silking interval (Fig. 4.26). Grain yield was negatively correlated to plant height and positively correlated to ear position and stalk lodging. Relationships among traits under low N (Fig. 4.27) and low pH (Fig. 4.28) are essentially identical. There was positive correlation between ears per plant, plant height, and grain yield and ear position, with ears per plant strongly correlated positively to grain yield, and ear position strongly correlated to plant height. All these traits were negatively correlated to anthesis-silking interval.

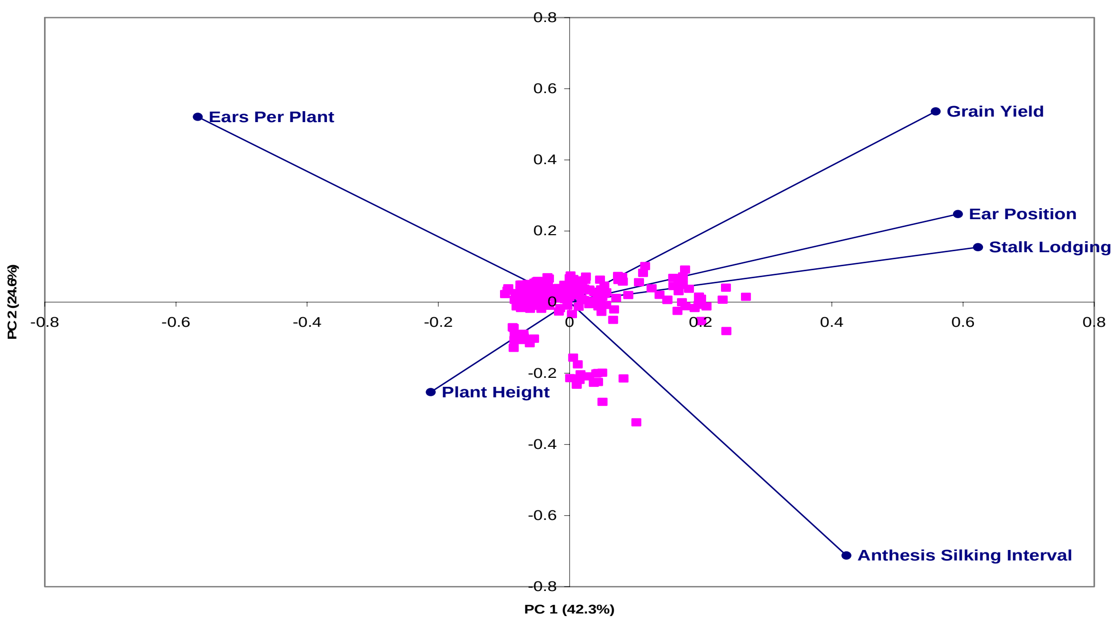

Fig. 4.26. Biplot showing the relationships among maize traits under drought in eastern and southern Africa locations for intermediate to late populations (ILPOP) from 2000 to 2002.

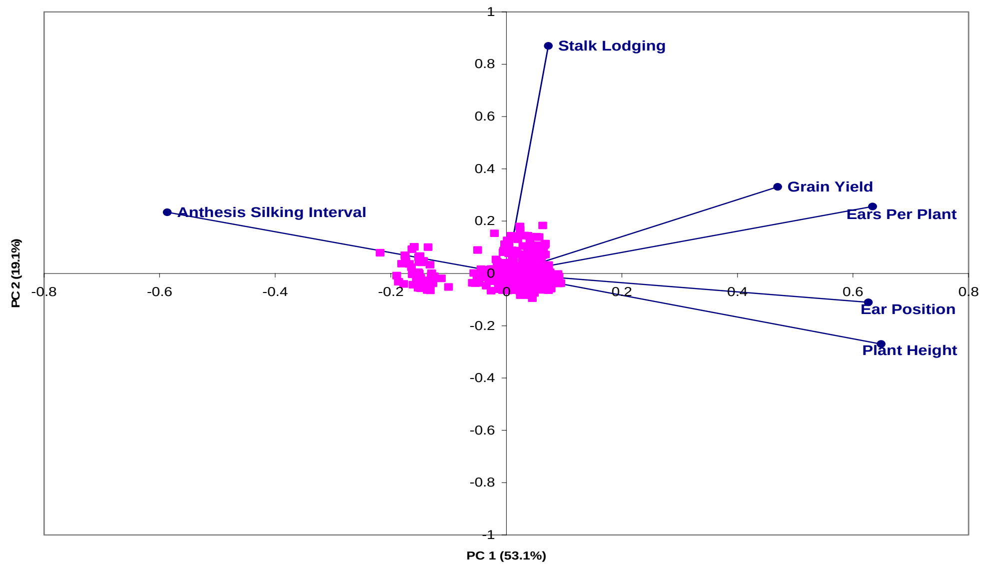

Fig. 4.27. Biplot showing the relationships among maize traits under low N locations in eastern and southern Africa for intermediate to late populations (ILPOP) from 2000 to 2002.

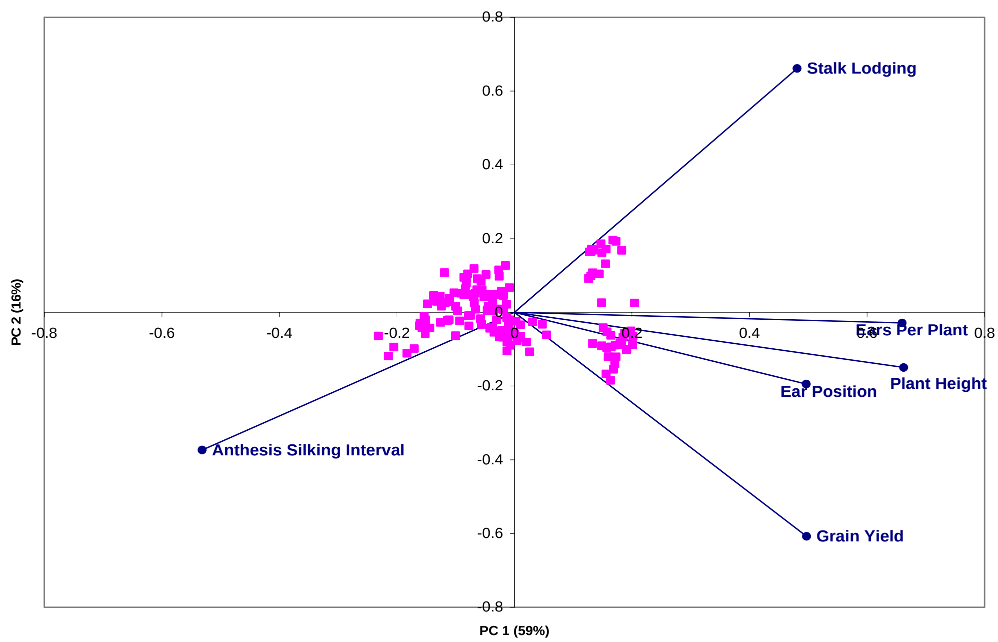

Fig. 4.28. Biplot showing the relationships among maize traits under low pH locations in eastern and southern Africa for intermediate to late populations (ILPOP) from 2000 to 2002.

DISCUSSION AND SUMMARY

The traits included in the evaluation were basically, reproductive traits. Hybrids (EIHYB and ILHYB) were analyzed separately from the open pollinated varieties (EPOP and ILPOP). The stress factors considered, drought, low N and low pH, might have affected plant growth in a similar manner. Chapman and Edmeades (1999) and Bänziger et al. (1999) analyzed the impact of drought and low N on gains from selection in some maize population. They reported similar gains, and therefore, suggested that common mechanisms were responsible for increased partitioning of assimilates to the developing ear and for increased yields under both types of stress. This perception is reinforced by findings of Andrade et al. (2002) who found that a common curve described the response of kernel number to crop growth rate around flowering whether the crop was stressed by inadequate water or by nitrogen deficiency. Other stress factor low pH or soil acidity may be independent or may be linked with low N and drought. Fan and Neumann (2004) reported that apoplastic pH is altered by drought. This assertion however must be noted with caution because there could be other stress factors, which may have less impact on productivity than others may as reported by Monneveux et al. (2005), who showed that high plant density affected plant growth differently from drought or low N.

In all the trials, both hybrids and open pollinated varieties, anthesis-silking interval was negatively correlated with grain yield. While the correlations among ears per plant (EPP), grain yield (GY), and anthesis-silking interval (ASI) under stress conditions have been demonstrated previously (Fischer et al., 1989; Bolaños and Edmeades, 1996), there was need and of real interest to examine this relationships using pre-released materials of hybrids and OPVs meant for production in eastern and southern Africa. The number and the diversity of locations, the large number of plant materials evaluated, and the managed stresses provided a unique opportunity to evaluate the relationship between traits under different conditions. Stress locations showed less grain yield and higher ASI than non-stress locations. Simple linear correlation coefficients (*r)* between grain yield and anthesis silking interval were -0.41, -0.55, -0.61, and -0.59 for EIHYB, ILHYB, EPOP, and ILPOP plant material across locations, respectively. Monneveux et al. (2006) reported that anthesis-silking interval is an easily observed external indicator of ear growth rate and hence partitioning and is a reasonably reliable predictor of grain yield under stress. It was highly negatively correlated with ear weight (r = –0.52) and final grain yield (r = –

0.53) across stress levels. Bänziger et al. (2000) also reported that anthesis silking interval was one of the secondary traits useful in drought-prone environments.

Relationships among additional traits were similar in all the tests. Results on 2000 showed some inconsistencies and that may be attributed to the quality of the season and trials' management. The traits evaluated were grain yield (GY), anthesis-silking interval (ASI), plant height (PH), ear position (EPO), ears per plant (EPP) and stalk lodging (SL). The consistent correlation trend was that grain yield was positively correlated with plant height, ear position, and ears per plant. Grain yield was strongly correlated to ears per plant, and ear position was strongly correlated to plant height. Although stalk lodging was negatively correlated to plant height in some sets, it was independent from other traits in other sets.

CHAPTER V

YIELD STABILITY OF HYBRIDS AND POPULATIONS IN MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

INTRODUCTION

Maize (*Zea mays* L.), in eastern and southern Africa, is mostly grown by subsistence farmers who are working in extremely difficult maize production environments. These farmers have little grain to spare for the market after meeting their families' needs, and so most lack the means of investing heavily in irrigation, fertilizer, pesticides, and other modern means of coping with the production constraints of diseases, insect pests, and the vagaries of nature (weather). Nor do those farmers have a strong incentive for making such an investment, since many do not grow the high-yielding, input-responsive maize varieties that would enable them to take maximum advantage of purchased inputs and better management practices.

Although improved tropical maize is now widely available in the region, the high grain yield potential of such material is often one of the less important considerations that enter into a small-scale farmer's decision about a variety. Other factors come into consideration when it comes to deciding what type of material to use. These may include grain color, cooking quality, taste, milling properties, ease of shelling and shelling percentage, forage yield, and resistance to ear rots and insect pests, both while the ear is on the plant and later in storage. Subsistence farmers are also interested in reduced variability of grain yield. Characteristics that contribute to greater stability include tolerance to water stress extreme plant densities, and resistance to diseases and insect pests. The CIMMYT Maize Program is attempting to satisfy many of these requirements in addition to improving grain yield. Other approaches being followed to improve yield stability include improvement of drought and greater nitrogen fertilizer use efficiency.

Stability can be assessed in a number of ways, one of the more common being a regression of genotypic performance on an environmental index. In general, the environmental index is nothing more than the deviation the mean phenotype at environment *j* from the overall mean phenotype of all environments. Thus, the phenotype of an individual genotype within each environment is regressed on the environmental index to generate a slope (b-value) for each genotype/cultivar being evaluated.

Stability can then be determined based on this regression. This approach has several limitations: stability of any sort depends on the locations and the genotypes included in the experiment. A genotype that is stable in one set of environments may not be in another; similarly, a stable genotype may not be stable if evaluated with a different set of other genotypes.

Sources of yield instability can be classified as spatial, temporal, and system dependent. Spatial variability results when a cultivar is grown at different locations. Location-specific environmental factors, such as soil type, general climate, endemic diseases, and pests, will vary from one location to another and will cause yield variability. These characteristics tend to be distinctively different between geographically separate locations and, hence, of a predictable nature (Allard and Bradshaw, 1964). This predictability enables plant breeders to target their research on specific environmental factors.

Temporal variability occurs when a given cultivar is grown over a number of seasons. The environmental factors contributing to this kind of variability tend to fluctuate from one year to the next (such as the amount and distribution of precipitation) and are thus less predictable. In general, this source of variation cannot be integrated as well into the plant breeding process.

System-dependent variability occurs when a given cultivar is grown under different farming systems. The factors contributing to this type of variation include the various aspects of the production process controlled by farmers: crop rotations, levels of mechanization and irrigation, and the amounts and types of fertilizer, herbicides, insecticides, and fungicides applied to the crop. All these factors can result in yield variability from one farming system to the next, but they can also decrease variability by modifying the natural environment. From a plant-breeding point of view, and within the constraints imposed by the availability of production inputs, system-dependent variability is largely predictable. The three sources of variation described above tend to be interdependent.

CIMMYT has been involved in developing and dissemination of improved maize germplasm to the region since 1975. In recent years the germplasm development process has involved conducting regional trials in scores of locations throughout the region. These locations vary quite considerably in terms maize growing conditions; physical and in terms of management. The trials are planned to capture some of the maize production constraints facing farmers in the region. These are drought, low N and low pH or soil acidity. Hundreds of materials are therefore evaluated every year in these regional trials, and are divided into hybrids, early to intermediate (EIHYB) and intermediate to late (ILHYB), and open pollinated populations, early populations (EPOP) and intermediate to late populations (ILPOP). CIMMYT recognizes the need for stable materials and that is one of the reasons the maize program conducts multilocation trials that are expected to improve the selection process for high yielding, tolerance to biotic and abiotic factors and thus improve yield stability. Specific analysis for stability of materials in the regional trials has not been conducted. This study was done to assess yield stability of materials in CIMMYT regional trials in eastern and southern Africa from 1999 to 2003.

REVIEW OF LITERATURE

The literature contains several methods for estimating stability of phenotypes across environments. There are parametric and non parametric methods that can be used in estimating stability. Parametric methods have been discussed by among others, Yates and Cochran (1938), Finlay and Wilkinson (1963), Eberhart and Russell (1966), and Lin et al. (1986).

Lin et al. (1986) reviewed and reported on nine stability statistics that have been used, other quite frequently and others very rarely. He was able to show that the nine stability statistics were derived from two components of the two way classification of the data: (1) the variance of a genotype across environment (S^2_i); (2) coefficient of variation of each genotype (CV_i) (Francis and Krannenberg, 1978); (3) the mean variance component for pairwise genotype x environment interaction (θi) (Plaisted and Peterson, 1959); (4) Plaisted's (1960) variance components for the GE interaction ($\theta_{(i)}$),where one genotype (*i*) is deleted from the entire set of data and the GE interaction variance from this subset is the stability index for genotype *i*; (5) Wricke's (1962) ecovalence (W^2_i) where the GE interaction for genotype *i* squared and summed across all the locations is the stability measure for genotype *i;* (6) Shukla's (1972) stability variance (σ^2_i) based on the residuals in a two-way classification, and the variance of a genotype across locations the measure of stability; (7) Finlay and Wilkinson's (1963) regression coefficient (*bi)*, where the observed values are regressed on environmental indeces defined as the difference between the marginal mean of the environments and the overall mean (if $b=0$ the genotype is stable); (8) Perkins and Jinks' (1968) regression coefficient (β_i), which is similar to (7) except that the observed values are adjusted for location effects before the regression; (9) Eberhart and Russell's (1966) deviation parameter, where the residual mean square of deviation from the regression defined in (7) is the measure of stability for the genotype.

The linear model proposed by Eberhart and Russell (1966) for joint regression analysis is as follows:

$Pij = \mu + gi + bi\ tj + \delta ij + eij$

where,

Pij is the mean phenotype of genotype or cultivar *i* in location *j*,

μ: is the grand mean across the whole experiment for all genotypes and locations,

gi is the effect of genotype *i* across all locations,

bi is the linear regression of *Pij* on *tj*,

tj is the environmental index (i.e., the effect of environment *j* across all genotypes),

δij is the deviation of *Pij* from the linear regression value for a given *tj*, and

eij is the within environment error.

Lin et al. (1986) and Bernardo (2002) reported three types of stability as follows:

Type I stability refers to a variety that performs equally well in all environments, i.e., its among environments variance is small. This is equivalent to the term *homeostasis*. Ideally, a known quantity such that we will always get the same yield year after year in all adapted locations would desirable. This is unrealistic and if it does occur, is generally associated with low yield. However, the value of this type of stability depends wholly on the range of environment sampled. If the range is wide, then this measure is probably of little use (hard to get the same, high productivity across a broad range), but if it is somewhat restricted (e.g., to central Iowa), then it may have utility.

Type II stability refers to a variety that has a response across environments that is parallel to the mean response of all genotypes in the trial (i.e., the mean regression on the environmental index). The mean regression will have a *b* value of 1; therefore, any genotype with $b = 1$ will be considered stable. If $b < 1$, then the response of the genotype to poor environments (low *tj*) is better than average; if $b > 1$, the response in good environments (high *tj*) is better than average.

Type III stability refers to a variety that has a small mean deviation (that is, the variance of its $\delta\ ij$ values) from the regression on environmental index. Deviations from the regression suggest that the regression itself is not predictive of the genotype's performance in any given environment, and hence the genotype is unstable.

Bernardo (2002) also reported that numerous other measures of stability are also present in the literature and that one that has generated more interest than most is the AMMI (additive main effects and multiplicative interaction) model, which aims at explicitly using genotype x environment information to improve the estimate of genotypic performance in any environment. The AMMI procedure uses an analysis of variance for the effects due to genotypes and environments, and principal component analysis of the genotype x environment interaction. As such, it should make selection more effective.

Tollenaar and Lee (2002) analilyzed yield potential, yield stability and stress tolerance in maize. They reported that yield stability could be defined as either static or dynamic (Fig 5.1) (Becker and Leon, 1988). According to Tollenaar and Lee (2002), in static stability, the performance of a genotype remains unchanged regardless of the environmental conditions. This is equivalent to homeostasis and Type 1 stability (Lin et al., 1986) and in dynamic stability, a genotype changes in a predictable manner across a wide range of environmental conditions; an equivalent to Type 2 stability (Lin et al., 1986). They pointed out that static stability is an absolute measure and yield of a genotype across a range of environments is expressed regardless of the performance of other genotypes under evaluation. Dynamic stability on the other hand is a relative measure. The environment influences yield of a genotype and the environment is typically defined by a common set of genotypes under evaluation and the value assigned to a particular genotype is relative to the yields of other genotypes under evaluation. In their analysis, they looked at dynamic stability using regression approach of Finlay and Wilkinson (1963) to assess stability. The Finlay and Wilkinson's stability analysis used the mean of all genotypes evaluated in an environment as an environmental yield index. Performances of individual genotypes were then regressed against the environmental index. Phenotypic stability (*b*-value) for a hybrid was the slope of a linear regression of the yield of that hybrid at a given location against the mean yield of all hybrids grown at the location. The mean yield of a hybrid was expressed as a percent of mean yield of the location to characterize its relative yield level.

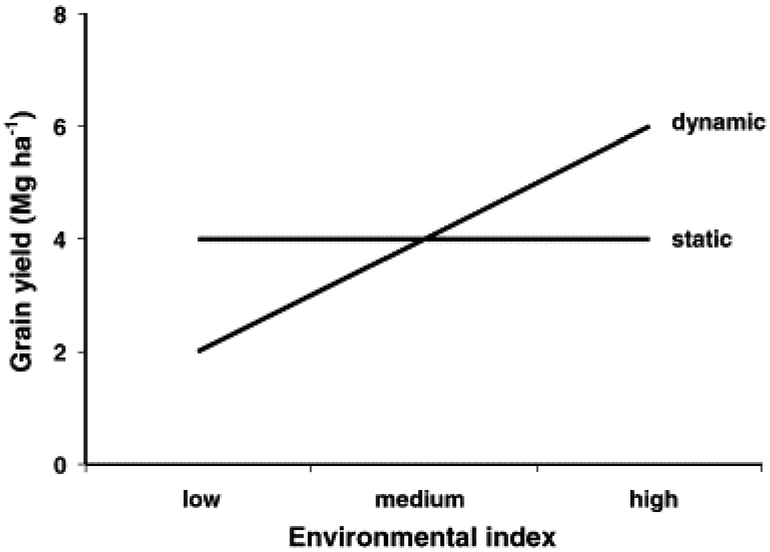

Fig. 5.1. Yield response of a maize hybrid grown across a range of environments in comparison to the environmental index. Source: Tollenaar and Lee, 2002.

Chloupek et al. (2004) classified regression slope as: (a) slope < 1, indicating higher stability, underresponsiveness; (b) slope = 1, average stability, average responsiveness; and (c) slope > 1, lower stability, higher responsiveness, adapted to high-yielding environments.

Joint regression is the most popular among the univariate methods because of its simplicity of calculation and application (Becker and Leon, 1988), whereas Additive Main Effects Multiplicative Interaction (AMMI) is gaining popularity and is currently the main alternative multivariate approach to the joint regression analysis in many breeding programs (Annicchiarico, 1997). Joint regression provides a conceptual model for genotypic stability (Becker and Leon, 1988, Romagosa and Fox, 1993). The genotype x environment interaction from analysis of variance is partitioned into heterogeneity of regression coefficients (b_i) and the sum of deviations ($\Sigma s^2 d_i$) from regressions. Finlay and Wilkinson (1963) defined a genotype with coefficient of regression equal to zero (b_i=0) as stable, while Eberhart and Russell (1966) defined a genotype with b_i=1 to be stable. Most biometricians consider $s^2 d_i$ as stability parameter rather than b_i (Eberhart and Russell, 1966, Becker and Leon, 1988). According to the joint regression model, a stable variety is one with a high mean yield, b_i=1 and $s^2 d_i$=0 (Eberhart and Russell, 1966).

Parametric models and parameters, based on simple linear regression analysis, are among the most widely used to identify superior cultivars (Scapim et al., 2000). They included the method proposed by Eberhart and Russell (1966), which interpreted the variance of the regression deviations as a measure of cultivar stability and the linear regression coefficient as a measure of the cultivar adaptability. Although regression is widely applied, mean of all the cultivars in each environment is taken as a measure of the environmental index and is used as an independent variable in the regression. That may be considered a serious limitation to this procedure because there cannot be independence among the variables, especially when the number of cultivars is less than 15 (Becker and Léon, 1988; Crossa, 1990). Variation of the estimates of the regression coefficient is usually so small, and thus presented a challenge in classification of genotypes for stability and adaptability because of the need to satisfy the assumptions of normality, the homogeneity of variance, and the additivity or linearity of the effects of genotypes and environment. That, according to Yue et al. (1997), was considered a significant limitation in use of parametric models. Yue et al. (1997) proposed non-parametric models, as a useful alternative for analyzing yield stability and adaptability because nonparametric stability measurements do not require any assumptions about the normality of the distribution and variance homogeneity.

Huehn (1990) proposed that the stability of a cultivar in response to environmental changes could be assessed based on its classification in various environments. Three nonparametric stability measurements ($S_i^{(1)}$, $S_i^{(2)}$ and $S_i^{(3)}$) were proposed such that the i-th cultivar could be considered stable in n environments under analysis if its classifications were similar in all environments, i.e., it would correspond to maximum stability. For a cultivar with maximum stability $S_i^{(1)} = S_i^{(2)} = S_i^{(3)} = 0$. In addition to not having the limitations of the parametric models, the models reduce or avoid the biases caused by points outside the adjusted regression equation (outliers), and the stability parameters are easy to use and interpret. Parametric methods are still frequently used because thy supply a ready and clear information about genotype adaptability which is not possible with non-parametric methods.

MATERIALS AND METHODS

Maize germplasm, trial management and locations

Hybrids and populations of diffetent matutities (EIHYB, ILHYB, EPOP, and ILPOP) were evaluated across a range of environments including managed stress environments in eastern and southern Africa from 1999 to 2003. Details about the maize germplasm and trial locations and management are presented in previous chapters.

Stability analysis

Regression (Eberhart and Russell, 1966) was used to determine yield stability of the entries (genotypes) among the maize various maize testing locations in the region. Regression techniques used to develop yield stability parameters were based on linear slope and deviation from that slope (Yates and Cochran, 1938; Finlay and Wilkinson, 1963). Stability analysis was conducted on each set (EIHYB, EIHYB, ILPOP and EPOP) from 1999 to 2003. Stability analysis included optimal locations as well as stress locations due to drought, low N, and low pH (soil acidity). The stability of an entry (genotype) was determined by the regression of genotypic means at each location (environmental index). Regression coefficient of b = 1.0 indicated a genotypic response parallel to the environmental index and thus very stable. The analysis was conducted using software IRRISTAT 4.3 for windows (IRRI., 2002). The analysis was possible for a maximum of 30 locations per analysis and it was conducted across optimal and managed stress locations, which combined drought and low nitrogen.

RESULTS AND DISCUSSION

Yield stability per trial (set) per season (1999 to 2003)

Early to intermediate hybrids (EIHYB)

Genotype performance and stability were analyzed across optimal and managed stress (drought and low nitrogen) locations. There were 130 entries of early to intermediate hybrids (EIHYB) evaluated from 1999 to 2003 and 53 of the entries appeared more than once during this period. Figures 5.2 to 5.11 show grain yield versus regression slope (*bi)* of early to intermediate hybrids (EIHYB) from 1999 to 2003. The closer regression slope was to 1.00 the stable the genotype. For EIHYB in 1999, across optimum locations (Fig. 5.2), grain yield ranged from 3.0 to 4.56 Mg/ha with an overall annual average of 3.9 Mg/ha. The most stable and high yielding genotype was CZH98021. It had a grain yield of 4.02 Mg/ha and a regression slope of 1. This meant that it had the slope parallel to the slope of overall regression. Genotype ZS255 had a *bi* = 0.99 and mean grain yield of 4.52 Mg/ha. Other hybrids that had high yield such as CZH98004 (4.56 Mg/ha) also had slopes significantly different from 1. The general relationship between grain yield and the regression slope under optimum conditions was that the higher the yield the higher the regression slope.

For early to intermediate hybrids in 1999, under managed stress (drought and low nitrogen conditions), the yield is significantly lower that that obtained under optimal conditions (Fig. 5.3). That confirmed the significance of these stress factors to maize production in the region. Grain yield ranged from 1.56 to 3.30 Mg/ha with an annual average yield of 2.45 Mg/ha. The most stable and relatively high yielding genotype under managed stress conditions was CZH98013 with a yield of 3.30 Mg/ha and a regression slope of 0.99. It also had an above average yield of 4.10 Mg/ha under optimal conditions. ZS255, which performed relatively highly under optimal conditions, suffered quite significantly from stress, dropping its yield from 4.52 Mg/ha under optimum conditions to 2.25 Mg/ha under stress. This hybrid was stable with a regression slope of 0.99 under both stress and optimal conditions. CZH98004 maintained above average yields under both stress and optimal growing conditions but was relatively unstable because its regression slope was significantly different from 1.00.

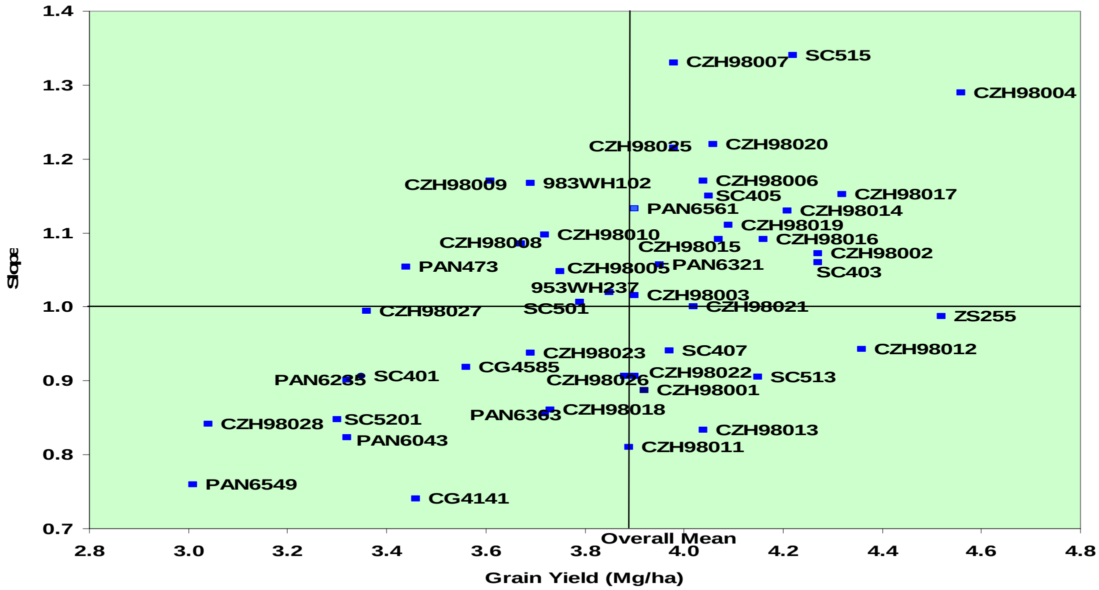

Fig. 5.2. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 1999 across optimal maize testing locations in eastern and southern Africa.

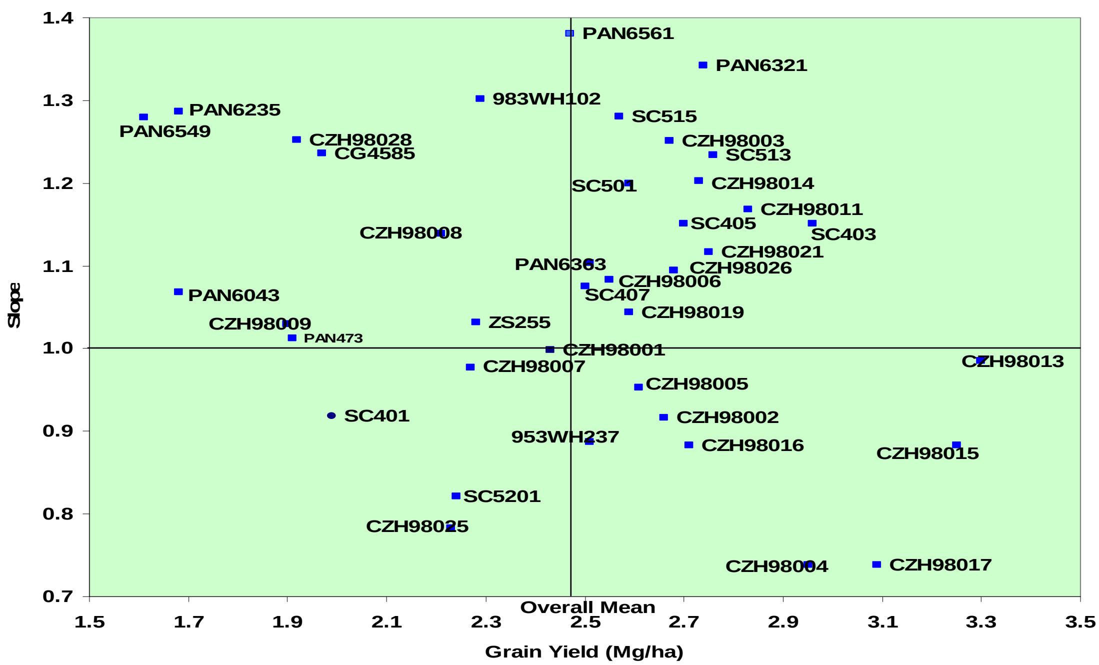

Fig. 5.3. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 1999 across stress maize testing locations in eastern and southern Africa.

Under optimal conditions in 2000 for early to intermediate hybrids (Fig 5.4), the trends were similar to that of the previous season (1999) in which the higher the yields the higher the regression slope. The hybrid yields ranged from 3.00 to 4.35 Mg/ha, with the overall mean of 3.84 Mg/ha. Relatively stable hybrids were CZH99007 (*bi* = 1.01), PAN31 (*bi* = 0.98), C8031 (*bi* = 0.98). Hybrid CZH99010 showed the highest yield (4.35 Mg/ha) in 2000 but also showed the highest regression slope (*bi*) = 1.28 and hence it was relatively unstable. Hybrid PAN31 although it showed high relative stability it was very poor yielding.

Under stress conditions, there was no specific trend as the regression slope/grain yield relationship displayed a random and wide spread distribution (Fig. 5.5). Hybrid CZH99010, which had the highest yield under optimal conditions suffered significantly from stress (drought and low nitrogen) as its yield dropped from 4.35 Mg/ha under optimal conditions to 1.95 Mg/ha under stress conditions (55% yield loss). Hybrid CZH99002 was the most stable genotype under stress, with a regression slope of 1.00, but it had very low average yield (1.8 Mg/ha). Hybrid C8031 had high relative stability (*bi* = 0.99) and above average grain yield under optimal and stress growing locations.

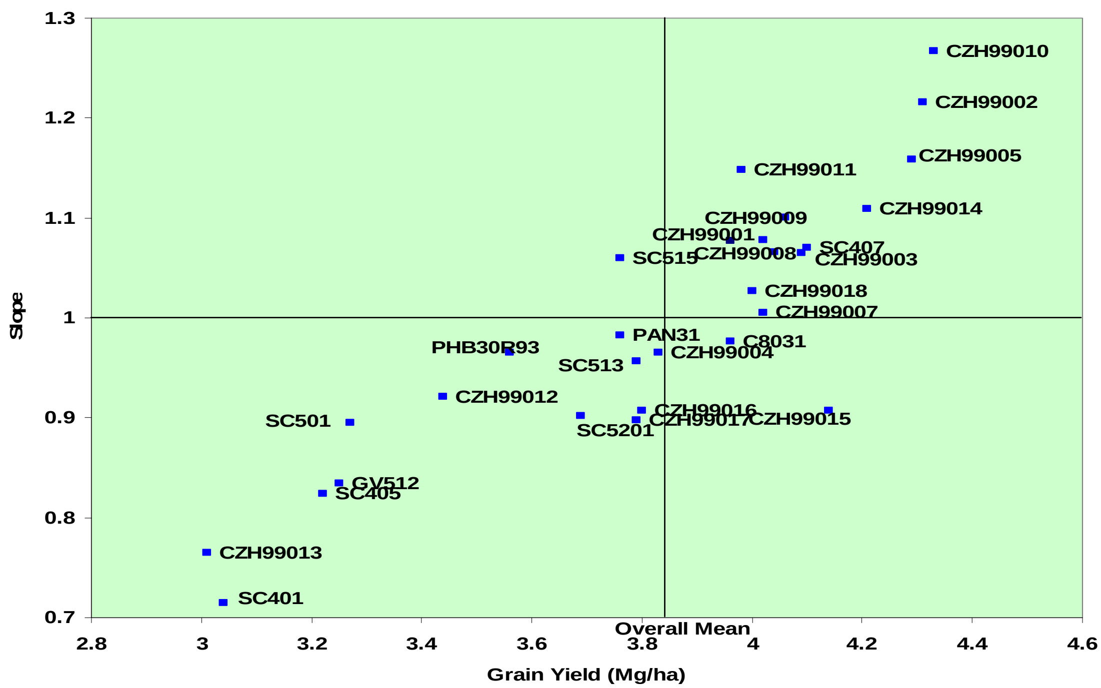

Fig. 5.4. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2000 across optimal maize testing locations in eastern and southern Africa.

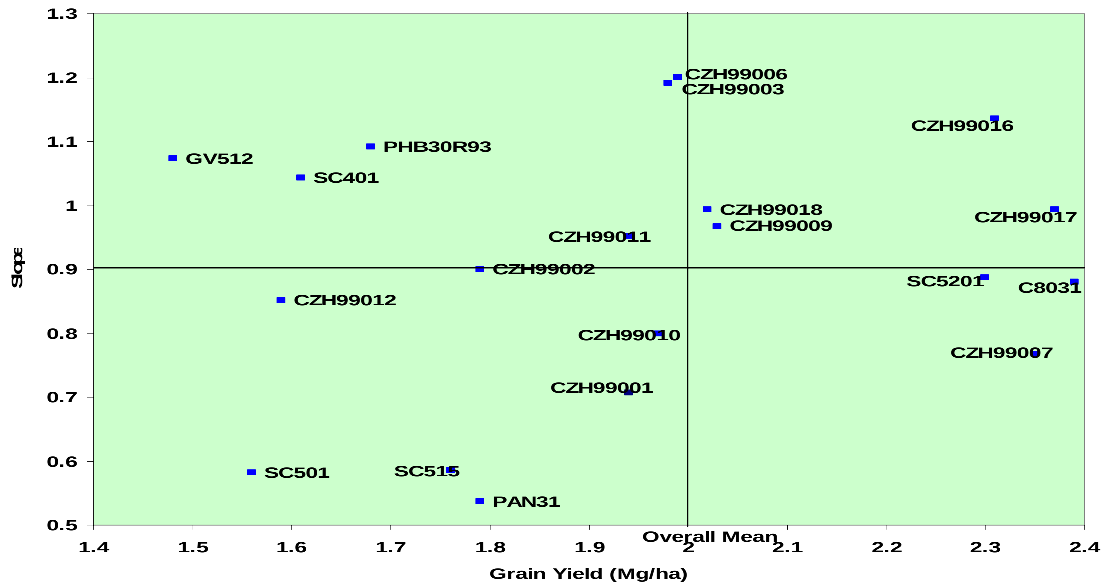

Fig. 5.5. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2000 across stress maize testing locations in eastern and southern Africa.

For EIHYB under optimum conditions in 2001, the regression slope/grain yield general trend indicated that high yield had high regression slope and vice versa (Fig 5.6). The yields ranged from 3.05 Mg/ha to 4.55 Mg/ha with a grain yield mean of 3.95 Mg/ha. Relatively stable hybrids were SC407 (*bi* = 1.00), SC513 (*bi* = 1.02), SC517 (*bi* = 1.02), CZH00018 (*bi* = 1.02), CZH00014 (*bi* = 1.02), CZH99002 (*bi* = 1.02), CZH99005 (*bi* = 1.02), CZH00002 (*bi* = 1.02), and CZH00003 (*bi* = 1.01). Hybrid CZH00010 had the highest yield of 5.90 Mg/ha but also showed one of the highest regression slope (*bi* = 1.01) and, therefore, it was found to be unstable.

Under stress conditions (drought and low nitrogen), there was a general and quite significant reduction in grain yield compared to the yield under optimum conditions (Fig. 5.7). High yields of hybrids were associated with high regression slopes. The yields ranged from 1.84 Mg/ha to 2.72 Mg/ha with a mean of 2.3 Mg/ha. Relatively stable genotypes under stress conditions were CZH99015 (*bi* = 1.02), CZH00013 (*bi* = 1.01) and PAN6479 (*bi* = 1.01). Hybrid PAN6479 was a low yielding genotype under both stress and optimal conditions. The relative highest yielding genotype was CZH00016 (*bi* = 1.25) with grain yield of 2.72 Mg/ha, This hybrid was unstable because its regression slope was significantly different from 1. Hybrid DK8031 and CZH00010 maintained relatively high yield under stress and optimal conditions.

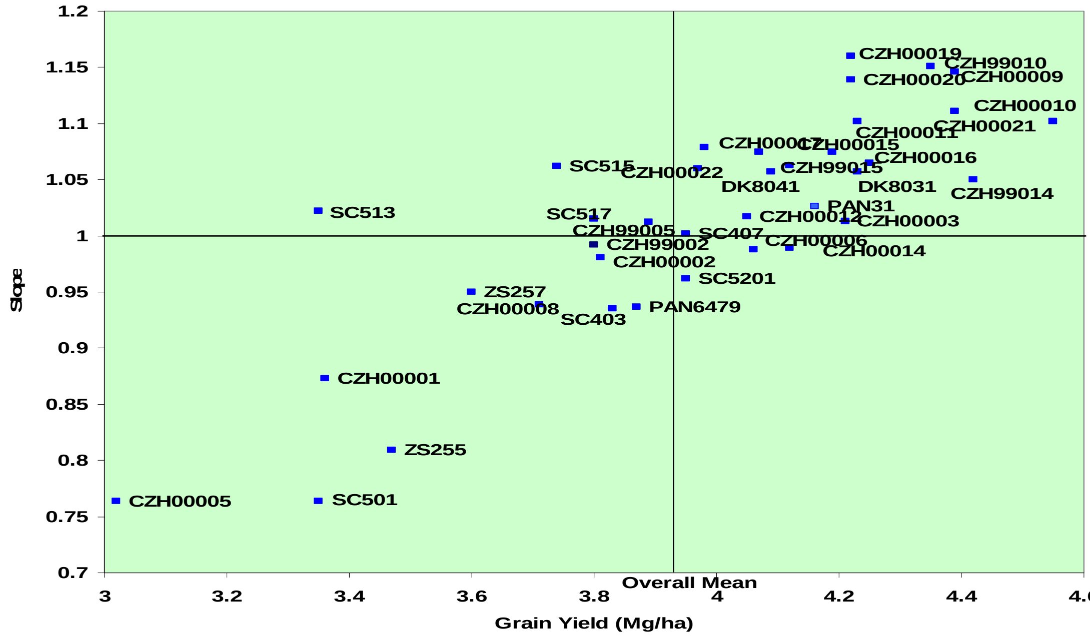

Fig. 5.6. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2001 across optimal maize testing locations in eastern and southern Africa.

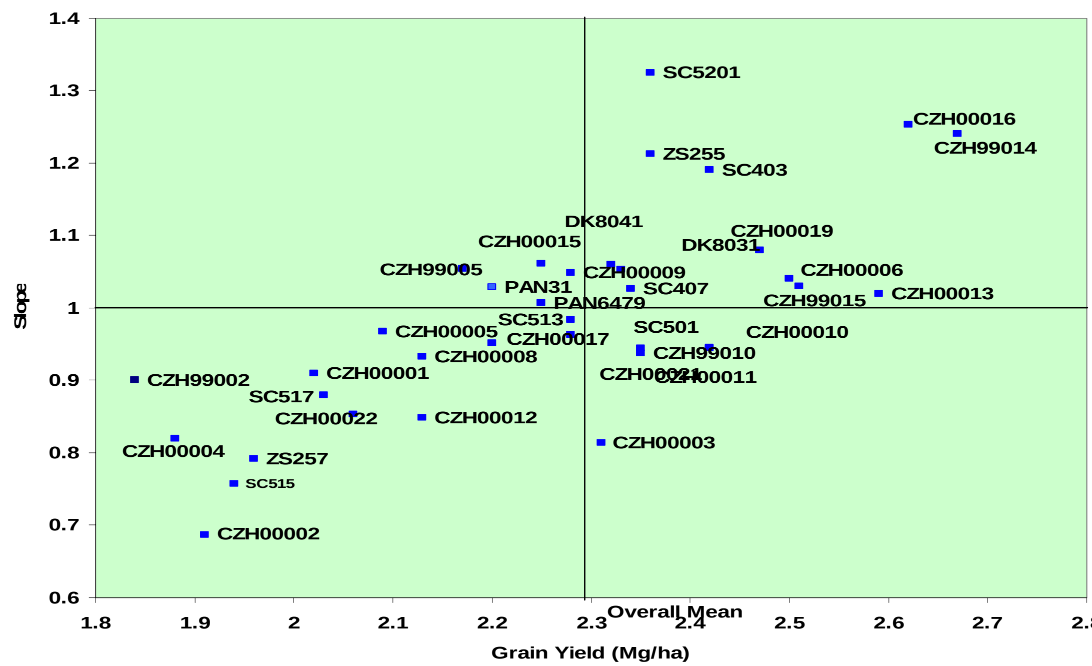

Fig. 5.7. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2001 across stress maize testing locations in eastern and southern Africa.

For EIHYB in 2002 under optimum conditions high yields were associated with high regression slopes and vice versa (Fig 5.8). The relationship showed that a larger proportion of genotypes had regression slope close to 1. Grain yields ranged from 3.25 Mg/ha to 5.55 Mg/ha with an average of 4.70 Mg/ha. For EIHYB in 2002, stable entries were CZH99007 (*bi* = 1.01), CZH01002 (*bi* = 1.01), CZH99015 (*bi* = 1.01), CZH00007 (*bi* = 0.99), CZH00012 (*bi* = 0.98), and GV470 (*bi* = 1.01). The highest yielding hybrid was CZH01008, with grain yield of 5.55 Mg/ha. It also showed the highest regression slope (*bi* = 1.24) and hence was unstable.

For EIHYB in 2002 under stress (drought and low nitrogen) conditions, high yield correspond also to high regression slope and vice versa (Fig 5.9). There was significant drop in grain yield under stress. The yields ranged from 2.15 Mg/ha to 4.20 Mg/ha with with an average of 3.20 Mg/ha. Relatively stable hybrids were SC403 (*bi* = 1.01), ZS255 (*bi* = 1.01), CZH01006 (*bi* = 1.01), CZH01004 (*bi* = 1.01), SC613 (*bi* = 1.01), and CZH01003 (*bi* = 1.01). The highest yielding hybrid under stress was CZH99014 with a yield of 4.20 Mg/ha and *bi* = 1.25. Hybrid SC403 maintained relatively high yields under stress and optimal conditions but was stable in stress locations and unstable in optimal conditions. Hybrid SC407 maintained relatively high yield and stability under both growing conditions. Materials that were managed by the seed companies were showing higher yields than those that were managed by most national programs except those managed by national programs of South Africa. This is because of differences in access of resources like fertilizer and the quality of management. But the overall stability results still hold true. This observation is important when planning regional research and deployment of improved maize germplasm because the level of the nation's development would likely affect of quality of participation and adoption.

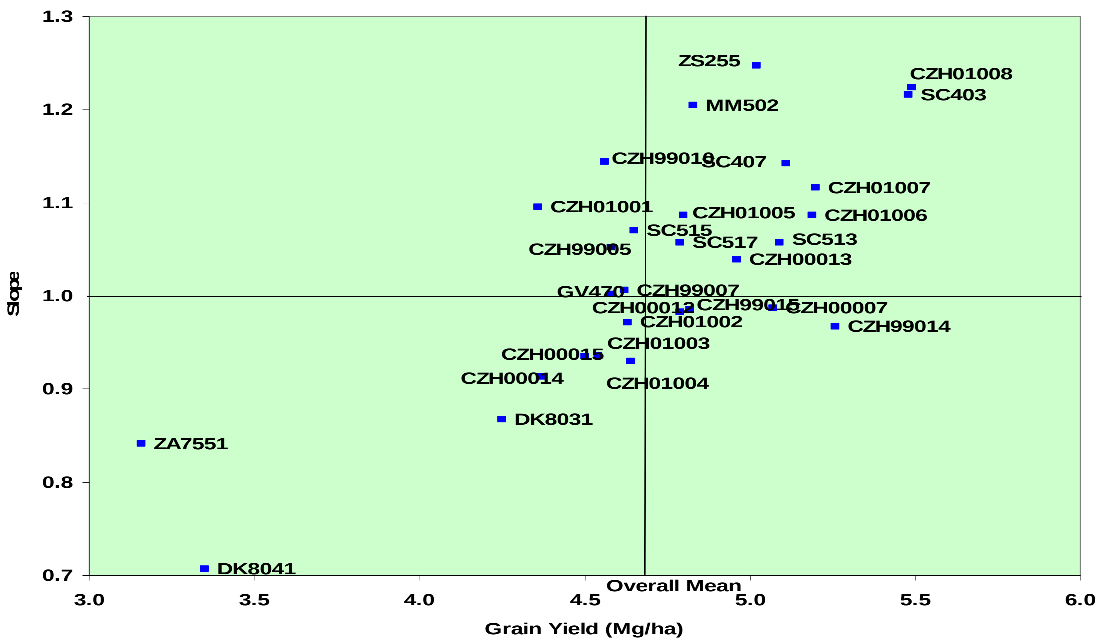

Fig. 5.8. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2002 across optimal maize testing locations in eastern and southern Africa.

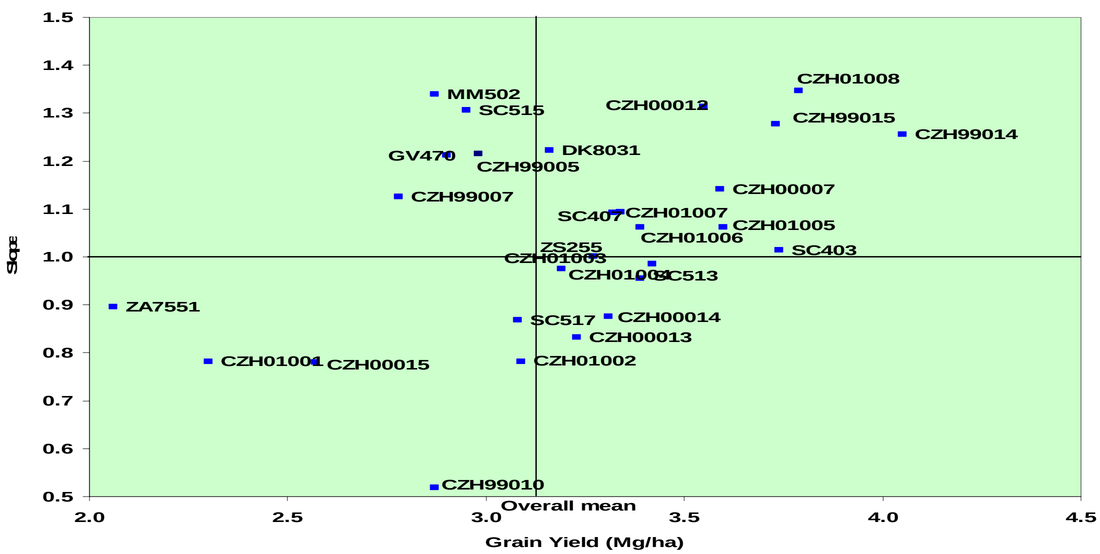

Fig. 5.9. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2002 across stress maize testing locations in eastern and southern Africa.

In 2003, for early to intermediate hybrids (EIHYB) under optimum conditions, high yield was associated with high regression slope and vice versa. The yields for the season were lower than from the previous four seasons and ranged from 2.94 Mg/ha to 3.96 Mg/ha with an average of 4.70 Mg/ha. Early to intermediate hybrids stable were PAN31 (*bi* = 1.01), MM502N (*bi* = 1.02), CZH02003 (*bi* = 1.01), and CZH02010 (*bi* = 1.01). CZH02010 might not be desirable because it had relatively low yield far below average. Just like in the 4 previous seasons, the highest yielding entry was CZH01008, and was relatively unstable as its slope was significantly different from 1.00.

For EIHYB in 2003, under stress (drought and low nitrogen) conditions, there was no relationship between regression slope and grain yield. Grain yields ranged from 1.52 Mg/ha to 2.26 Mg/ha with an average of 2.0 Mg/ha. Relatively stable genotypes were SC513 (*bi* = 1.01), CZH00013 (*bi* = 1.01), CZH00012 (*bi* = 1.01). Hybrid SC513 might not be desirable because it has very low yield. The relatively highest yielding genotype under stress was CZH01005 (*bi* = 0.78) with grain yield of 2.26 Mg/ha. Hybrids CZH00012 and CZH00007 maintained relatively high yield and stability under stress and optimal growing conditions.

Early to intermediate hybrids generally produced lower yields than late hybrids. Early hybrids are very important for short rainfall season of unimodal rainfall areas of countries like Malawi, Mozambique, Zambia and they can be useful to escape drought, depending on the rainfall distribution. Short season (early) hybrids would also fit well in bimodal rainfall regimes of eastern African nations like Uganda.

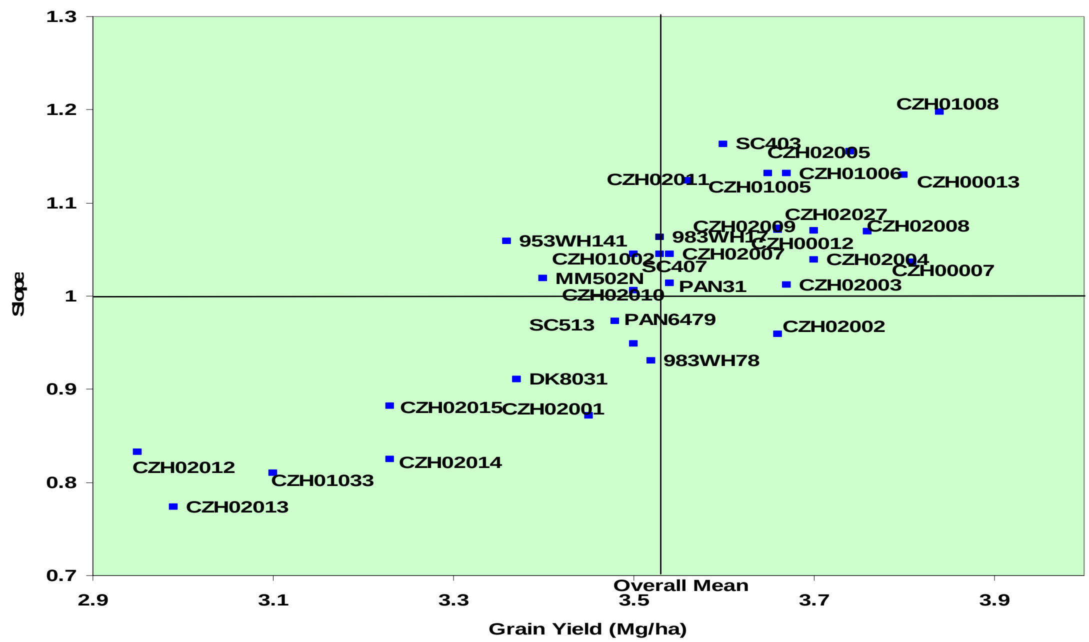

Fig. 5.10. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2003 across optimal maize testing locations in eastern and southern Africa.

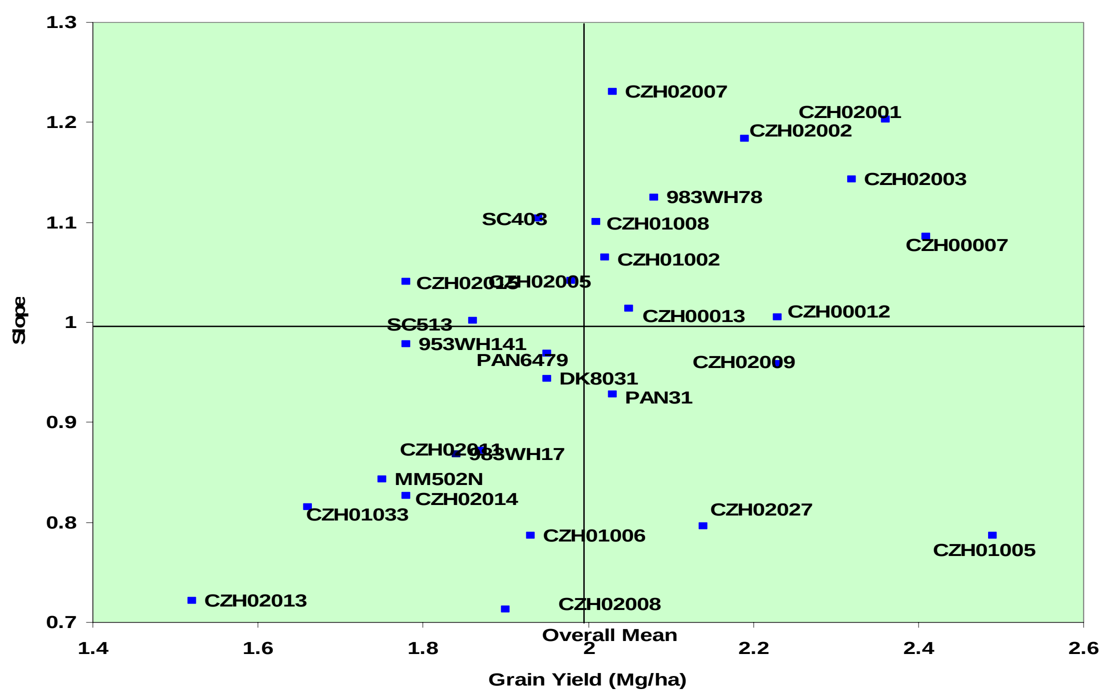

Fig. 5.11. Grain yield vs. regression slope for early to intermediate hybrids (EIHYB) in 2003 across stress maize testing locations in eastern and southern Africa.

Intermediate to late hybrids (ILHYB)

There were 162 entries of intermediate to late hybrids (ILHYB) evaluated from 1999 to 2003 and 74 of the entries appeared more than once during the period. Figures 5.12 to 5.21 show grain yield versus regression slope (*bi)*, of intermediate to late hybrids (ILHYB) from 1999 to 2003. The regression slope/grain yield general trend indicated that high yield had high regression slope and vice versa. Intermediate to late hybrids produced higher yields in general, as expected, than the early hybrids.

For ILHYB in 1999, across optimum locations (Fig. 5.12), grain yield ranged from 4.60 to 6.43 Mg/ha with an overall test and annual average of 5.35 Mg/ha. Relatively stable late hybrids were CZH98043 (*bi* = 1.00) and CZH98056 (*bi* = 0.98) and PAN6573 (*bi* = 1.01). The highest yielding hybrid was CZH99021 (*bi* = 1.35), with the mean yield of 6.43 Mg/ha. Its slope was far greater than 1.00 and therefore the highest yielding genotype was unstable,

For intermediate to late hybrids in 1999, under managed stress (drought and low nitrogen conditions), the yield is significantly lower that that obtained under optimal conditions (Fig. 5.13). There was no specific trend of relationship between grain yield and regression slope. The yield ranged from 1.31 to 3.80 Mg/ha and had set and annual average yield of 2.85 Mg/ha. Relatively stable late hybrids under managed stress (drought and low nitrogen) were CZH98031 (*bi* = 1.00). Hybrids CZH98053 (*bi* = 1.01), and CZH98043 (*bi* = 1.00). Hhbrid CZH98031 may not be desirable because of its low yields. The highest yielding genotype under stress was CZH98052 (*bi* = 1.03), and its slope was not significantly different from the slope of overall regression and therefore it was highest yielding as well as stable which is desirable for cultivar development for wide adaptation. Hybrids PAN6573 and CZH98045 maintained relatively high yields and stability under stress and optimal conditions.

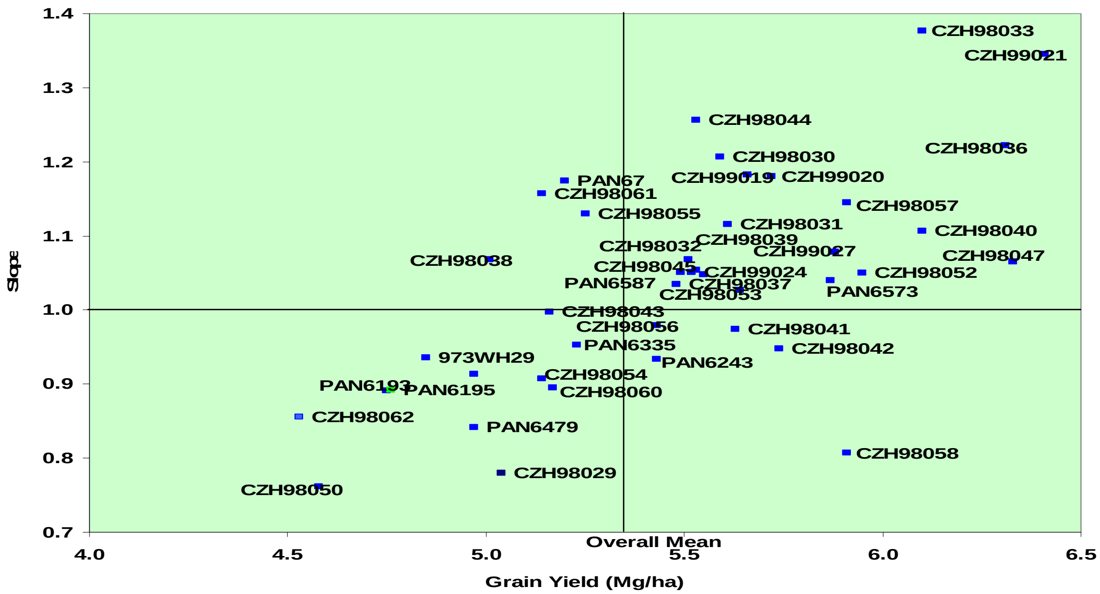

Fig. 5.12. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 1999 across optimal maize testing locations in eastern and southern Africa.

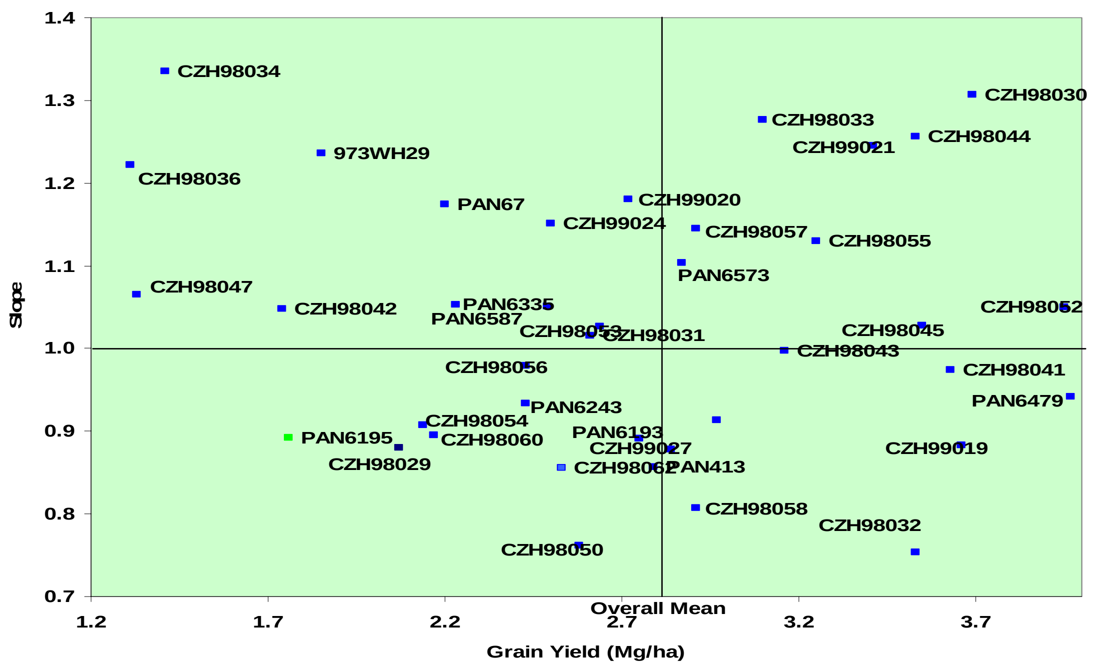

Fig. 5.13. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 1999 across stress maize testing locations in eastern and southern Africa.

Under optimal conditions in 2000, for intermediate to late hybrids (Fig 5.14), the trends were similar to that of the previous season (1999) in which the higher the yields the higher the regression slope. The hybrid yields ranged from 4.16 to 6.50 Mg/ha, with the overall mean of 5.45 Mg/ha. A larger proportion of genotypes had regression slope of close to and greater than 1.00 and yields above average (5.45 Mg/ha). Relatively stable hybrids were identified be CZH99022 (*bi* = 1.00), CZH99024 (*bi* = 1.02) and SC715 (*bi* = 1.01). The highest yielding entry was CZH99038 (*bi* = 1.26) and was identified to be relatively unstable because its slope was significantly different from that of overall regression.

For ILHYB in 2000, under stress (drought and low nitrogen) conditions, there was no clear specific trend although the regression slope/grain yield relationship displayed a more random spread, which somehow indicated that the lower the yield the higher the regression slope (Fig. 5.15). There was reduction in yield from optimal locations to stress locations. The yield ranged from 2.5 to 4.45 Mg/ha with the test annual average of 3.3 Mg/ha. Stable genotypes under stress were identified to be SC627 (*bi* = 0.99), SC715 (*bi* = 0.98), CZH99019 (*bi* = 0.98) and CZH99037 (*bi* = 0.98). The relatively highest yielding genotype under stress was CZH99030 (*bi* = 0.85) but was unstable. Hybrid CZH99030 produced relatively high yields under stress and optimal conditions. It is stable under optimal conditions and unstable under stress (drought and low nitrogen.

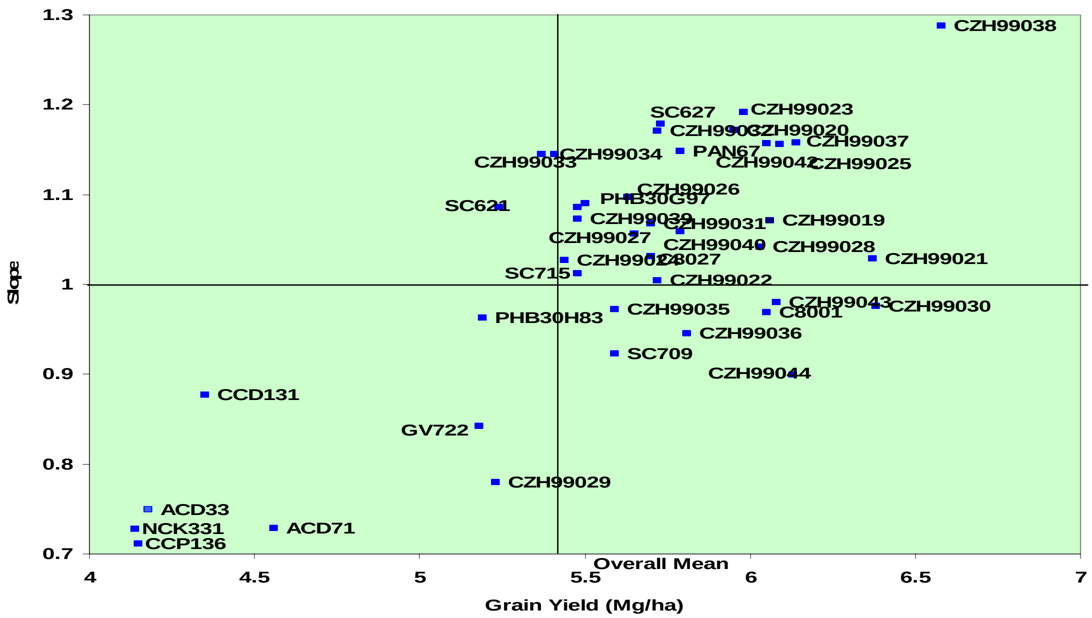

Fig. 5.14. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2000 across optimal maize testing locations in eastern and southern Africa.

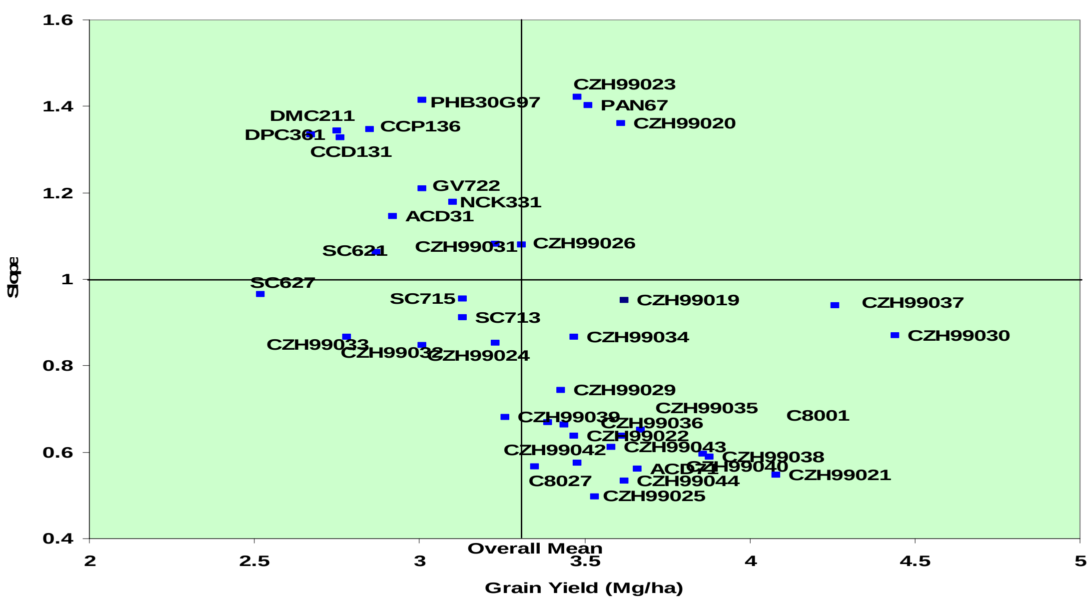

Fig. 5.15. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2000 across stress maize testing locations in eastern and southern Africa.

For intermediate to late hybrids (ILHYB) in 2001, under optimum conditions, (Fig 5.16) the regression slope/grain yield general trend indicated that high yield had high regression slope and vice versa. The yields ranged from 3.74 Mg/ha to 5.70 Mg/ha with the mean test annual mean of 4.85 Mg/ha. Relatively stable hybrids in 2001 were CZH00029 (*bi* = 1.01), CZH00030 (*bi* = 1.00) and PHB30H83 (*bi* = 0.98). Hybrid PHB30H83 may not be desirable because of its low yields. The highest yielding entry was CZH99038 (*bi* = 1.14) and was relatively unstable as its slope was significantly different from that of overall regression for the set.

Under stress conditions (drought and low nitrogen), there was a general and quite significant reduction in grain yield compared to the yield under optimum conditions (Fig. 5.17). The general trend for the season indicated that high yields showed high regression slope. The yields ranged from 1.64 Mg/ha to 2.92 Mg/ha with the mean test annual average of 2.25 Mg/ha. Relatively stable genotypes under the stress conditions were PAN6573 (*bi* = 0.99) and CZH99038 (*bi* = 0.98) Hybrid PAN6573 may not be desirable because of low yield. The highest yielding late hybrid under stress in 2001 was DK8051 (*bi* = 0.87) but was not stable, its yield varied significantly from location to location. Hybrid CZH00030 was stable and produced relatively high yields under stress and optimal conditions. Drought and low nitrogen stress factors are very important in the region. In terms of planning for research for producing improved materials, low nitrogen is easier to plan for because the soil conditions do not change as much year to year, location to location as in climatic factors.

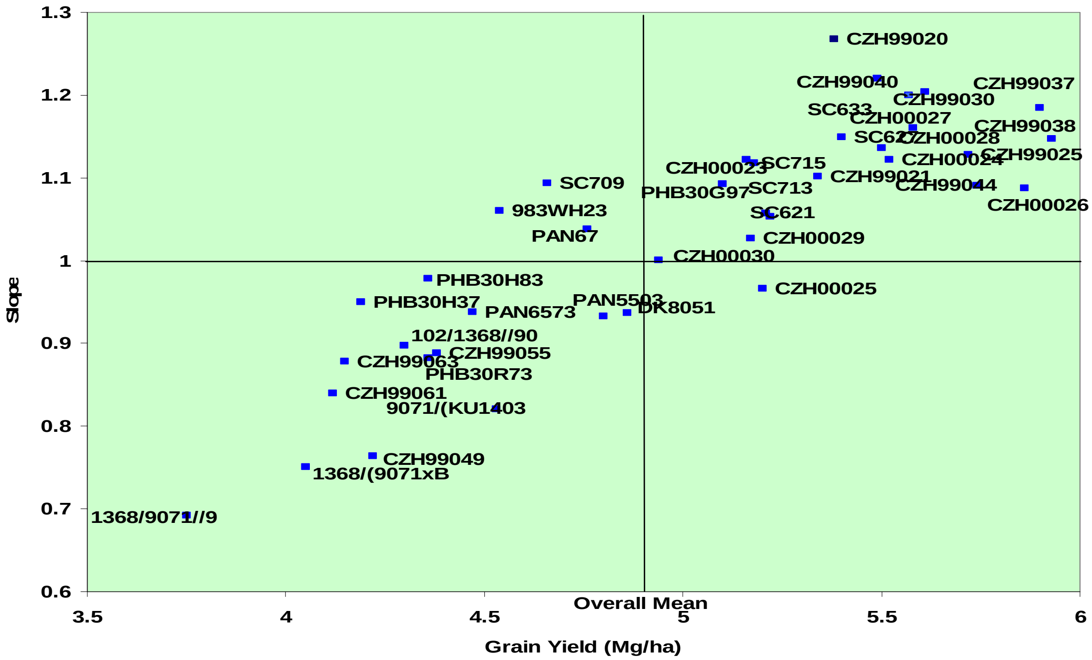

Fig. 5.16. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2001 across optimal maize testing locations in eastern and southern Africa

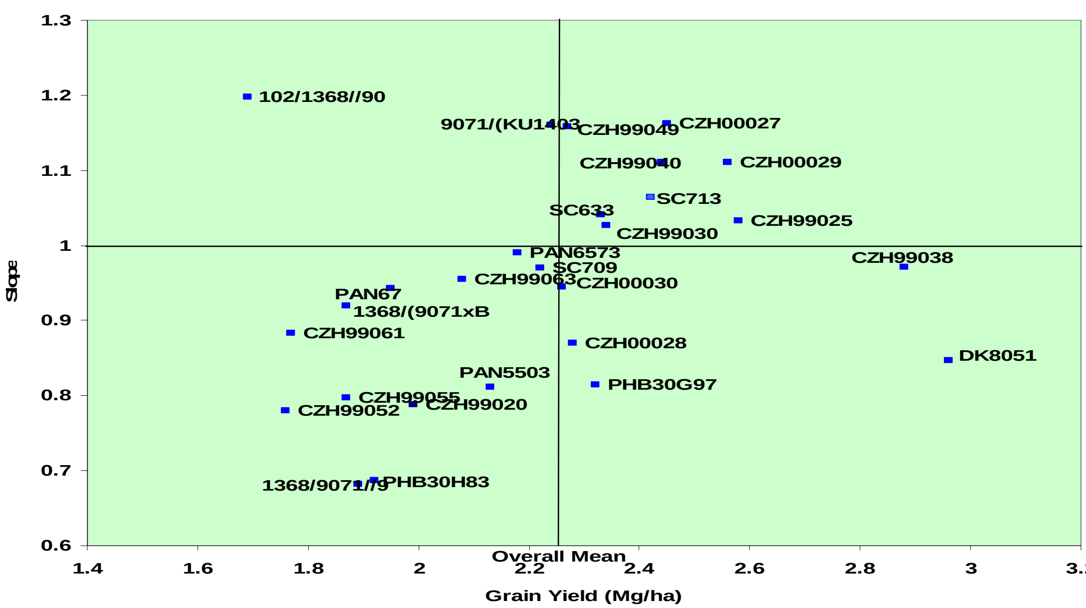

Fig. 5.17 Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2001 across stress maize testing locations in eastern and southern Africa.

For intermediate to late hybrids (ILHYB in 2002, under optimum conditions, the regression slope/grain yield general trend indicated that high yield had high regression slope (Fig 5.18). MM603 has one of the lowest yields (3.15 Mg/ha) and as the lowest regression slope regression (*bi* = 0.75). The relationship between grain yield and slope showed that a larger proportion of genotypes had regression slope close to 1.The yields ranged from 3.13 Mg/ha to 4.60 Mg/ha with the mean test annual mean of 3.90 Mg/ha. For ILHYB in 2002, relatively stable hybrids were CZH01016 (*bi* = 1.02), CZH00027 (*bi* = 1.02) CZH00029 (*bi* = 1.00) CZH01020 (*bi* = 1.00) DK8051 (*bi* = 0.98) PHB30G97 (*bi* = 1.00) GV704 (*bi* = 0.99) and SC715 (*bi* = 1.00). The highest yielding hybrid was CZH01015 (*bi* = 1.24) and its performance varied significantly from location to location as evidenced by the slope that was significantly different from that of overall regression.

For ILHYB in 2002, under stress (drought and low nitrogen) conditions, (Fig 5.19) the regression slope on grain yield indicated no particular trend. There was significant drop in grain yield under stress. The yields ranged from 1.43 Mg/ha to 2.94 Mg/ha with the mean test annual mean of 2.50 Mg/ha. Relatively stable genotypes under stress were SC627 (*bi* = 1.00), CZH01017 (*bi* = 1.01) and PHB30H83 (*bi* = 1.00). The relatively highest yielding hybrid under stress was CZH01015 (*bi* = 1.35) with the grain yield of 2.94 Mg/ha. Hybrid CZH01015 also produced the highest yield under optimal conditions but like under optimum conditions it was unstable. CZH01014 maintained relatively high yields under stress and optimal conditions but remained unstable under both conditions while hybrid CZH01018 maintained high yields, was stable under and stress and optimal conditions.

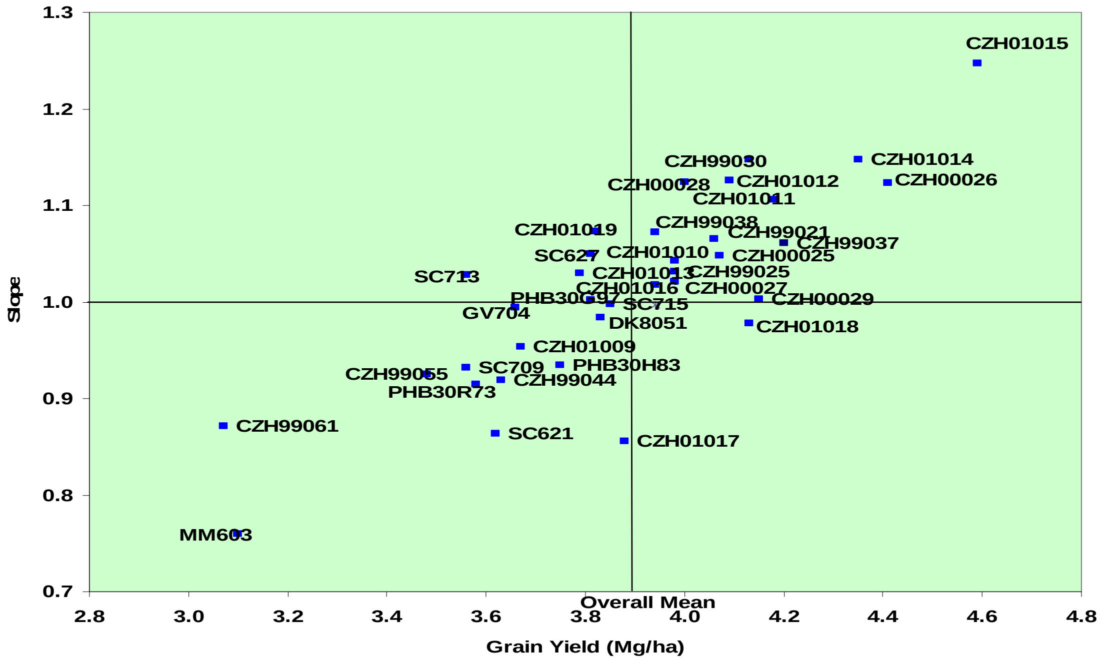

Fig. 5.18. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2002 across optimal maize testing locations in eastern and southern Africa.

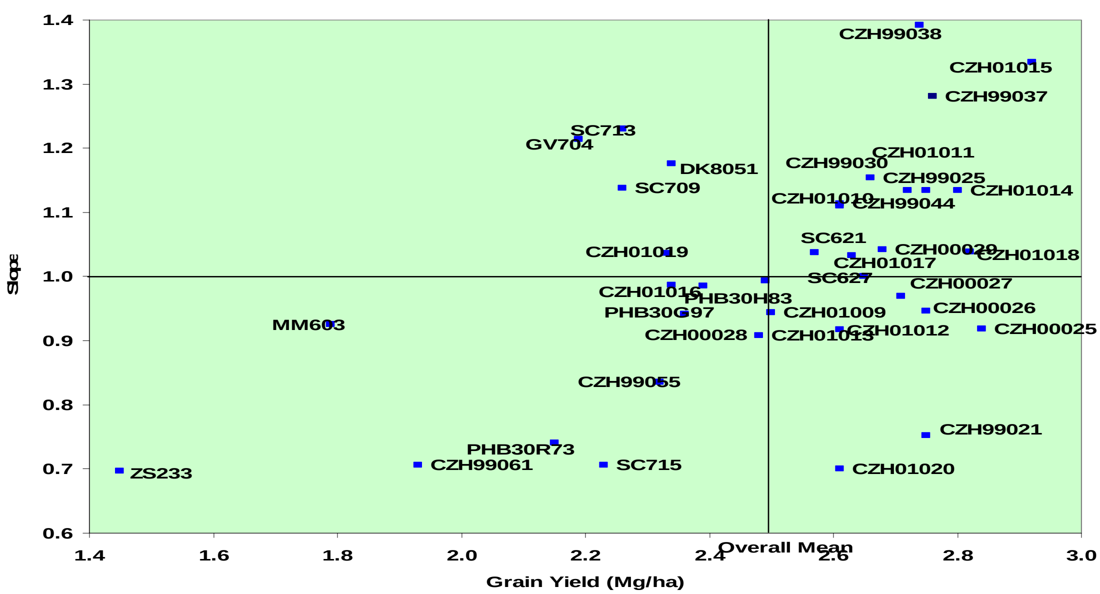

Fig. 5.19. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2002 across stress maize testing locations in eastern and southern Africa.

In 2003, for intermediate to late hybrids (ILHYB) under optimum conditions, (Fig 5.20) the regression slope/grain yield general trend indicated that high yield had high regression slope. PAN45 had the lowest yield of 2.85 Mg/ha and least regression slope of 0.71. The yields under optimal conditions ranged from 2.85 Mg/ha to 4.35 Mg/ha with the mean test annual mean of 3.80 Mg/ha. These yields were similar to those obtained in 2002 but were both lower than those obtained in the three previous seasons of 1999, 2000 and 2001. Intermediate to late hybrids identified as stable were in 2003 were PAN57 (*bi* = 1.02), PAN77 (*bi* = 0.98), PHB30G97 (*bi* = 0.98), PHB30T47 (*bi* = 0.98), CZH02018 (*bi* = 1.01) CZH01020 (*bi* = 0.98). The highest yielding hybridtry was CZH02020 (*bi* = 1.08) with the mean grain yield of 4.35 Mg/ha. The highest yielding genotype was unstable because its slope was significantly different from the slope of overall regression.

For ILHYB in 2003, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.21). There was significant drop in grain yield under stress. The yields ranged from 1.70 to 3.18 Mg/ha with the mean test annual mean of 2.35 Mg/ha. Relatively stable genotypes under stress were CZH02019 (*bi* = 1.00), CZH01011 (*bi* = 0.98), and PAN77 (*bi* = 1.02. However, PAN77 may not be desirable because of its very low grain yield. The relatively highest yielding genotype under stress was CZH02020 (*bi* = 1.25) with the grain yield of 3.18 Mg/ha maintained relatively high yield under stress and optimal growing conditions but was stable only under stress conditions.

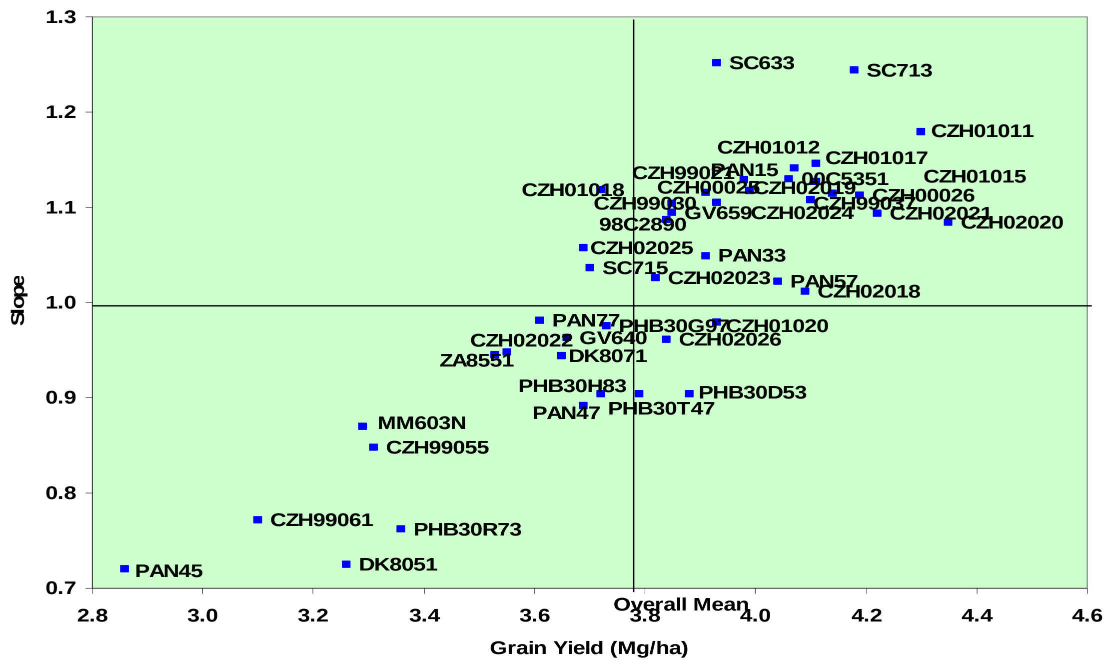

Fig. 5.20. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2003 across optimal maize testing locations in eastern and southern Africa.

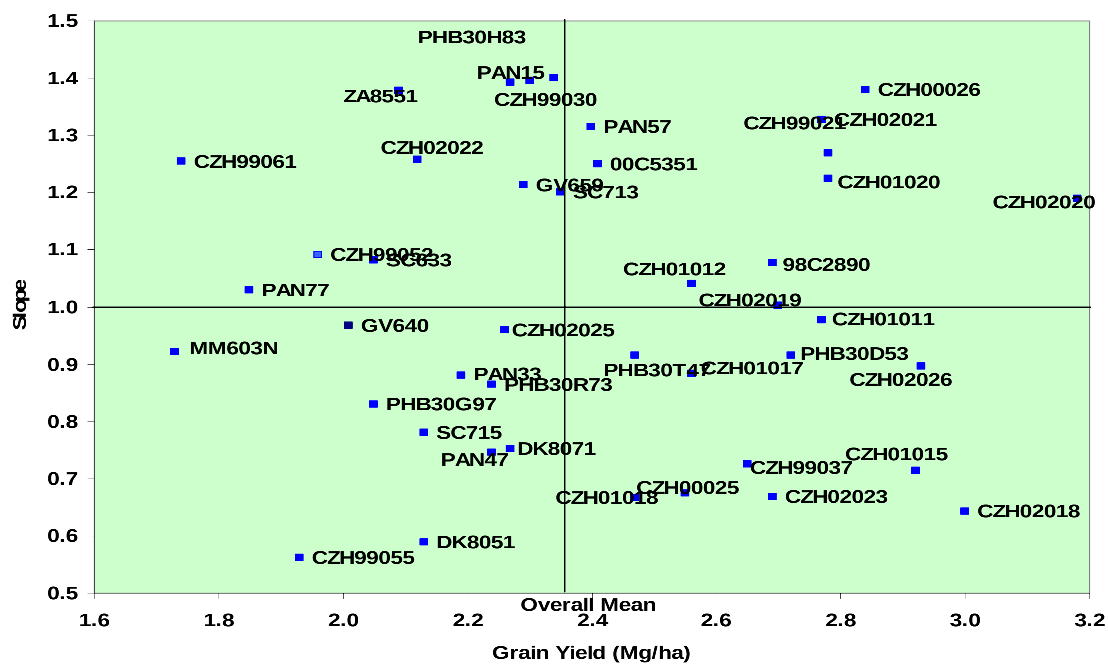

Fig. 5.21. Grain yield vs. regression slope for intermediate to late hybrids (ILHYB) in 2003 across stress maize testing locations in eastern and southern Africa.

Early populations (EPOP)

There were 73 entries of early populations (EPOP) evaluated from 1999 to 2003 and 38 of the entries appeared more than once during the period. Tables 5.22 to 5.31 show grain yield versus regression slope (*bi)*, of early population (EPOP) from 1999 to 2003. The regression slope/grain yield general trend indicated that high yield had high regression slope. Parameter (*bi*) was a qualitative and quantitative stability measure and this was the regression slope for the genotypes. The closer it was to 1.00 the stable the was the genotype and if it was significantly different from the slope of overall regression, then that suggested that the yield of the genotype varied significantly from location to location.

Under optimal conditions in 1999 for early populations (EPOP), the relationships between grain yield and regression slope showed a loose trend in which the higher the yields the higher the regression slope (Fig. 5.22). The early population yields ranged from 2.75 to 3.72 Mg/ha, with the overall mean of 3.16 Mg/ha. The yields of populations were much lower than yields obtained from hybrids. Relatively stable materials were Z97EWA (*bi* = 1.02), TEWD-SRDRTO (*bi* = 0.99), EV7992/POOL (*bi* = 1.00), SYNTHETIC DR (*bi* = 1.00) and SYNTHETIC NU (*bi* = 1.01). The highest yielding entry was SADVI1 F1 (*bi* = 1.02), with a mean yield of 3.72 Mg/ha. This population was relatively stable because it had a slope not significantly different from the slope of overall regression. SADVI1 F1 would, therefore, be a desirable genotype in cultivar development, especially for wide adaptation.

For EPOP in 1999, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.23). There was a drop in grain yield under stress but not as much as was the case in hybrids. The yields under stress ranged from 2.05 to 3.18 Mg/ha with the mean test annual mean of 2.50 Mg/ha. Relatively stable populations under stress were EARLY-MID-1 (*bi* = 1.01), and SADV1F1 (*bi* = 1.02). However, EARLY-MID-1 may not be desirable because of its very low grain yield. The relatively highest yielding genotype under stress was SADV2F1 (*bi* = 1.12) with the grain yield of 3.18 Mg/ha. SADV1F1 maintained relatively high yield and stability under stress and optimal growing conditions and population SADV2F1 maintained high yields under stress and optimal conditions but was unstable under both growing conditions.

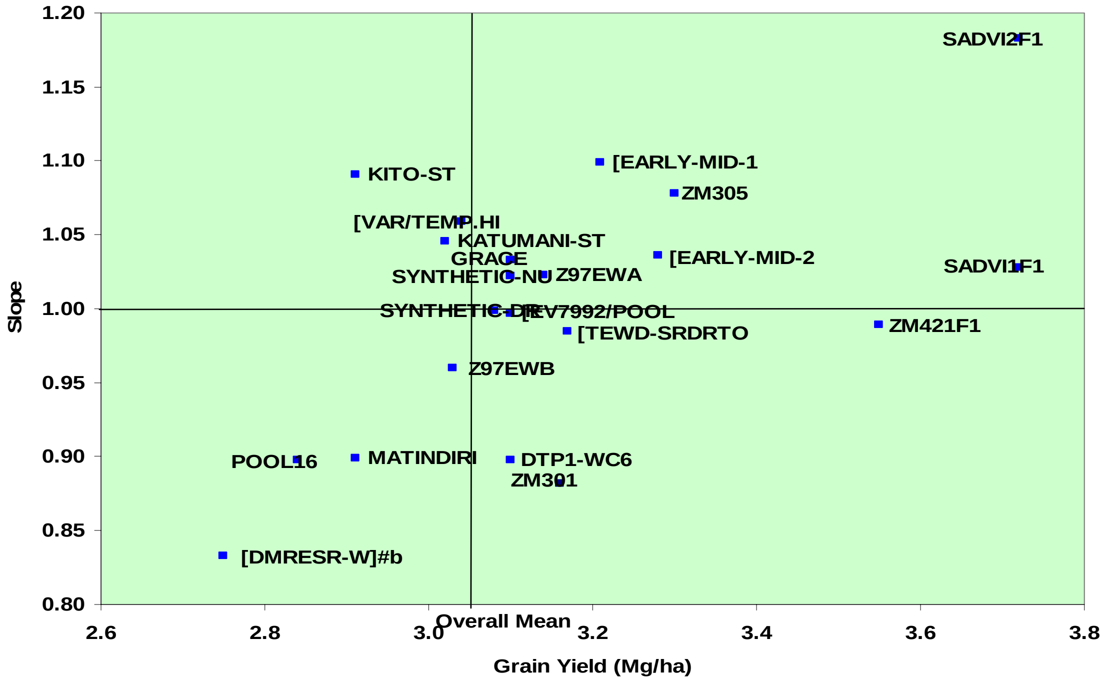

Fig. 5.22. Grain yield vs. regression slope for early populations (EPOP) in 1999 across optimal maize testing locations in eastern and southern Africa.

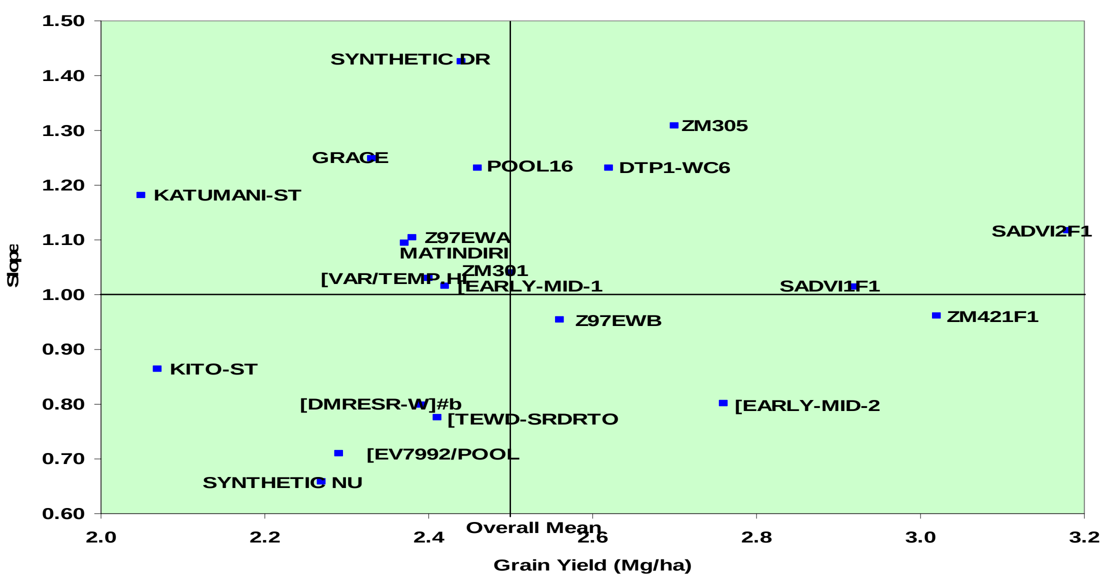

Fig. 5.23. Grain yield vs. regression slope for early populations (EPOP) in 1999 across stress maize testing locations in eastern and southern Africa.

Under optimal conditions in 2000 for early populations (EPOP), there was a clear trend with respect to the relationship between grain yield and regression slope (Fig 5.24). The higher the yields the higher was the regression slope. Grain yields of populations under optimum conditions ranged from 2.21 to 3.64 Mg/ha, with the overall mean of 2.88 Mg/ha. Relatively stable populations were ZM421 (*bi* = 1.02), POP101 x KAT (*bi* = 0.99) and Matuba (*bi* = 0.99). SADVI1 F1 (*bi* = 1.02), with a mean grain yield of 3.64 Mg/ha, was the highest yielding genotype. However, it was unstable because its slope was significantly different from the slope of the overall regression of 1.00.

For EPOP in 2000, under stress (drought and low nitrogen) conditions, there was a loose trend in which the higher the grain yield, the higher the regression slope (Fig. 5.25). There was less reduction in yield from optimal locations to stress locations compared to the reduction experienced in hybrids. The yield ranged from 1.60 to 2.40 Mg/ha with the test annual average of 1.97 Mg/ha. Relatively stable populations under stress conditions were CCD (*bi* = 0.97) and SADVI1F2 (*bi* = 1.02). CCD however had very low yield and thus might not be desirable during selection and cultivar development. The relatively highest yielding population was ZM521F1 (*bi* = 1.20) with grain yield of 2.40 Mg/ha. SADVI2F2 maintained relatively high yield under stress and optimal conditions but was unstable under both growing conditions. CCD was amongst the very early population which was produced in Harare Zimbabwe. Its poor performance in recent years compared to the ones currently used may be testimony to general improvement of materials that were in use currently in the region.

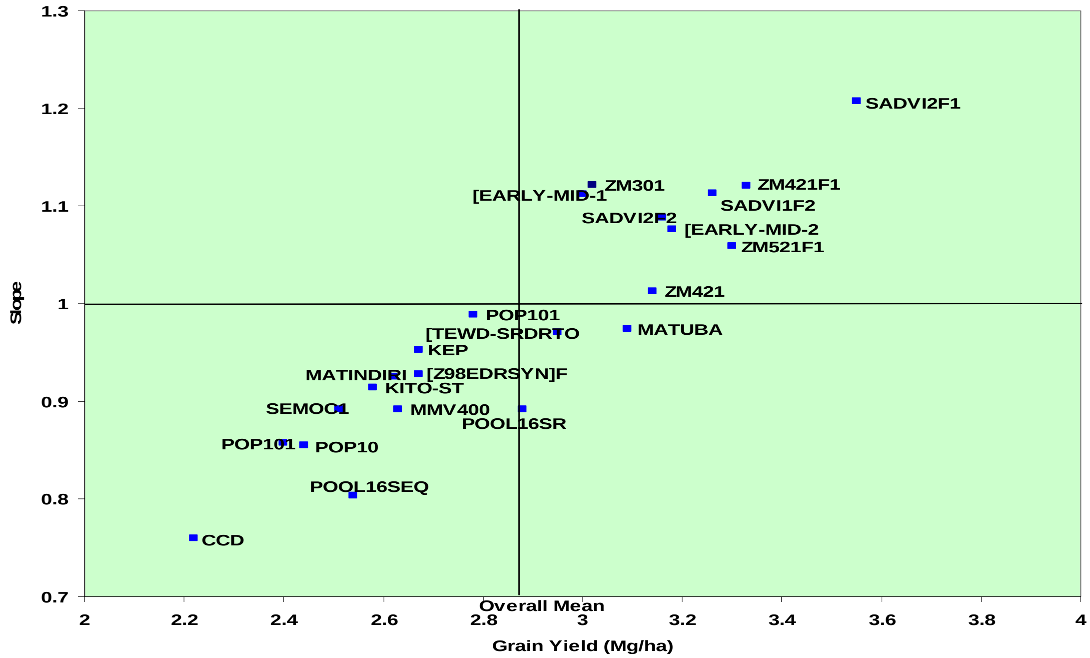

Fig. 5.24 Grain yield vs. regression slope for early populations (EPOP) in 2000 across optimal maize testing locations in eastern and southern Africa.

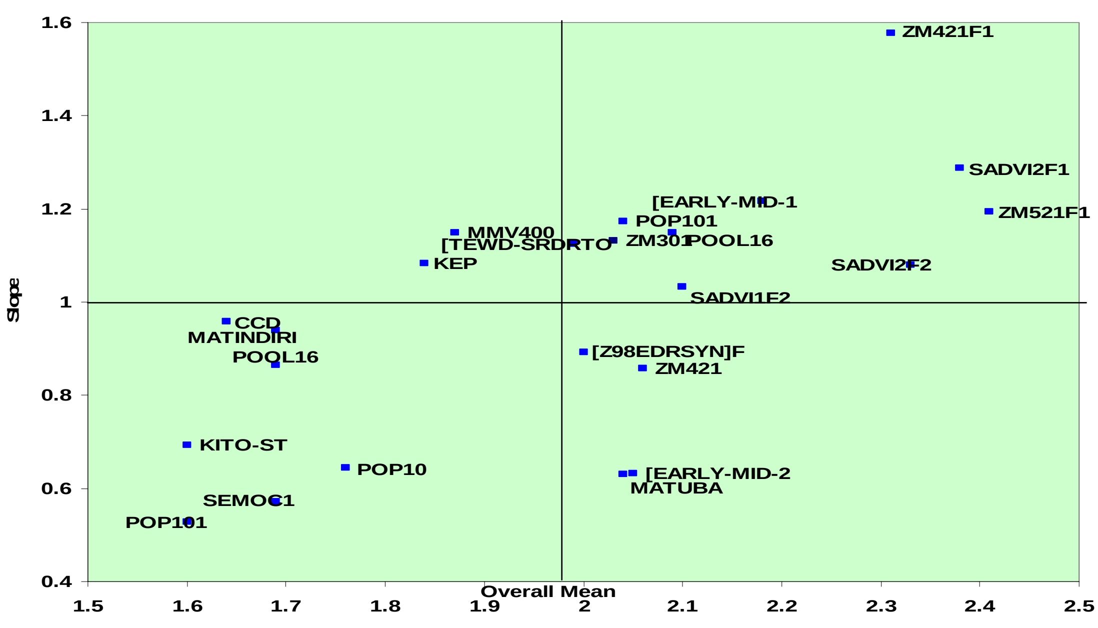

Fig. 5.25 Grain yield vs. regression slope for early populations (EPOP) in 2000 across stress maize testing locations in eastern and southern Africa.

In 2001, for early population (EPOP) under optimum conditions, the regression slope/grain yield general trend indicated that high yield had high regression slope (Fig. 5.26). Population KEP had the lowest yield of 2.52 Mg/ha and the least regression slope of 0.82. Population ZM521-FLINT had the highest yield of 3.45 Mg/ha with very high regression slope of 1.13. The yields under optimal conditions ranged from 2.52 Mg/ha to 3.45 Mg/ha with the mean test annual mean of 2.95 Mg/ha. Relatively stable early population was EARLY MID-1 (*bi* = 0.98) but it produced low yields. Population ZM305F1 (*bi* = 1.04) could be desirable as it has fair stability and yield well above average of 3.34 Mg/ha.

For EPOP in 2001, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.27). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The population yields under stress ranged from 2.08 to 2.98 Mg/ha with the mean test annual mean of 2.55 Mg/ha. Relatively stable genotypes under stress were ZM421-FLINT (*bi* = 1.01) and ZM521 (*bi* = 1.03). The relatively highest yielding genotype under stress was ZM521 (*bi* = 1.03) with the grain yield of 2.98 Mg/ha. Population ZM521 maintained relatively high yield under stress and optimal growing conditions but was stable only under stress conditions. Population ZM 521 was produced directly from the Soil Fertility and Drought Project by CIMMYT. It has been observed to do well in most of the countries, and was being cited as one of the indicators for success of the project.

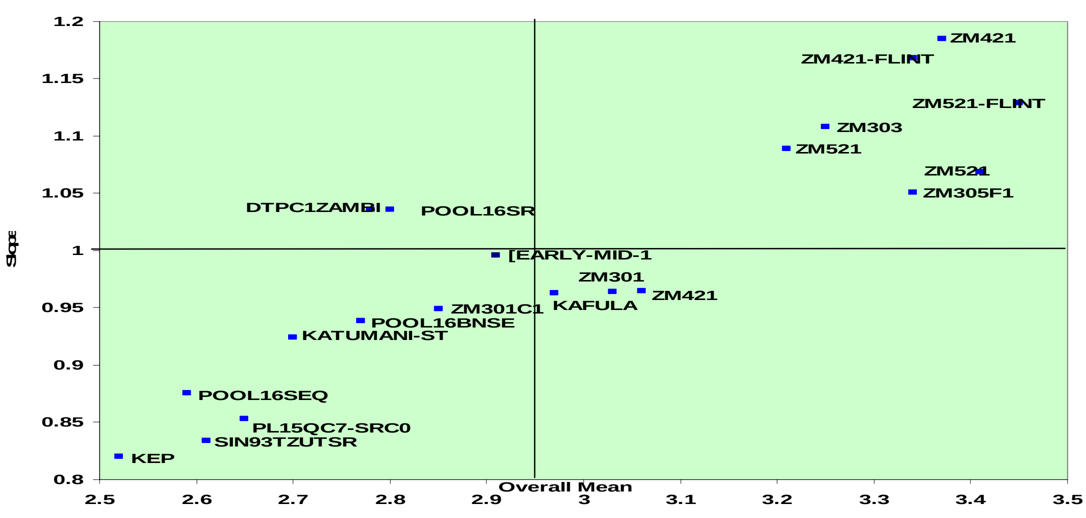

Fig. 5.26. Grain yield vs. regression slope for early populations (EPOP) in 2001 across optimal maize testing locations in eastern and southern Africa.

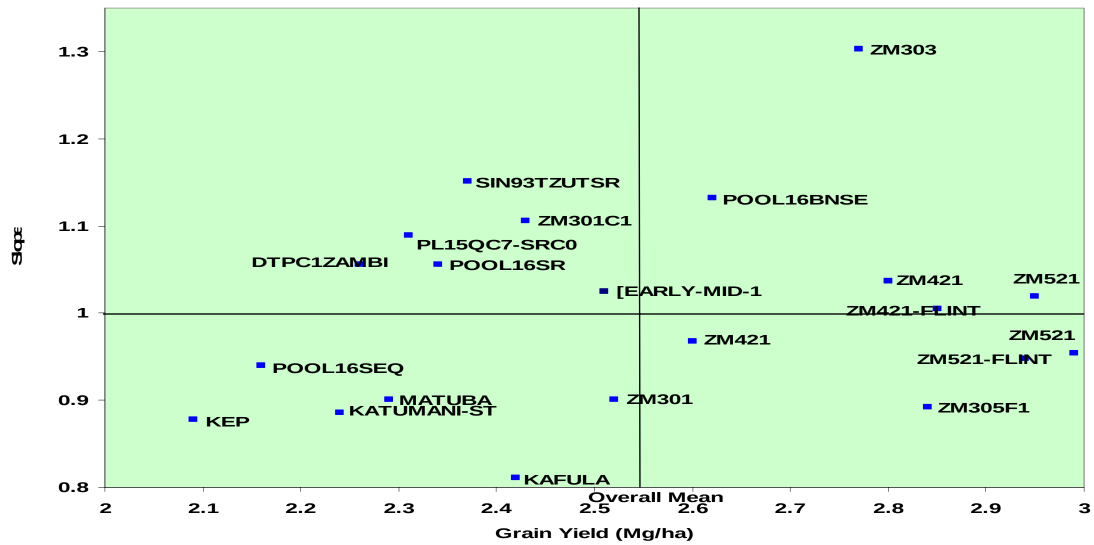

Fig. 5.27. Grain yield vs. regression slope for early populations (EPOP) in 2001 across stress maize testing locations in eastern and southern Africa.

In 2002, for early population (EPOP) under optimum conditions, the regression slope/grain yield general trend indicated that high yield had high regression slope (Fig. 5.28). Population MATUBA had the lowest yield of 3.25 Mg/ha and the least regression slope of 0.84. Population ZM523 had the highest yield of 4.52 Mg/ha with very high regression slope of 1.25. The yields under optimal conditions ranged from 3.25 Mg/ha to 4.52 Mg/ha with the mean test annual mean of 3.92 Mg/ha. Relatively stable populations were 00SADV1 (*bi* = 1.01), ZM521FLINT (*bi* = 1.00), ZM305 (*bi* = 1.02), KATUMANI (*bi* = 0.99) and ZM303 (*bi* = 0.99). However, populations KATUMANI and ZM303 may not be desirable because of their low grain yields.

For EPOP in 2002, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.29). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The early population yields under stress in 2002 ranged from 2.45 to 3.10 Mg/ha with the mean test annual mean of 2.70 Mg/ha. Relatively stable early populations under stress were ZM429 (*bi* = 1.00) and ZM521 (*bi* = 1.02). The relatively highest yielding population under stress was ZM529 (*bi* = 1.00) with the grain yield of 3.10 Mg/ha. It was the highest yielding and the most stable, which might be highly desirable in cultivar development for wide adaptation. Population ZM423 maintained relatively high yield and fair stability under stress and optimal growing conditions.

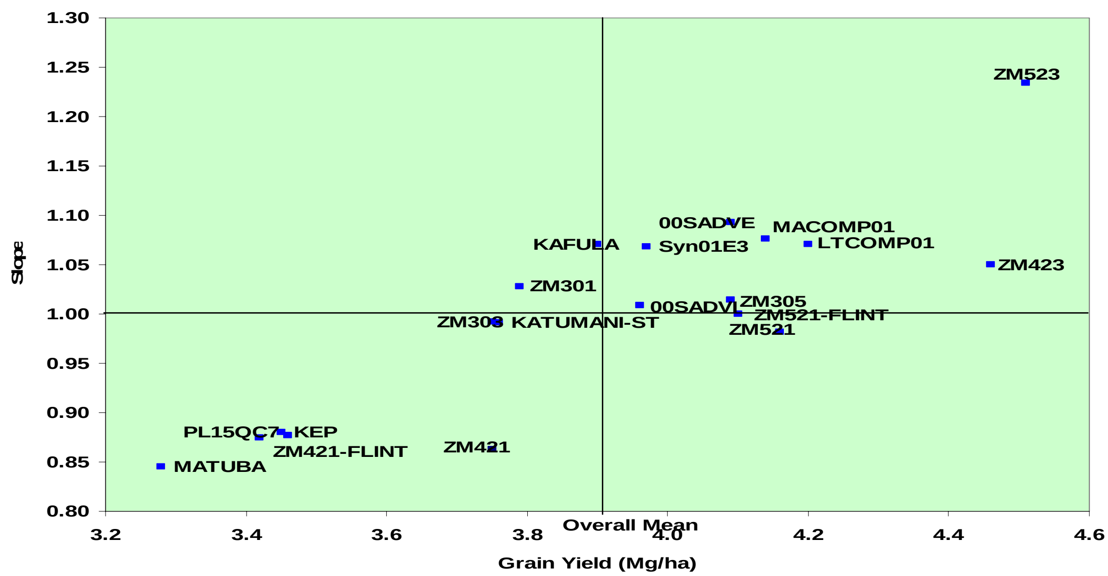

Fig. 5.28 Grain yield vs. regression slope for early populations (EPOP) in 2002 across optimal maize testing locations in eastern and southern Africa.

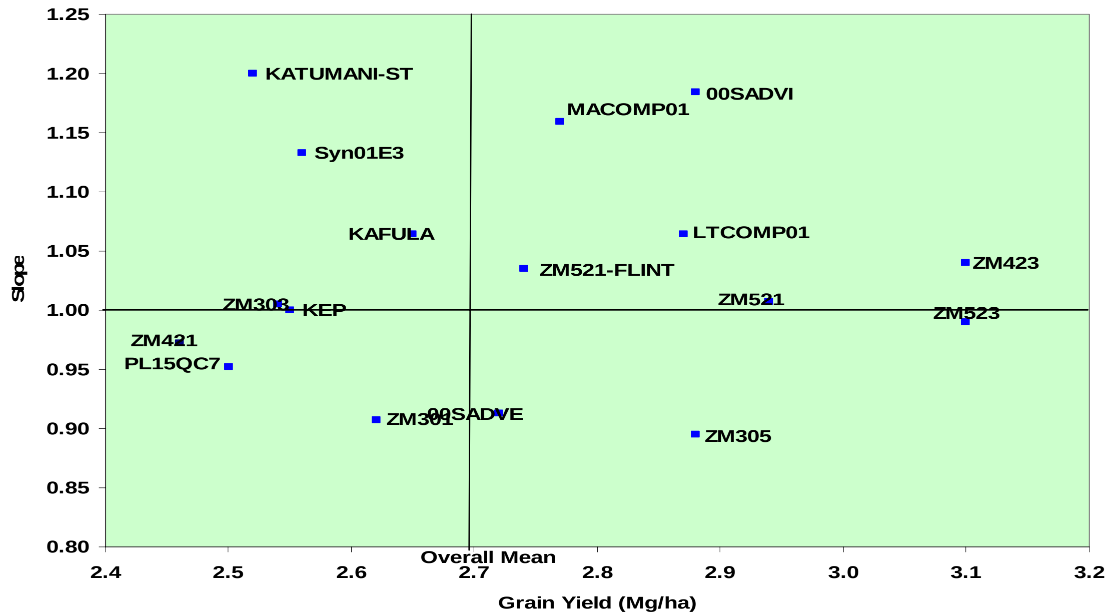

Fig. 5.29 Grain yield vs. regression slope for early populations (EPOP) in 2002 across stress maize testing locations in eastern and southern Africa.

For early population (EPOP) under optimum conditions in 2003, the regression slope/grain yield general trend was clear and distinct and indicated that high yield had high regression slope (Fig. 5.30). Population KEPC1 had the lowest yield of 2.12 Mg/ha and the least regression slope of 0.64 and 99SADVIF2 with highest yield of 3.35 Mg/ha with very high regression slope of 1.25. The yields under optimal conditions ranged from 2.12 Mg/ha to 3.35 Mg/ha with the mean test annual mean of 2.82 Mg/ha. Relative stable populations were ZM521 F2 (*bi* = 1.01), ZM421-FLINT (*bi* = 0.99) and VV021 (*bi* = 1.00). Population 99SADVIF2 (*bi* = 1.25) with mean grain yield of 3.35 Mg/ha was the highest yielding early population. It was unstable because of its high slope, which was significantly different from the slope of the overall regression.

For EPOP in 2003, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.31). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The early population yields under stress in 2003 ranged from 1.46 to 2.60 Mg/ha with the mean test annual mean of 2.10 Mg/ha. Relatively stable genotypes under stress were Syn01E3F2 (*bi* = 0.98) and ZM521F2 (*bi* = 0.99). The relatively highest yielding genotype under stress was Syn01E2F2 (*bi* = 1.35) with a grain yield of 2.60 Mg/ha. It was the highest yielding but unstable population. Population ZM521F2 maintained relatively high yield and stability under stress and optimal growing conditions.

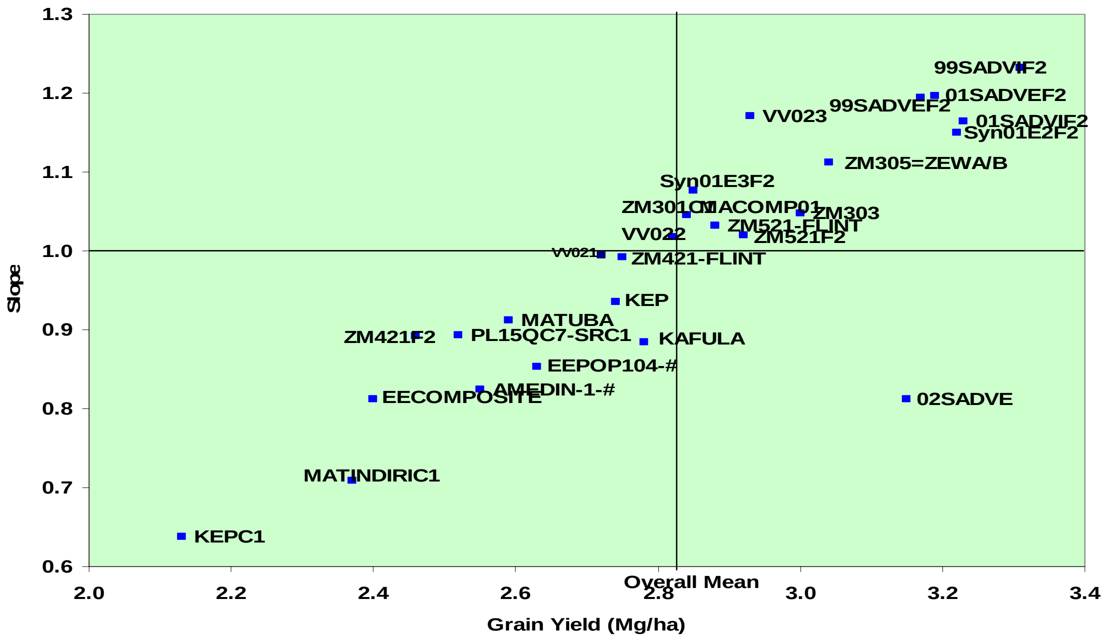

Fig. 5.30. Grain yield vs. regression slope for early populations (EPOP) in 2003 across optimal maize testing locations in eastern and southern Africa.

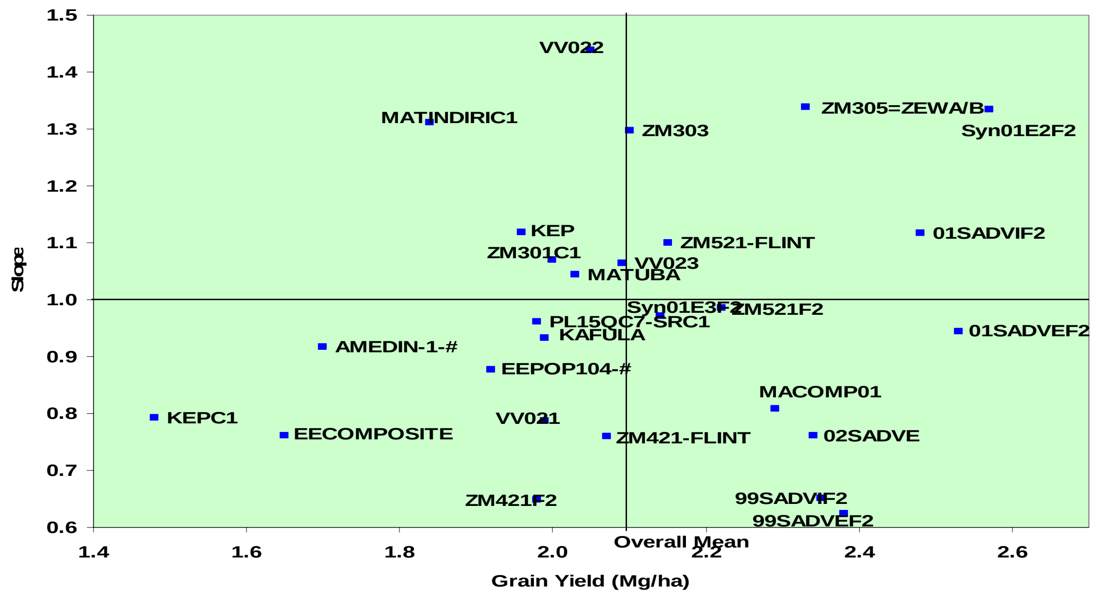

Fig. 5.31. Grain yield vs. regression slope for early populations (EPOP) in 2003 across stress maize testing locations in eastern and southern Africa.

Intermediate to late populations (ILPOP)

There were 72 entries of intermediate to late populations (ILPOP) evaluated from 1999 to 2003 and 32 of the entries appeared more than once during the period. Figures 5.32 to 5.41 show grain yield versus regression slope (*bi)*, of intermediate to late population (ILPOP) from 1999 to 2003. The regression slope/grain yield general trend indicated that high yield had high regression slope. Regression slope (*bi*) was a qualitative and quantitative measure of stability for the genotypes. The closer it was to 1.00 the stable the was the genotype and if it was significantly different from the slope of overall regression, then that suggested that the yield of the genotype varied significantly from location to location.

Under optimal conditions in 1999 for intermediate to late populations (ILPOP), the relationships between grain yield and regression slope showed a trend in which the higher the yields the higher the regression slope (Fig. 5.32). The intermediate to late population yields ranged from 3.05 to 4.56 Mg/ha, with the overall mean of 3.72 Mg/ha. The yields from intermediate to late populations were higher than the yields obtained from early populations. Relatively stable late populations were [TSEQZIM] C1F (*bi* = 1.03), INTAC1F1/INT (*bi* = 1.00) STAHA (*bi* = 1.02).and DRACOSYNF1D (*bi* = 1.03). STAHA may not be desirable because it had low average grain yield. Population ZM621 F1 (*bi* = 1.19) was the highest yielding late population, with mean grain yield of 4.56 Mg/ha. It was relatively unstable based on the slope, which was significantly different from the slope of overall regression.

For ILPOP in 1999, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.33). There was a drop in grain yield under stress but not as much as was the case in hybrids. The yields under stress ranged from 1.74 to 2.88 Mg/ha with the mean test annual mean of 2.30 Mg/ha. Relatively stable intermediate to late genotype under stress was SUNDWE (*bi*) = 1.04 but it may not be desirable because it performed poorly in terms of yield. The relatively highest yielding genotype under stress was MASIKA (*bi* = 1.35) with a grain yield of 2.88 Mg/ha. Populations MASIKA and Z97SYNGLS (B) maintained relatively high yield under stress and optimal growing conditions but were unstable under both growing conditions.

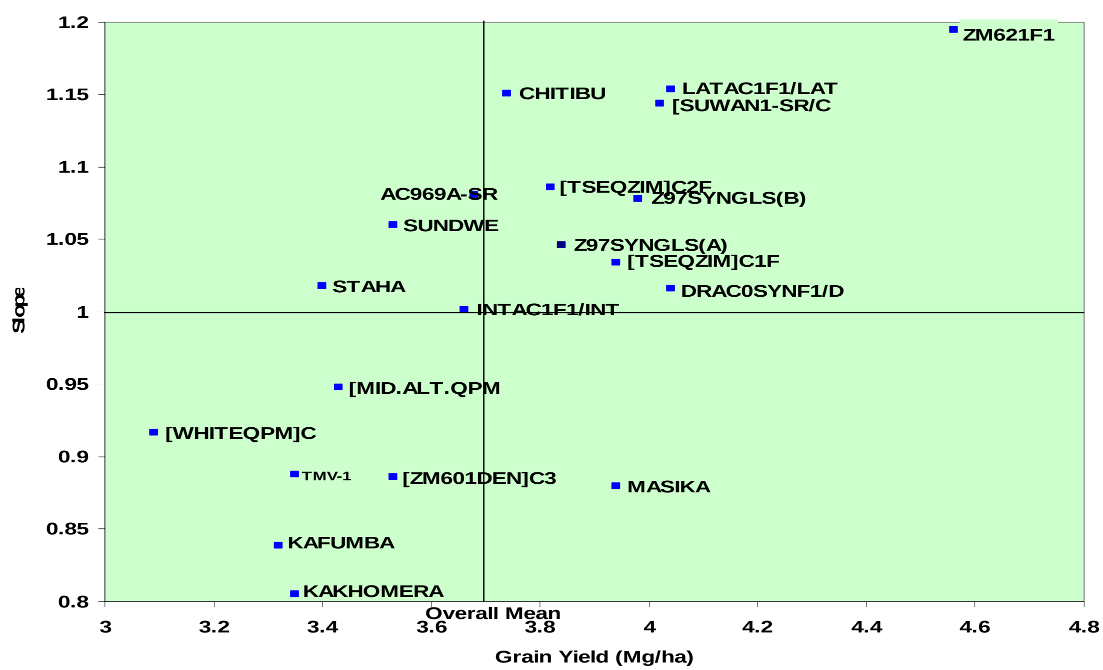

Fig. 5.32. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 1999 across optimal maize testing locations in eastern and southern Africa.

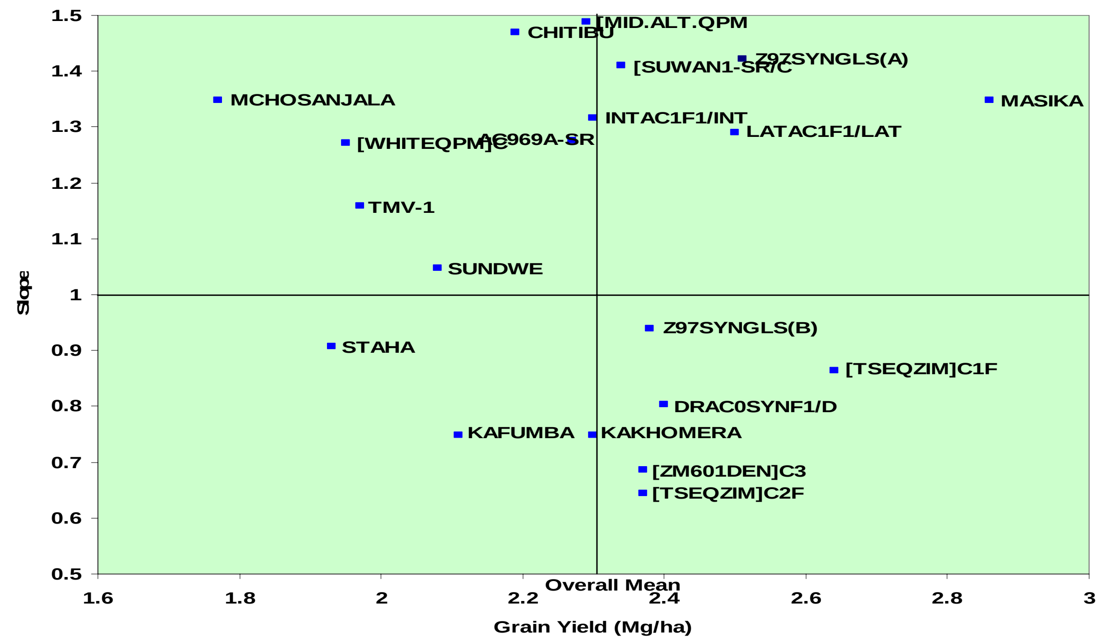

Fig. 5.33. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 1999 across stress maize testing locations in eastern and southern Africa.

Under optimal conditions in 2000 for intermediate to late populations (ILPOP), the relationships between grain yield and regression slope showed a trend in which the higher the yields the higher the regression slope (Fig. 5.34). The intermediate to late population yields in 2000 ranged from 3.61 to 4.95 Mg/ha, with the test annual mean of 4.05 Mg/ha. Relatively stable late populations were Z97SYNGLS (B) (*bi* = 1.01), OBATANPA (*bi* = 0.99), MASIKA (*bi* = 1.02), KILIMA SR (*bi* = 0.97), AC969A-SR (*bi* =1.03) and TASEQ (*bi* = 0.97). Of all these, only MASIKA and Z97SYNGLS (B) may be desirable because they had yields higher than the average. Population ZM611 F1 (*bi* = 1.07) was the highest yielding entry with the yield of 4.95 Mg/ha. The genotype may be desirable because it is fairy stable and high yielding.

For ILPOP in 2000, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.35). There was a drop in grain yield under stress but not as much as was the case in hybrids. The yields under stress ranged from 1.64 to 3.10 Mg/ha with the mean test annual mean of 2.20 Mg/ha. Relatively stable intermediate to late population under stress was ZM605C4 (*bi* = 0.94) but it may not be desirable because it performed poorly in terms of yield. The relatively highest yielding genotype under stress was ZM611 (*bi* = 1.30) with the grain yield of 3.10 Mg/ha. Populations MASIKA and ZM611 maintained relatively high yield under stress and optimal growing conditions but were unstable under both growing conditions.

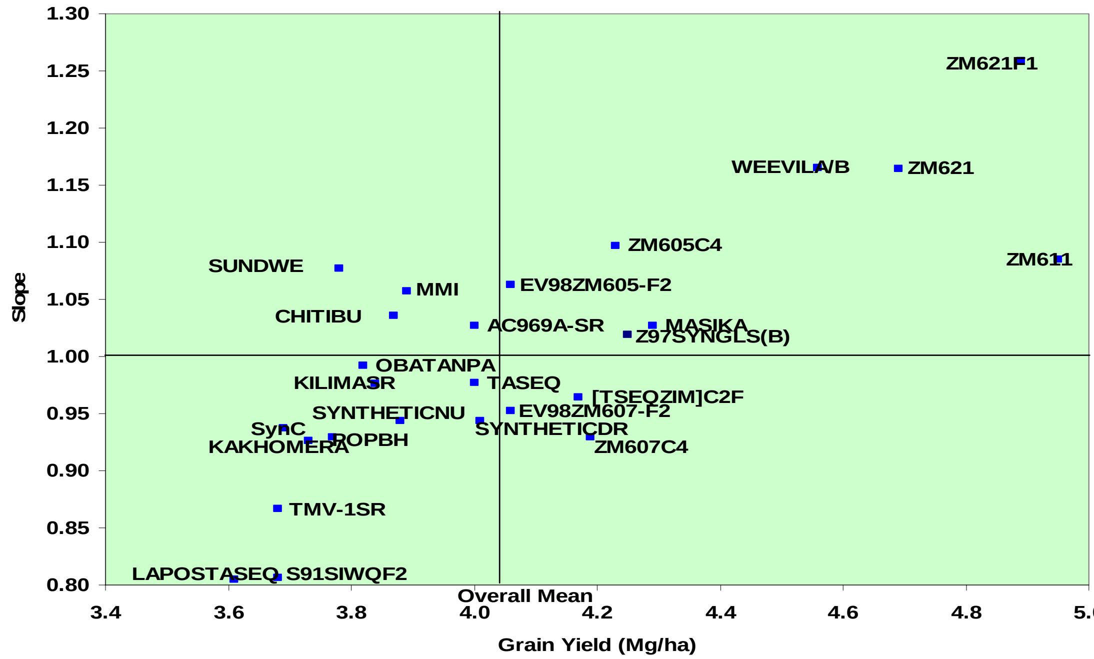

Fig. 5.34. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2000 across optimal maize testing locations in eastern and southern Africa.

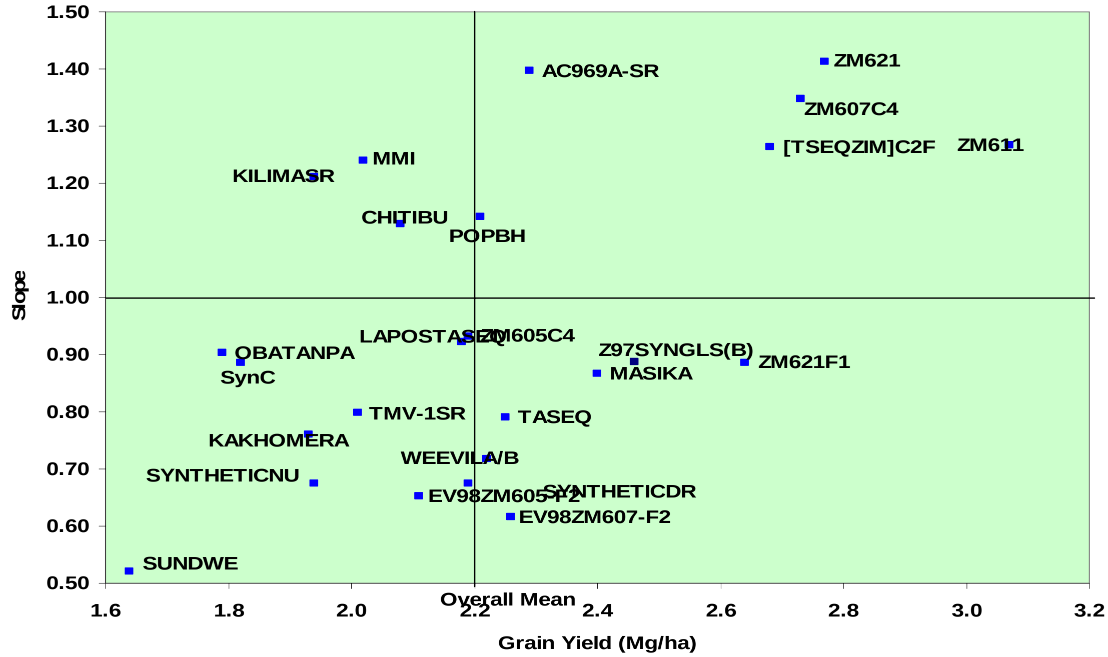

Fig. 5.35. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2000 across stress maize testing locations in eastern and southern Africa.

In 2001, for intermediate to late population (ILPOP) under optimum conditions, there was no particular trend with respect to the relationship between regression slope and grain yield (Fig. 5.36). The yields under optimal conditions ranged from 3.65 Mg/ha to 6.35 Mg/ha with the mean test annual mean of 4.62 Mg/ha. These yields were much higher than the yields obtained from early populations and they compared favorably with yields for the hybrids. Relatively stable intermediate to late population were ZM605C4 (*bi* = 0.99), MASIKA (*bi* = 0.99), TZLCOMP (*bi* = 0.98) and ZM621 (*bi* = 1.01). MASIKA may be the most desirable because it was high yielding and stable and is the most commonly used OPV in Malawi.

For ILPOP in 2001, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.37). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The population yields under stress ranged from 2.34 to 3.12 Mg/ha with the mean an annual mean of 2.72 Mg/ha. Relatively stable genotypes under stress were Z97SYNGLS (B (*bi* = 0.99) and ACR9222-SR (*bi* = 1.01). The relatively highest yielding genotype under stress was ZM621F1 (*bi* = 1.03) with a grain yield of 3.12 Mg/ha. Populations ZM621F1 and Z97SYNGLS (B) maintained relatively high yield under stress and optimal growing conditions but were stable only under stress conditions. Some intermediate to late populations produced yields just as high as hybrids and sometimes even higher. ZM621 consistently yielded high under all conditions. It is now being used in most maize seed production programs in Malawi, Zambia, Mozambique and Zimbabwe.

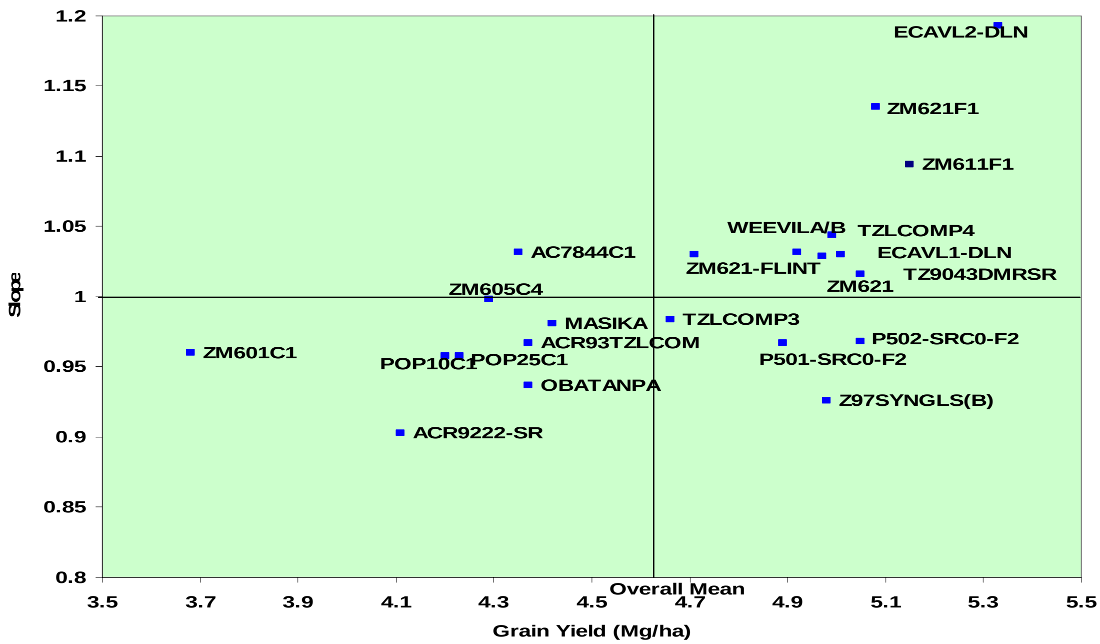

Fig. 5.36. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2001 across optimal maize testing locations in eastern and southern Africa.

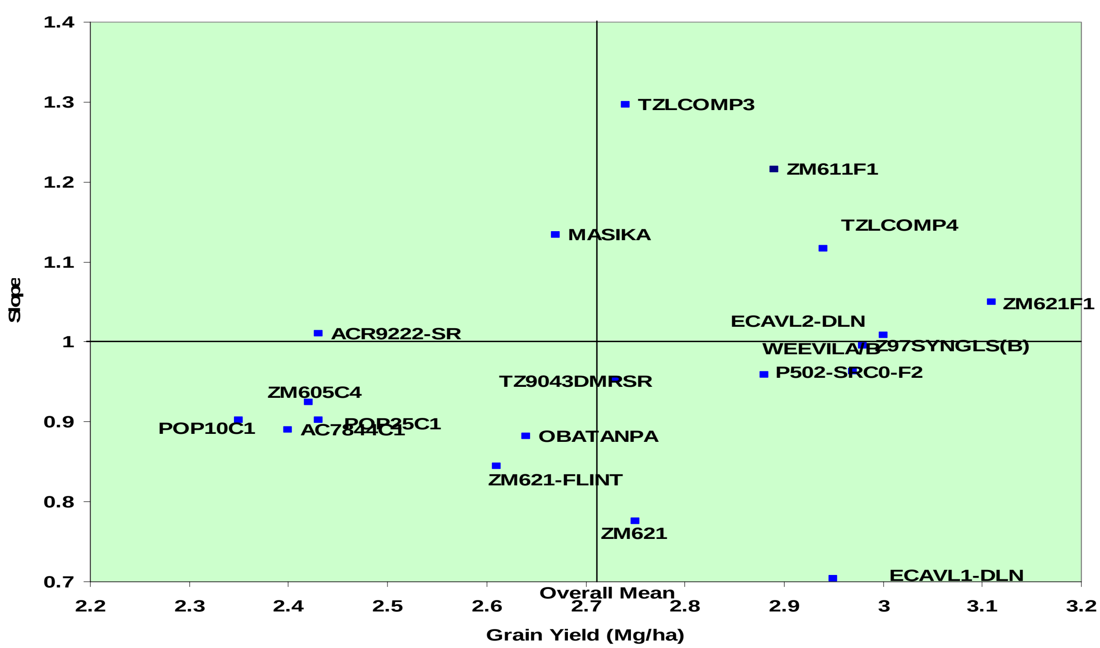

Fig. 5.37. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2001 across stress maize testing locations in eastern and southern Africa.

In 2002, for intermediate to late population (ILPOP) under optimum conditions, there was a trend in the the relationship between regression slope and grain yield. The higher the yields, the higher the regression slopes (Fig. 5.38). Population LTSYN01 (*bi* = 0.84) with the lowest regression slope had the least yield of 3.54 Mg/ha and Population ZM623 (*bi* = 1.14) with one of the highest regression slopes has the highest yield of 6.68 Mg/ha. These yields were much higher than the yields obtained from early populations and they compared favorably with yields for the hybrids. Relatively stable populations were OBATANPA (*bi* = 1.01) and ZM621 (*bi* = 0.99). OBATANPA may not be desirable because it had low yields.

For ILPOP in 2002, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.39). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The population yields under stress ranged from 2.52 to 3.28 Mg/ha with the mean test annual mean of 2.85 Mg/ha. Relatively stable population under stress was ZM621 (*bi* = 0.99). The relatively highest yielding population under stress was WEEVIL (*bi* = 1.35) with grain yield of 3.28 Mg/ha. The highest yielding genotype had poor stability. Population ZM621 maintained relatively high yield and stability under stress and optimal growing conditions.

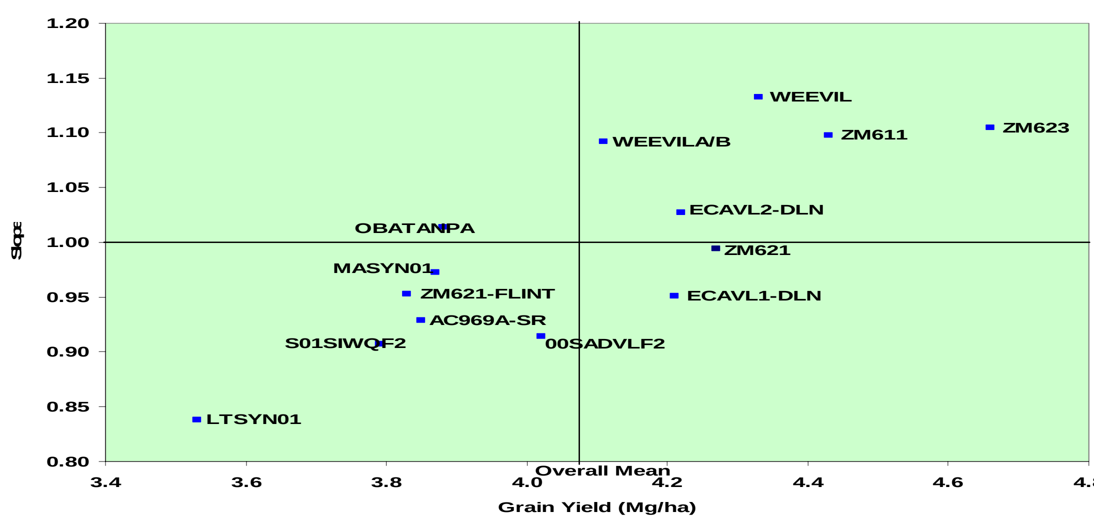

Fig. 5.38. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2002 across optimal maize testing locations in eastern and southern Africa.

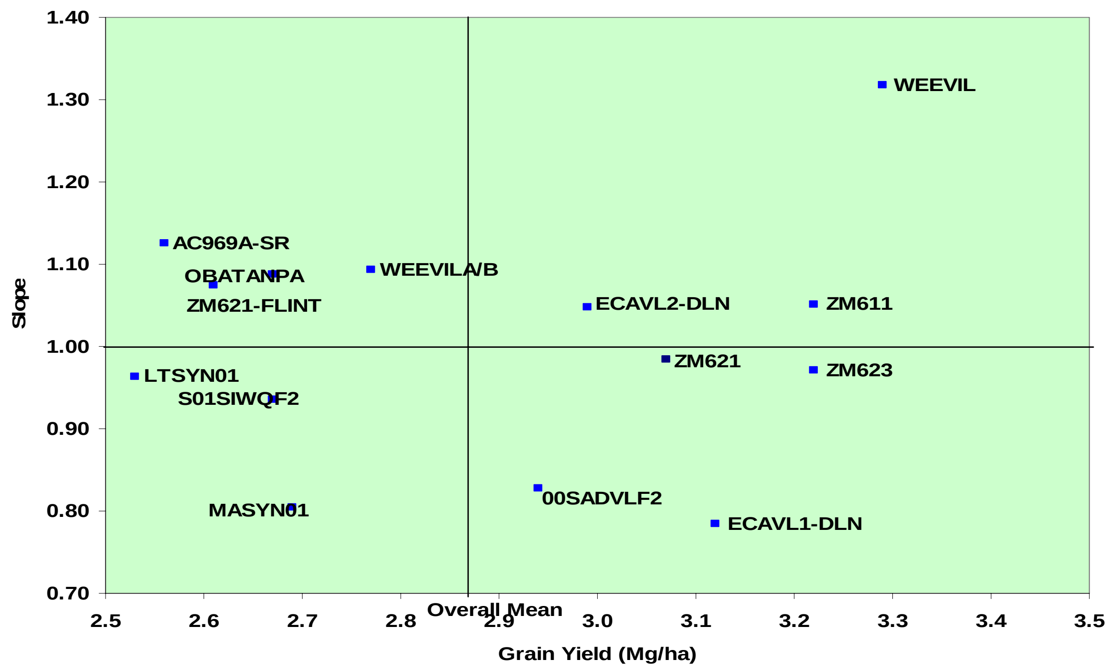

Fig. 5.39. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2002 across stress maize testing locations in eastern and southern Africa.

In the final season of 2003, for intermediate to late population (ILPOP) under optimum conditions, there was a trend with respect to the relationship between regression slope and grain yield (Fig. 5.40). High grain the yields were associated with high the regression slopes. Population S01S1WQC1F2 (*bi* = 0.82) with one of the lowest regression slopes had the least yield of 2.47 Mg/ha. Population 02SADV (*bi* = 1.16) with one of the highest regression slopes has the highest yield of 3.2 Mg/ha. These yields were much lower than yields obtained from the optimum location, illustrating quite a significant impact drought and low can exert on productivity of maize. Relatively stable populations were ZM621-FLINT (*bi* = 1.00), MASIKA (*bi* = 0.98), and TMV-1 DR C1 (*bi* = 1.01). MASIKA may be the only one desirable because it had high yields.

For ILPOP in 2002, under stress (drought and low nitrogen) conditions, there was no particular trend with respect to the relationships between regression slope and grain yield (Fig 5.41). There was a drop in grain yield under stress but at the lesser magnitude than that experienced in hybrids. The population yields under stress ranged from 1.90 to 2.90 Mg/ha with t an annual mean of 2.42 Mg/ha. Relatively stable populations under stress were 01SADVL (*bi* =

0.99) and ECAVL1-DLN (*bi* = 1.01). The relatively highest yielding population under stress was 99SADVL (*bi* = 1.45) with the grain yield of 3.20 Mg/ha. The highest yielding genotype had poor stability. Population 99SADVL maintained relatively high yield under stress and optimal growing conditions but was unstable under both growing conditions.

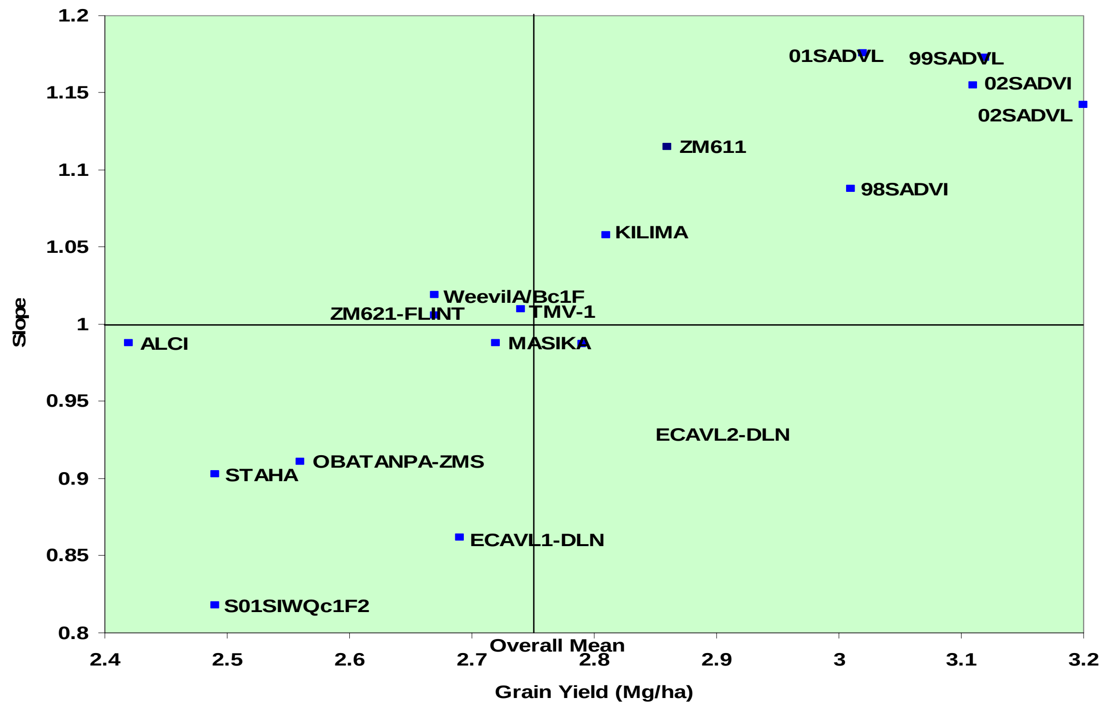

Fig. 5.40. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2003 across optimal maize testing locations in eastern and southern Africa.

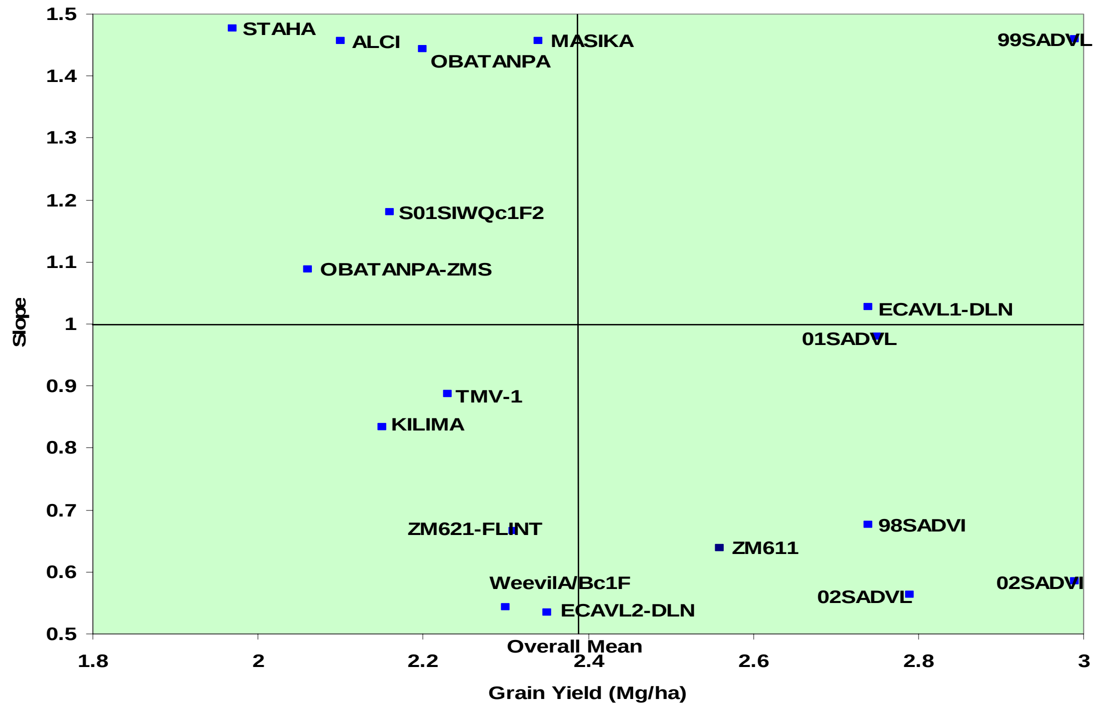

Fig. 5.41. Grain yield vs. regression slope for intermediate to late populations (ILPOP) in 2003 across stress maize testing locations in eastern and southern Africa.

SUMMARY

Stability analysis was conducted in groups of maize genotypes, separating hybrids and open pollinated varieties, and different maturity groups. Löffler et al. (1986) justified this grouping and stated that differences in yield stability among genotypes were a function of relative maturity, which suggested that evaluations of yield stability would be more efficient if genotypes with minimal maturity differences were tested as a group. It had been observed in this study that stability of genotypes was different depending on the type of genotypes. It was not possible to combine the analysis across season because the entries each season were different. Therefore, the analyses were conducted by year and group. Hybrids showed significant drop in yield under stress conditions. Populations (open pollinated) varieties had lower yield than hybrids but suffered less reduction in performance due to stress (drought and low nitrogen). More stable and high yielding genotypes were identified in both hybrids and populations.

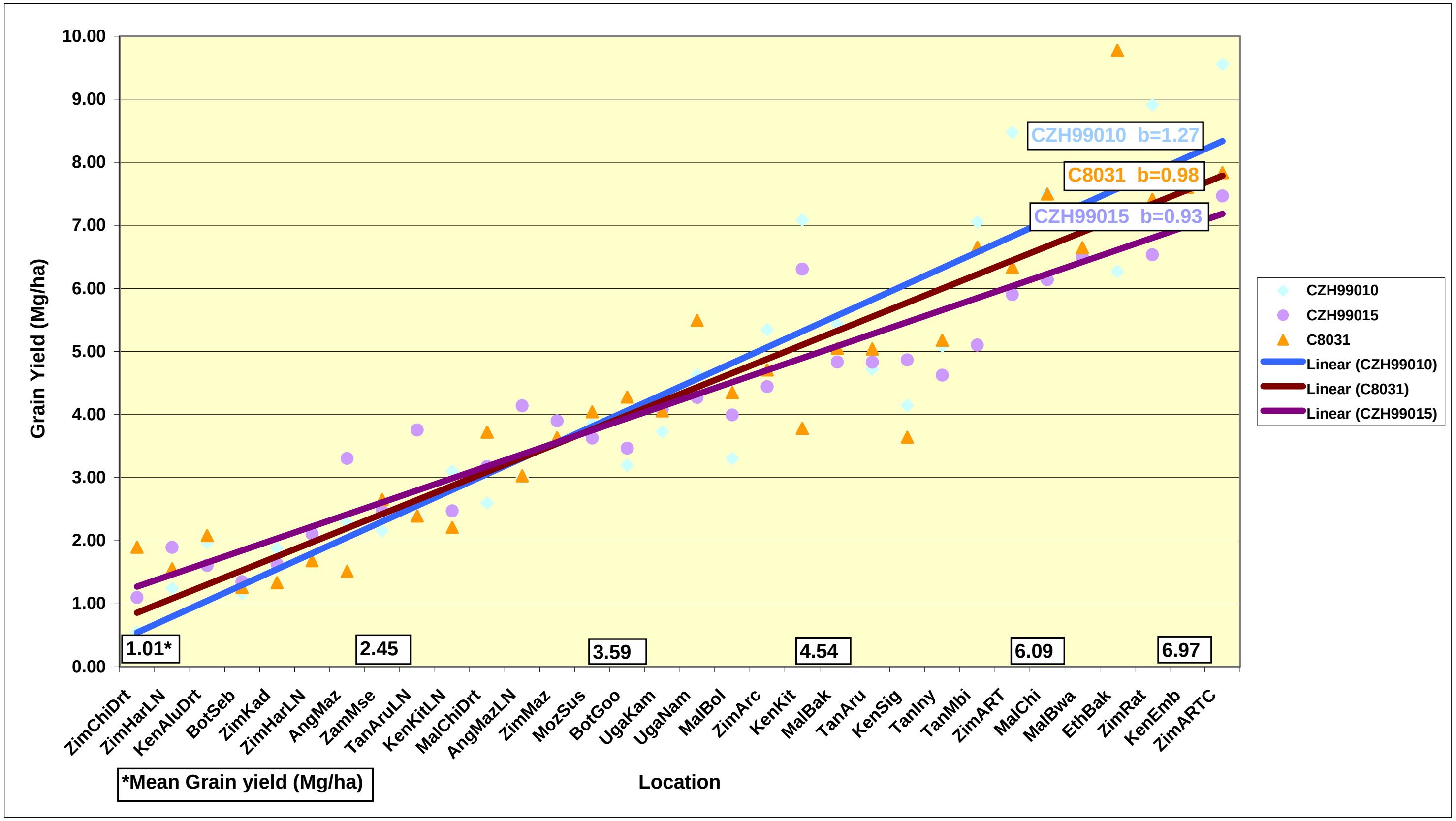

Fig. 5.42. Regressions of grain yield of three maize hybrids on environmental means of locations in eastern and southern Africa for EIHYB during 2001.

Among the hybrids, it was observed that most single cross hybrids had consistent performance. When developing materials for developing countries, stability may be more important than yield. Figure 5.42 demonstrated important responses of maize genotypes to varying growing conditions. Hybrid CZ99010 performed poorly under stress but produced much higher yields under optimal conditions. Hybrid C8030 performed as expected in each environment, which meant that for farmers who can afford high inputs they can use the hybrid because it will respond adequately to favorable conditions. Hybrid CZH99015 performed better under stress conditions and this favors farmers with limited resources as the hybrid can perform under fairly well under conditions that were less than optimal. Stability analysis was an important complimentary parameter to choose suitable cultivars (hybrids or populations) for the region. Selections made in certain locations may result in suitable germplasm for other areas (Paliwal and Sprague, 1982; Crossa et al, 1988). Hence, understanding realiontship among locations would ultimately result in increases in efficiencies in selection and cultivar development. By considering both yield potential and stability, selected genotypes will not only be tolerant to drought and low nitrogen, but will also have good stability.

The most severe limitation of the regression approach to study genotype stability is the poor repeatability of b_i and the large number of environments needed for reliable estimate (Becker and Léon, 1988). The large number of locations (over 30 locations per set) used in this study and the quality of the regional data resulted in highly improved repeatability of b_i and meant that the regression approach was appropriate in identifying stable genotypes.

The highlight of this work was the emergence and confirmation of ZM621 as a high yielding and very stable open pollinated maize cultivar. It showed consistency under both stress and optimal conditions, and it is not surprising that most of the maize seed production programs in the region are using this germplasm.

CHAPTER VI

CONCLUSIONS

RELATIONSHIPS AMONG MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

Sequential retrospective pattern analysis was successful in identifying similarities among locations and grouped them into durable groupings which could be used by plant breeders easily and effectively. The reduced D-matrix returned 63 major testing locations, and this was adequate, with high discrimination power. The pattern analysis for individual annual tests conducted with IRRISTAT complemented the discrimination across tests and across years. Single value decomposition (AMMI) biplot analysis was also very effective in displaying relationship among locations and genotypes. Stress locations were clustered together but showed high genotype by environment interaction when analyzed separately. The grouping of locations was based on environmental conditions beyond political boundaries. This validates the rationale for regional maize germplasm deployment.

Work on characterization and better understanding of the maize testing locations should continue. The results of this work will only complement efforts of establishing magaenvironments with the aim of making testing more effective and efficient, especially for stress environments. As the population continues to grow and more and more people are forced into marginal areas, an understanding of testing locations will become ever more relevant. The cluster and thus the groupings produced are expected to be durable and when used effectively can help plant breeders in choosing appropriate tests for testing maize genotypes in the region both for stress and non stress conditions. This work can be used in refining the already established megaenvironments, which are based on long term climatic factor, relief, and edaphic consideration. It is possible to effectively reduce the number of testing locations without significant loss in the performance assessment of testing genotypes in relevant environments in the region. Further implementation of Geographical Information Systems (GIS) technology can be used to develop more accurate maps for megaenvironments for eastern and southern Africa,

The information from this work is also useful in more efficient variety release as varieties released in one given area can be potentially deployed or tested in similar regions.

PHENOTYPIC AND GENETIC ANALYSIS OF MAIZE TESTING EVALUATIONS IN EASTERN AND SOUTHERN AFRICA

Analysis of components of variation showed that location contributed over 60% and sometimes up to 85% of total variation that was observed for grain yield. The high proportion of variation due to environment as well as the significant genotype by location interaction detected, emphasize the need for multi-location testing to identify high yielding stress tolerant germplasm in the region.The effect of location is reduced under stress locations. The proportion of variation components changed under stress. Both genotypic and error variances decreased. In general, repeateabilities also decreased under stress when compared with optimal conditions. These results are consistent with those of Ud-din et al. (1992), Calhoun et al. (1994), Bänziger et al. (1997), Bertin and Gallais (2000), and Sinebo et al. (2002), who found that heritabilities are generally lower under lower input level or in stressed conditions than under optimum or high input conditions. Among the three stress factors considered, low pH resulted in significant reduction in repeatability for grain yield. Low nitrogen and drought remain the most important stress factors affecting maize production in the region. The fact that most of the variation observed was due to location and location by genotype interaction emphasized the need for this kind of analysis when testing is conducted over a number of locations. The alpha lattice field design used for these trials was appropriate as all the components of variation were significant in the partition of variation. Despite the changes in the distribution of components of variation in response to stress conditions (dought, low pH and low N), maize testing can be successfully conducted successfully under both optimum and stress conditions. Genotypic variation is higher under optimum conditions that under stress conditions. Adequate generation, testers, field experimental and statistical approaches and careful management of stress facilitate meaningful evaluations under stress conditions.

RELATIONSHIPS AMONG TRAITS IN MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

The relationships among traits suggested that plant breeders should be encouraged to incorporate additional traits to grain yield when identifying and selecting superior genotypes. Secondary traits such as anthesis-silking interval had been shown to be more useful when selecting under stress conditions like drought and low nitrogen conditions. Anthesis-silking interval showed clear and consistent responses in both stress and non-stress conditions in this study. This trait is confirmed as of real potential to be used for evaluation of maize genotypes especially under stress environments. Ears per plant as a measure of barrenness was also a very important trait. Therefore, where feasible and economical, additional secondary traits that complement grain yield should be used to improve efficiencies of plant breeding that are translated into enhanced genetic gains.

YIELD STABILITY OF HYBRIDS AND POPULATIONS IN MAIZE TESTING LOCATIONS IN EASTERN AND SOUTHERN AFRICA

Stability analysis provided an opportunity to look at the performance of individual genotypes in all locations across all seasons. The analysis was useful in identifying materials for advancement and deployment. Very high yielding materials were not the most stable. The analysis therefore identified materials that are suitable for farming systems in the region, which ultimately will stimulate adoption and use. Farmers in the region rather select materials that have stable yields and produce fair yields in stress conditions, although these genotype might not have very high yielding potential under ideal conditions. Populations were more stable than hybrids. Population ZM621 was stable and high yielding and is currently being used by farmers in most parts of the region. Although much focus is placed on the successes of populations ZM 421, ZM521 and ZM 621, because of their impact on the livelihoods of the smallholder farmer, it is important to note that development of high yielding and stable hybrids constitute an real alternative for various breeding programs. Provision of high producing hybrids to those who can use them, improves not only the availability of the seed to farmers but has a huge impact on production of maize in the region, because some of those who use hybrids cultivate in the best conditions possible and obtain hign yields. So development of better producing open pollinated varieties (OPVs) should go hand in hand with programs producing the best hybrids in the region.

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