AN EVALUATION OF CULTIVAR STABILITY IN ARC MAIZE TRIALS OVER A SIX YEAR PERIOD

By

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CHAPTER 1

GENERAL INTRODUCTION

Maize is widely grown in most parts of the world over a wide range of environmental conditions, between 50º latitude north and south of the equator. It is also grown from sea-level to over 3000 meters above sea-level (Singh, 1987). It is believed that the crop originated from Mexico and that it was introduced to West Africa during the early 1500's by Portugese traders. Maize is one of the most important products in human food, feed for livestock and industrial purposes.

Crop breeders have been striving to develop genotypes with superior grain yield, quality and other desirable characteristics over a wide range of different environmental conditions. Genotype x environment (GxE) interaction is one of the main complications in the selection of broad adaptation in most breeding programs. The phenotype of an organism is determined by the combined expression of the environment and the genotype which interact with one another. Numerous studies have shown that a proper understanding of the environmental and genetic factors causing the interactions as well as an assessment of their importance in the relevant genotype – environment system, could have a large impact on plant breeding (Basford and Cooper, 1998; Magari and Kang, 1993). GxE interaction occurs universally when genotypes are evaluated in several different environments (Becker and Leon, 1988; Kang, 1990; Magari, 1989). GxE interaction further complicates the selection of superior genotypes across environments. Magari and Kang (1993) found that the contribution of different environmental factors, to the yield stability of maize in yield trials, had a significant impact on the heterogeneity of the results.

If the GxE interaction is significant, it reduces the usefulness of overall genotype means for identifying cultivars which perform better than others across different/all environments (Magari and Kang, 1993). Therefore, several researchers tried to combine yield and performance stability into a single selection criterion (Kang et al., 1991; Bachireddy et al., 1992). Previous studies also showed that an accurate definition of the environmental factor(s), which participate in the GxE interaction is important for determination of the relevance of the observed differences (Basford and Cooper, 1998). In 1989, Kang and Gorman found that no information was available on the contribution of weather variables and environmental index to GxE interaction for yield in maize. So they conducted a study on maximum and minimum temperatures, rainfall for the growing season, pre-season rainfall and relative humidity on GxE interaction for yield. They concluded that all factors must be included into the model (if there's more than one independent environmental factor to consider) for determining the relative contribution of each variable to GxE interaction.

The term 'stability' has a variety of meanings and therefore needs to be defined clearly for each study. According to Lin et al. (1986) stability statistics can be divided into four groups which are determined by whether they are based on the deviations from the average genotype effect or on the GxE term, and whether or not they incorporate a regression model on an environmental index. Furthermore, they found that these groups are related to three concepts: i) a stable genotype results if the among-environment variance is small, ii) if its response to an environment is directly proportional to the mean response of all genotypes in the trial and iii) if the residual mean square from a regression model on the environment index is small. These three concepts represent the mentioned different aspects of stability. The alternative option is a non-parametric approach in which genotypes are grouped according to their similarity of response to a range of environments (Lin et al., 1986).

Becker (1981) distinguished between two basic concepts of phenotypic stability: i) a biological concept which states that a stable genotype should have a minimal variance under different environmental conditions and, ii) an agronomic concept, a stable genotype should show minimal interactions with environments as measured by the ecovalence. Since the coefficients of regression are almost perfectly correlated with variances, and mean squares for deviations from regression are almost perfectly correlated with ecovalence, the widely used method of regressing the yield of each genotype in the different environments on the respective means of all genotypes in the trial, may be regarded as a combination of these two concepts (Becker, 1981).

The objectives of this study were:

1. determination of the most appropriate stability parameter for Genotype x Environment interaction analysis as well as stability analysis of maize in South Africa
2. determination of the most stable maize cultivar in the overall South African maize production, concentrating on yield, for the periods of 2001-2003 and 1998-2003 respectively
3. studying the mean yield progress of 80 cultivars planted at one locality for the period of 2001-2003.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Yield is the most important agronomic characteristic of the maize crop, and therefore determines the superiority of cultivars. Successful cultivars need to possess high performance for yield along with other essential agronomic characters. Its success will be measured over a wide range of environmental conditions. GxE interactions, which occur often, cause differences between genotypes in their yield stability. Basford and Cooper (1998) defined genotype by environmental interaction to be a differential expression across environments. Genotypes represent the set of genes in a cultivar that is responsible for the expression of the traits under investigation, while the environment represents the non-genetic factors which influence the expression of the traits.

Ramagosa and Fox (1993) reported that GxE interaction reduces the association between phenotypic and genotypic values, causing the selected cultivar of one environment to perform poorly in another. Therefore, plant breeders need to concentrate on genotype adaptation. The breeding strategy for cultivars for adaptation to specific environments is determined by the appropriate measurements. The common variety testing strategy is to test these cultivars (genotypes) over a representative range of environments. Breeders have to include a representative sample of locations, which include a wide spectrum of different conditions and environmental variation. According to Ramagosa and Fox (1993), increasing tolerance to different stress factors is the best way to create a widely adapted cultivar and consequently selection in multiple environments is the best way to breed stable genotypes.

Stability has different definitions and concepts which were developed to apply in crop breeding programs (Lin et al., 1986; Becker and Leon, 1988). Becker and Leon (1988) defined two different concepts of stability, the static and dynamic. The traits under consideration determine which of these two must be applied, although both seem to be useful. The static concept defines stable genotypes to have no variance in performance at all, regardless of any variation of the environmental conditions. For the dynamic concept, it is the prediction of response of a genotype to a change in environment, as long as the stable genotype has no deviation from this response to environments.

Generally speaking, the more factors involved in the interaction component, the more difficult it becomes to identify broadly adapted genotypes. The identification and distinguishing of repeatable and non-repeatable interactions is of utmost importance. For repeatable interactions, specific adaptation strategies should be followed, non-repeatable interactions need to be accommodated by selection for broad adaptation (Basford and Cooper, 1998). Ramagosa and Fox (1993) concluded that if a genotype maintains high yield over a wide range of environments, it is referred to as having general or wide adaptation. On the other hand, if this is true only for a limited range of environments, that genotype has specific or narrow adaptation.

According to Lin et al. (1986) basic stability parameters can be classified into three types. For the first one, stability is analogous to homeostasis where a genotype is stable if its among environment variance is small. For the second type, genotype stability is determined by its response to environments and whether its response is parallel to the mean response of all genotypes in the trial. The third type is derived from the regressions on the environmental index and is measured by the residual mean squares from the regression model. Numerous authors feel that all three concepts have shortages in interpretations and application in breeding programs (Lin et al., 1986; Westcott, 1986).

2.2 DEFINITION OF STABILITY AND RELATED TERMS

Stability of yield is defined as the ability of a genotype to avoid substantial fluctuations in yield, over a range of environments (Heinrich et al., 1983). Achieving this objective in plant breeding programs is challenging. Heinrich et al. (1983) found that the causes of yield stability often are unclear, and physiological, morphological and phonological mechanisms that impart stability are diverse. Factors of yield stability can be categorized as: genetic heterogeneity, yield component compensation, stress tolerance and capacity to recover rapidly from stress. The stability of yield is one of the main measurements in selection of superior cultivars.

Genotype x Environment (GxE) interaction reduces the correlation between phenotypic and genotypic values (Kang and Gorman, 1989). This interaction complicates selection for broad adaptation, while their nature and causes need to be understood and analyzed clearly in selection for specific adaptation. The different environmental factors contributing to the GxE interactions has been particularly important in determining the relevance of observed differences in plant adaptation to the target population environments (Basford and Cooper, 1998).

2.3 CONCEPTS OF STABILITY

Stability has been described in many different ways over the years. There have also been different concepts of stability (Lin et al., 1986). Researchers use the terms adaptation, phenotypic stability and yield stability in different ways (Becker and Léon, 1988).

Lin et al. (1986) identified three concepts of stability:

Concept 1: If the among-environment variance of a genotype is small, the genotype is considered to be stable. This concept is useful for quality traits, disease resistance or for stress characters. According to this concept a genotype performs the same in different environments or under different environmental conditions. This stability is static or can be seen as a biological concept of stability (Becker en Léon, 1988). Genotype variances across environments (Si^2) and the coefficient of variability (CVi) are used as parameters to describe this type of stability (Francis and Kannenburg, 1978).

Concept 2: The stability of a genotype is measured by its response to environments compared to the mean response of all genotypes in the trial. According to Becker and Léon (1988) this concept is called a dynamic or agronomic concept of stability. In this case, a stable genotype has no deviations from the general response to environments and creates a possible way of predicting the response of a genotype to a certain environment. Parameters used to describe this type of stability are regression coefficients (bi) (Finlay and Wilkinson, 1963) and Shukla's (1972) stability variance ($\sigma^2 i$).

Concept 3: A genotype is considered to be stable if the residual mean squares from the regression model on the environmental index is small. The environmental index is the mean yield of all the genotypes in each location minus the grand mean of all the genotypes in all locations (Eberhart and Russel, 1966; Perkins and Jinks, 1968).

All stability procedures based on quantifying GxE interaction effects is part of the dynamic concept (Becker and Léon, 1988). These are Wricke's (1962) ecovalence, Shukla's (1972) stability of variance, Eberhart and Russell (1966) and non-parametric stability analysis.

Lin et al. (1986) defined four groups of stability statistics; they integrated concept 1, concept 2 and concept 3 stabilities within the four groups. Group A was regarded as concept 1, groups B and C as concept 2 and group D as concept 3 stability:

Group A:	DG (Deviation of average genotype effect)	SS (sum of squares)
Group B:	GE (GE interaction term)	SS
Group C:	DG or GE	Regression coefficient
Group D:	DG or GE	Regression deviation

Lin and Binns (1988) used predictable and unpredictable non-genetic variation to develop concept 4, for stability analysis with locations being the predictable component and years the unpredictable component. They suggested the use of a regression approach for the predictable portion and the mean square for years x locations for each genotype as a measure of the unpredictable variation.

2.4 STATISTICAL METHODS TO MEASURE GXE INTERACTION

Most commonly, a combined analysis of variance procedure is used to identify the existence of GxE interactions from replicated multi location trials. With a significant GxE interaction variance, one or more of the various methods for measuring the stability of genotypes can be used to determine the stable cultivars. The wide range of methods available for analysis of GxE interaction can be classified into four groups: the analysis of components of variance, stability analysis, multivariate methods and qualitative methods.

2.4.1 Conventional analysis of variance

Conventionally the analysis of variance was used to evaluate a trial in which the yield of G genotypes is measured in E environments over R replicates. This is also the classic way of measuring the total yield variation (Fisher, 1918; 1925). Differences in the genotype means, occur due to soil fertility and other factors like shading and competition from one plot to another. This is measured by the within environment residual mean square. When this replicate effect is taken into consideration and removed from the data, it can be separated into two groups: i) additive main effect for genotypes and environments and ii) non-additive effects due to GxE interactions. The analysis of variance of the combined data expresses the observed (Yij) mean yield of the ith genotype at the jth environment as

$$Yij = \mu + Gi + Ej + GEij + eij \qquad (1)$$

where μ is the general mean; Gi, Ej and GEij represent the effect of the genotype, environment, and the GxE interaction, respectively; and *e*ij is the average of the random errors associated with the rth plot that receives the ith genotype in the jth environment. In formula (1) the non-additive effects is defined and implies that the expected value of the ith genotype in the jth environment (Yij) depends not only on the levels of G and E separately but also on the particular combination of levels of G and E (Crossa, 1990).

This analysis has some limitations such as that it is an additive model and therefore describes only the main effects effectively. The ANOVA can test the significance of the GxE interaction, but this test may be misleading. It does not explain the particular patterns of genotypes or environments which lead to the interaction (Zobel et al., 1988). The valuable information contained in (G-1) (E-1) degrees of freedom is particularly wasted if no further analysis is done. Since the non-additive structure of the data matrix has a non-random (pattern) and random (noise) component, the advantage of the additive model is lost if the pattern component of the non-additive structure is not further partitioned into functions of one variable each

(Crossa, 1990). An ANOVA test of the significance of the GxE interaction may find it non-significant when, in reality, the interaction is agronomically important, where a more appropriate statistical model may both detect significance and describe interesting patterns in the interaction (Zobel et al., 1988).

Variance components related to different sources of variation, including genotypes and GxE interactions, can be estimated from the analysis of variance, which is one of the useful aspects of this model. Variance component methodology is important in multilocation trials since GxE interactions is one of the main reasons for errors in determining yield performance of genotypes. The size of this interaction is required to i) obtain efficient estimates of the genotypic effects and ii) determine optimum resource allocations (number of plots and locations to be included in future trials). Variance component methodology is used to estimate the heritability and predicted gain of a trait under selection, in breeding programs (Crossa, 1990).

2.4.2 Parametric approach

A general summery of the response patterns of genotypes to different environments is given by the stability analysis. The main type of stability analysis, namely joint linear regression (JLR), was first proposed by Yates and Cochran (1938) and then widely used and described by many authors (Finlay and Wilkinson, 1963; Eberhart and Russel, 1966; Perkins and Jinks, 1968; Shukla, 1972; Becker and Leon, 1988; Baker, 1988; Crossa, 1990). Linear regression models combine additive and multiplicative components and thus analyze main effects and their interaction (Zobel et al., 1988). Joint regression analysis provides a method of testing a genotype for characteristic linear responses to changes in environments. This process is done by regression of the genotypic means on an environmental index.

2.4.2.1 Regression coefficient (b_i) and deviation mean square (s^2d_i)

According to Ramagosa and Fox (1993) simple linear regression provides a conceptual model for genotypic stability and is the most widely used statistical technique in plant breeding. This model is also called the Finlay and Wilkinson (1963) approach. The regression of each genotype's mean yield against the mean yields of an environment is determined and the stability range is determined by the main effects multiplied by the regression coefficients of genotypes. The GxE interaction is divided into two segments, i) a component due to linear regression (b_i) of the ith genotype on the environment mean, and ii) a deviation (d_{ij}):

$$GE_{ij} = b_i E_j + d_{ij} \qquad (2)$$

therefore

$$Y_{ij} = \mu + G_i + E_j + (b_i E_j + d_{ij}) + e_{ij} (3)$$

The marginal means of the environments is used as independent variables in the regression analysis and the interaction is restricted to multiplicative form. The GxE from analysis of variance is partitioned between heterogeneity of regression and deviations from regressions (Becker and Leon, 1988). Different authors used different bi values to define genotype stability. Finlay and Wilkinson (1963) defined a genotype with $b_i = 0$ as stable (static concept), and Eberhart and Russell (1966) defined a genotype with $b_i = 1$ as stable (dynamic concept). Becker and Leon (1988) suggested that ecovalence rather be used, since it combines bi and s^2d_i into one parameter. Many scientists consider b_i as a response parameter and s^2d_i as a stability parameter, since additional information on the average response of a genotype to favorable environments is given by b_i.

This is schematically presented in Figure 2.1 as cited in Becker and Leon (1988) adapted from Haufe and Geidel (1978).

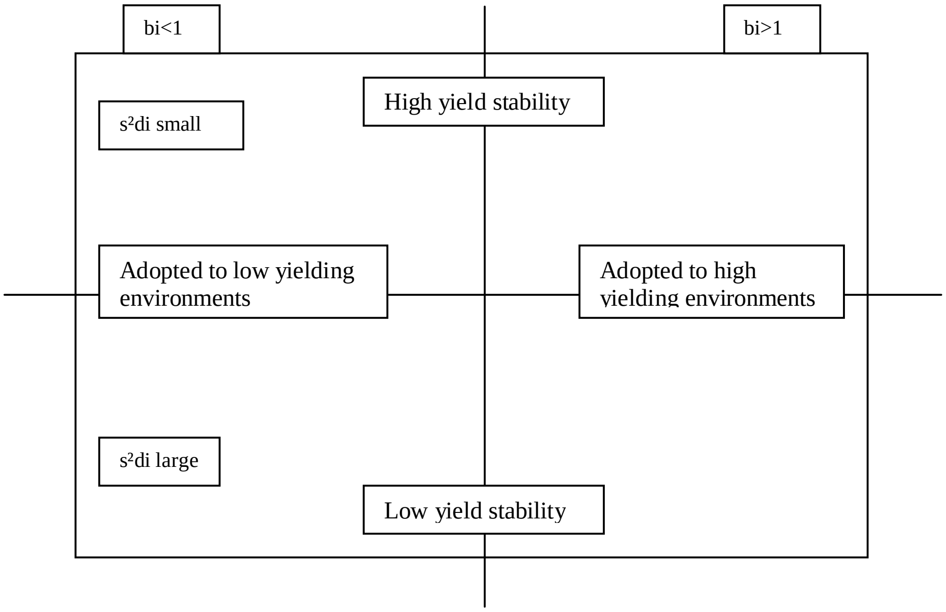

Figure 2.1 Interpretation of the parameters bi and s^2d_i of the regression approach (Becker and Leon, 1988).

Finlay and Wilkinson (1963) determined the regression coefficient by regressing the mean of all genotypes on the environmental mean, and plotting the obtained genotype regression coefficients against the genotype mean yields. Figure 2.2 illustrates the genotype pattern obtained when genotype regression coefficients are plotted against genotype mean yields.

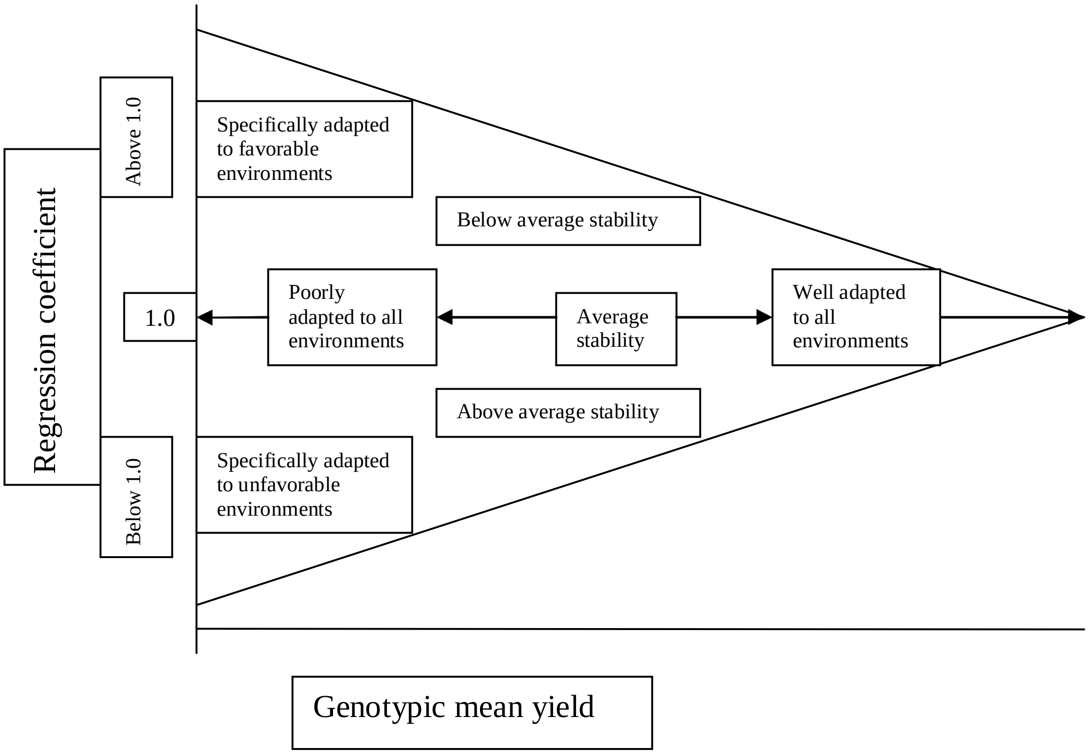

Figure 2.2 A generalized interpretation of the genotypic pattern obtained when genotypic regression coefficients are plotted against genotypic mean, adapted from Finlay and Wilkinson (1963).

The deviation sums of squares are the sums of variance due to deviation from regression divided by (S-2), and subtracting pooled error mean square, where S stands for the number of locations for each variety (Eberhart and Russell, 1966). Therefore, varieties which have a less predictable response for a given set of environments, have a probability of a F value close to zero and will deviate significantly from linearity.

$$S^2d_i = \frac{1}{E-2}\left[E_j(X_{ij} - \bar{X}_i - \bar{X}_j + \bar{X}\ldots)^2 - (b_i - 1)^2\, E_j(\bar{X}_j - \bar{X}\ldots)^2\right] \qquad (4)$$

Although many authors and breeders used the regression approach, simultaneous studies emphasized the limitations, biologically and statistically (Freeman and Perkins, 1971; Westcott, 1986).

There are three statistical limitations. Firstly the genotypes mean and marginal means of the environments is not independent from one another. This problem may be overcome by a large number of genotypes used (Freeman and Perkins, 1971). Secondly, errors associated with the slopes of the genotypes are not statistically independent (Crossa, 1990). And thirdly, this method assumes a linear relationship between interaction and environmental means, which is not always the case and results may be misleading (Westcott, 1986).

Biologically the limitation seems to be in the case where only a few low or high yielding sites are included in the analysis and the genotype's position in the range is mostly determined by its performance in a few extreme environments (Crossa, 1990; Westcott, 1986).

2.4.2.2 Ecovalence (W_i)

Wricke (1962) measured the stability of a genotype by using the GxE interaction effects for each genotype, squared and summed across all environments.

$$W_i = [\bar{Y}_{ij} – \bar{Y}_{i} – \bar{Y}_{j} – \bar{Y}_{..}]^2 \qquad (5)$$

Where Y_{ij} is the mean performance of genotype i in the jth environment, and Y_i and Y_j are the genotype and environment mean deviations, respectively, $Y_{..}$ is the overall mean. Therefore genotypes with a low W_i value have smaller deviations from the mean across environments and are thus more stable. Becker and Leon (1988) described the ecovalence as the measurement of a genotypes contribution to the GxE interaction (genotype with zero W_i is regarded as stable).

2.4.2.3 Coefficient of determination (r_i^2)

Pinthus (1973) as cited by Becker (1981) proposed to use the coefficient of determination (r_i^2) instead of deviation mean squares to estimate stability of genotypes, because r_i^2 is strongly related to S^2d_i.

$$r_i^2 = 1 - \frac{S^2d_i}{S^2x_i} \qquad (6)$$

Both r_i^2 and b_i has the advantage of being dependent of units of measurement.

2.4.2.4 Shukla's stability variance parameter (σ_i^2)

In this method, the stability variance of genotype i is its variance across environments after the main effects of environmental means have been removed (Shukla, 1972). The stability variance (σ_i^2) is based on the residual ($GE_{ij} + e_{ij}$) matrix in a two way classification, since the genotype main effect is constant, and is calculated as follows:

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)} \left[G(G-1)\sum_{j}(Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y}_{..})^2 - \sum_{i}\sum_{j}(Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y}_{..})^2\right] \qquad (7)$$

where Y_{ij} is the mean yield of the ith genotype in the jth environment, Y_i is the mean of the genotype i in all environments and Y_j is the mean of all genotypes in jth environments and $Y_{..}$ is the mean of all genotypes in all environments.

A stable genotype's σ_i^2 would be equal to the environmental variance (σ_e^2) which means that $\sigma_i^2 = 0$. An unstable genotype would have a relatively big σ_i^2 value. Shukla (1972) also determined that negative estimates of variance, which are not uncommon, since it is the difference between to squares, may be taken as equal to zero. Wricke and Weber (1980) found that stability variance is a linear combination of the ecovalence and therefore both W_i and σ_i^2 are equivalent for ranking purposes.

2.4.2.5 Cultivar performance measure (P_i)

The superiority measure (P_i) of the ith genotype is defined by Lin and Binns (1988) as the mean square of distance between the ith genotype and the genotype with maximum response as

$$P_i = [n(y_i - M_{..})^2 + (Y_{ij} - Y_i + M_j + M_{..})^2]/2n \qquad (8)$$

where Y_{ij} is the average response of the i^{th} genotype in the j^{th} environment, Y_i is the mean deviation of genotype i, M_j is the genotype with maximum response among all genotypes in the j^{th} location, and n is the number of locations. By using this method, all genotypes are compared to the genotype with maximum yield. The smaller the value of P_i, the smaller is the difference between genotype i and the genotype with maximum yield. A combination of GxE interaction mean square between the maximum and each genotype is also calculated.

2.4.3 Crossover interactions and non-parametric analysis

Lin and colleagues (1986) explained this approach as the grouping of genotypes according to their similarity of response to a range of environments. When GxE interactions are present, the differences between genotypes depend on the environment. These interactions may (not necessarily), result in different rank orders of genotypes in different environments. This is demonstrated in Figure 2.3. For two genotypes A and B, and two different environments X and Y, the basic types of relationships between GxE interaction and changes of rank are illustrated. Crossover or qualitative interactions are more important in agricultural production than non-crossover or quantitative interactions (Baker, 1988; Crossa, 1990).

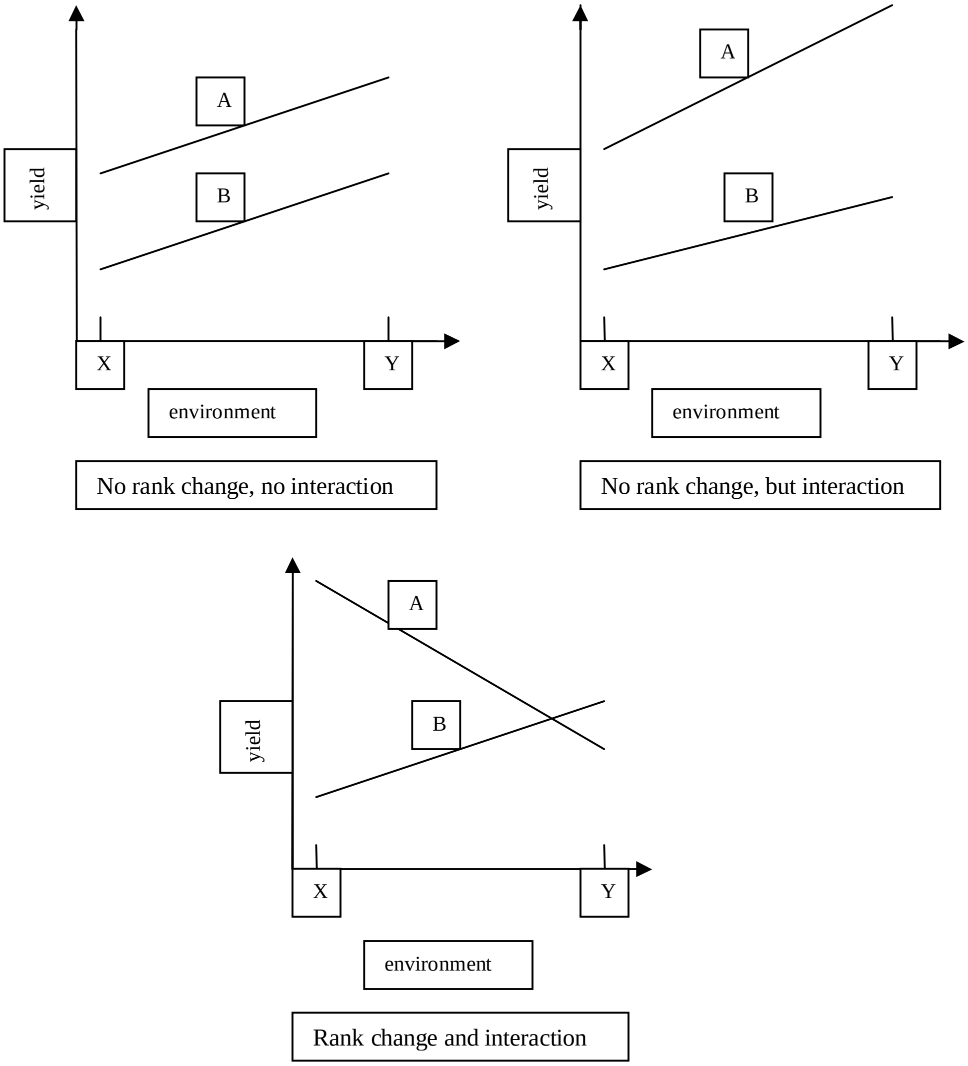

Figure 2.3 Genotype x environment interactions and changes of rank orders – different types of relationships (modified from Wricke, 1965).

If the breeder or scientist is only interested in the existence of rank order differences over different environments, the non-parametric statistics for GxE interactions based on ranks provide a useful alternative to parametric approaches currently used, which are based on absolute data. In these cases, the relative characteristics and comparisons of the genotypes are more important than absolute characterizations and comparisons. Further advantages of non-parametric stability statistics are expected to be less sensitive to errors of measurement than parametric estimates and the addition or deletion of one or a few observations is not likely to cause great variation in the estimate as would be the case for stability statistics (Nassar and Huehn, 1987).

2.4.4 Multivariate Analysis Technique

This technique is used to provide information on the real multivariate response of genotypes to environments. Crossa (1990) defined three main purposes of multivariate analysis: i) to eliminate noise from the data pattern (i.e. to distinguish systematic from non-systematic variation); ii) to summarize the data; and iii) to reveal a structure in the data. By using multivariate analysis, genotypes can be placed into groups with similar responses, hypothesis can be generated and later be tested so that data can be summarized and analyzed more easily.

Crossa (1990) further distinguished between two groups of multivariate techniques to explain the internal structure of GxE interaction: the ordinary and classification techniques. Multivariate analysis is appropriate for analyzing two-way matrices of G genotypes and E environments. The response of any genotype in E environments may be conceived as a pattern in E-dimensional space, with the coordinate of an individual axis being the yield or other metric of the genotype in one environment.

- Ordinary techniques represents data in a low-dimensional space, with similar genotypes and environments near each other, and dissimilar items further apart. In this case, data is assumed to be continuous and include methods such as principal component analysis, principal coordinate analysis and factor analysis. Ordination is effective for showing relationships and reducing noise (Gauch, 1982a,b).
- Classification techniques such as cluster analysis and discriminant analysis, seek discontinuities in the data. These methods group similar entities in clusters and summarize abundances of data effectively (Crossa, 1990; Purchase, 1997).

2.4.4.1 Principal Component Analysis

Crossa (1990) and Purchase (1997) found principal component analysis (PCA) to be the most frequently used multivariate method. This method aims to transform the data from one set of coordinate axis to another, which preserves, as far as possible, the original configuration of the set of points and concentrates most of the data structure in the first principal component axis. Many limitations for this technique have been noted (Zobel et al., 1988; Crossa, 1990). PCA is a generalization of linear regression, but in an improved way, that overcomes the problem of univariate analysis (Crossa, 1990).

2.4.4.2 Principal Coordinate Analysis

Principal Coordinate Analysis is a generalization to the PCA in which any measure of similarity between individuals can be used. Its objectives and limitations are similar to those of PCA. Crossa (1990) highlighted some of the advantages:

i) it is trustworthy when used for data that include extremely low or high yielding sites;
ii) it does not depend on the set of genotypes included in the analysis;
iii) and it is simple to identify stable varieties from the sequence of graphic displays.

2.4.4.3 Factor Analysis

Factor analysis is also related to PCA. The variables of the factor analysis are similar to the components of the latter. In this procedure, a large number of variables are reduced to a small number of main factors. Variation is explained in terms of general factors common to all variables and in terms of factors unique to each variable (Crossa, 1990).

2.4.4.4 Cluster Analysis

Cluster analysis defines groups of clusters of individuals by using a numerical classification technique. Hierarchical and non-hierarchical classifications are the two types of classifications. Several limitations to this technique was noted by Crossa (1990) and Becker and Leon (1988).

2.4.4.5 Additive Main Effects and Multiplicative Interaction Method (AMMI)

Additive main effects and multiplicative interaction (AMMI) is a combination of analysis of variance for the genotype and environment main effects with principal component analysis of the GxE interaction (Gauch, 1988; Zobel et al., 1988). The results can be presented on a graphical biplot which shows both main effects and GxE interaction, it is easy to interpret and very informative. The AMMI model can separate the data into a pattern rich model and discard noise-rich resisual to gain accuracy, and has been used with great success over the past few years (Crossa, 1990).

The AMMI method is used for three main purposes:

i) *Model diagnoses*. AMMI is more appropriate in the initial statistical analysis of yield trials. It provides and analytical tool of diagnosing other models as sub cases when these are better for a particular data set (Gauch, 1988).

ii) *Clarification of the GxE interaction*. AMMI summarizes patterns and relationships of genotypes and environments (Zobel et al., 1988; Crossa, 1990).

iii) *Improving the accuracy of yield estimates*. Gains have been obtained in the accuracy of yield estimates that are equivalent to increasing the number of replicates by a factor of two to five (Zobel et al., 1988; Crossa, 1990).

AMMI combines analysis of variance (ANOVA) into a single model with additive and multiplicative parameters. The model equation is:

$$Y_{ij} = \mu + G_i + E_j + (\sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij}) \qquad (9)$$

where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_j are the genotype and environment deviations from the grand mean, respectively; λ_k is the eigenvalue of the PCA axis k; α_{ik} and γ_{jk} are the genotype and environment principal component scores for axis k; n is the number of principal components retained in the model and e_{ij} is the error term.

The interaction is explained by using a graphical biplot where PCA scores are plotted against each other and it provides visual illustration which can be used for interpretation and inspection of the GxE interaction. Genotypes can be grouped based on similarity of performance across diverse environments.

CHAPTER 3

MATERIALS AND METHODS

3.1 MATERIALS

Ninety four maize genotypes, listed in Table 3.1, were evaluated over a six year period from 1998 to 2003 over a total of 80 environments (locations) in South Africa.

The trial were planted and data collected by the ARC over a period of six years, from 1998 to 2003. South Africa is divided into two main regions: East and West (the N1 highway from Cape Town to Johannesburg being the division, see Figure 3.1). The irrigation trials were planted all over the irrigation regions of South Africa. The ARC further divided these two regions into smaller research regions under which they have conducted the trials, collected and filed the results from the trials. The general climate of the western region is much dryer and warmer than the eastern region. For the stability analysis only the last three years (2001-2003), data was used. Most cultivars and localities were included for this period and the cultivars used were the most relevant for current genotypes used in the industry. From these analyses we concluded the best-fitted stability parameter and applied that on the six year data comparison for all three regions.

A randomized complete block design with three replications was used throughout. For the irrigation trials 75 cm wide rows with 47 000 plants per hectare were used. Ninety cm wide rows and 36 000 plant per hectare were the plant density in the eastern region and 150 cm wide rows with 16 500 plants per hectare were used in the western region. Fertilization was applied according to target yield recommendations for each region (Maize Information Guide each year respectively). The maize was harvested at 13% moisture.

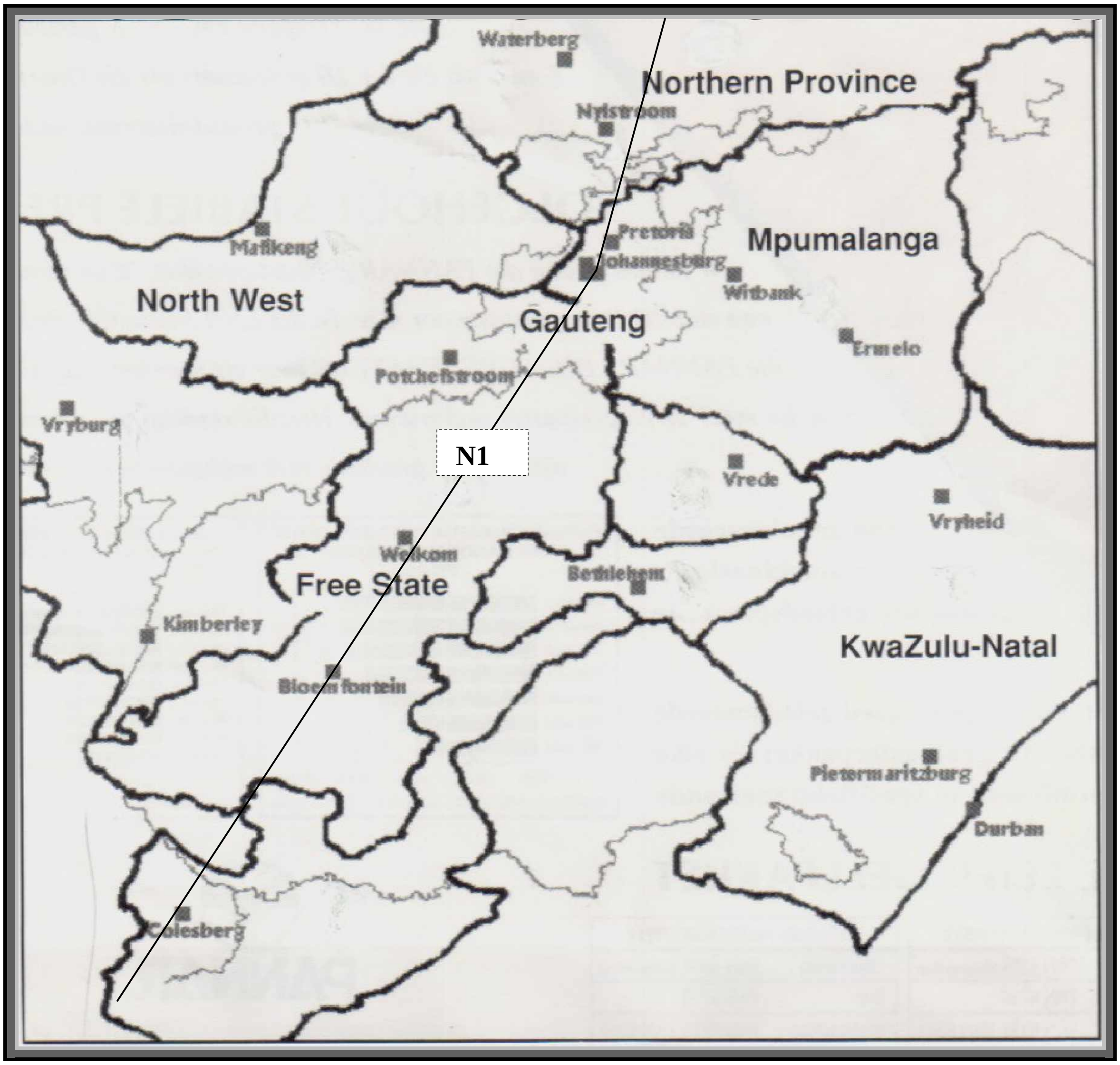

Figure 3.1 Map of South Africa's maize production region.

3.2 STATISTICAL ANALYSIS

A range of statistical analysis was conducted. The data were grouped into tables containing 1) 2003's data, 2) 2003 and 2002's data for the common localities and cultivars, 3) 2001-2003's data for the common localities and cultivars 4) as well as the data from all six years for the common localities and cultivars. Therefore the statistical analyses were conducted on each of these four tables for all six research regions used by the ARC. All analyses were done using Agrobase (2000). The grouping of the data was done to compare the cultivar performance of the (1) last year, (2) last two years, (3) last three years and (4) last six years over the different localities. The following statistical analyses were conducted:

Table 3.1 Summary of the regions, number of entries, number of localities and the different periods in which the trials were conducted.

	Irrigation Region		**Eastern Region**		**Western Region**	
	Six Year Data	**Three Year Data**	**Six Year Data**	**Three Year Data**	**Six Year Data**	**Three Year Data**
Number of Entries	6	25	6	25	7	21
Number of Localities	3	3	6	6	5	5
Trial Period (Years)	1998-2003	2001-2003	1998-2003	2001-2003	1998-2003	2001-2003

Table 3.2 Color of maize, cultivar name and entry number of different maize genotypes that were evaluated over 80 localities from 1998 to 2003

COLOR	CULTIVAR	ENTRY	COLOR	CULTIVAR	ENTRY
Y	PAN 6568	1	W	SC 625	48
Y	SNK 2778	2	W	PAN 6927	49
Y	QS 7608	3	Y	CRN 4070B	50
Y	CRN 3760	4	Y	PAN 6734	51
Y	PAN 6966	5	Y	SC 602	52
Y	SNK 2900	6	Y	PAN 6146	53
Y	Phb 3442	7	Y	PAN 6710	54
Y	CRN 3604	8	Y	SNK 2972	55
Y	PAN 6730	9	Y	PAN 6480	56
Y	SNK 2472	10	Y	PAN 6844	57
Y	LS 8508	11	W	DK 2551	58
Y	DKC 80-10	12	W	LS 8501	59
Y	PAN 6740	13	W	PAN 6845	60
Y	NS 5914	14	W	SC 709	61
Y	Phb 30H22	15	Y	PAN 6234	62
Y	SNK 8520	16	W	PAN 6825	63
Y	CAP 611	17	W	Phb 30N35	64
Y	PAN 6026	18	Y	CRN 3414	65
Y	DKC 63-20	19	Y	PAN 6256	66
Y	LS 8502	20	W	CRN 3815	67
Y	SYNCERUS	21	Y	PAN 6242	68
Y	NS 9100	22	Y	Phb 31R88	69
W	PAN 6479	23	Y	SNK 2962B	70
W	SNK 2969	24	Y	PAN 6414	71
W	SC 401	25	Y	SNK 2682	72
W	PAN 6029	26	Y	PAN 6364	73
W	CRN 3505	27	Y	SNK 2626	74
W	LS 8507	28	Y	SNK 2942	75
W	SC 405	29	W	PAN 6335	76
W	PAN 6939	30	W	SC 627	77
W	SNK 2911	31	W	PAN 6633	78
W	PANTHERA	32	W	SNK 2721	79
W	Phb 30D05	33	W	PAN 6243	80
W	SC 407	34	Y	CRN 3524	81
W	PAN 6839	35	Y	CRN 3818	82
W	LS 8525	36	Y	PAN 6332	83
W	Phb 30G03	37	W	SNK 2021	84
W	PAN 6777	38	W	CRN 3631	85
W	SAFFIER	39	Y	PAN 6770	86
W	SNK 2551	40	W	PAN 6811	87
W	PAN 6757	41	W	PAN 6561	88
W	CRN 3549	42	W	PAN 6043	89
W	SC 403	43	Y	PAN 6036BT	90
W	PAN 6615	44	W	CAP 614	91
W	Phb 3203W	45	W	PAN 6053	92
W	SC 621	46	W	PAN 6611	93
W	PAN 6573	47	W	PAN 6967	94

Table 3.3 The general site, research table name, town, abbreviation and locality number, for the different localities at which the trials were conducted

REGION	IRRIGATION OR DRYLAND	TOWN	LOCALITY NAME	LOCALITY NUMBER
East	Irrigation	Cradock	CDOCK	1
East	Irrigation	Klerksdorp	KDORP	2
East	Irrigation	Upington	UTON	3
East	Irrigation	Groblersdal	GDAL	4
East	Irrigation	Vaalharts CC	VHARTC	5
East	Irrigation	Vaalharts CO	VHARTO	6
East	Irrigation	Burgerhall	BHALL	7
West	Irrigation	Carletonville 1	CVILL	8
West	Irrigation	Carletonville 2	CVILLS	9
East	Irrigation	Newcastle	NCASTL	10
West	Koelo	Behlehem 3	BHEM\3	11
East	Koelo	Jim Fouche	JIMF	12
East	Koelo	Robbertsdrift	RDRIFT	13
East	Koelo	Athole	ATHOLE	14
East	Koelo	Wonderfontein	WFTEIN	15
East	Koelo	Bethal 1\A	BETH\1\A	16
East	Koelo	Nooitgedacht	NDACHT	17
East	Koelo	Bethal 2\B	BETH\2\B	18
West	Koelo	Bethlehem 1	BHEM\1	19
West	Koelo	Bethlehem 2	BHEM2	20
West	Koelo	Behtlehem s\m	BHEMS\M	21
East	Koelo	Kokstad	KSTAD	22
East	Koelo	Reitz	REITZ	23
East	Koelo / Maoos		ARNOT	24
East	Maoos	Bergville	BVILLE	25
East	Maoos	Bloemkomspruit \1	BKOMS\1	26
East	Maoos	Bronkhorstspruit	BSPRUIT	27
East	Maoos	Delmas\P\1	DELM\P\1	28
East	Maoos	Delmas\M\S\2	DELMA\M\S\2	29
East	Maoos		OFTEIN	30
East	Maoos	Argent	ARGENT	31
East	Maoos	Dundee	DUNDEE	32
East	Maoos	Petit C	PETITC	33
East	Maoos	Petit P	PETITP	34
East	Maoos	Bloekomspruit \2	BKOMS\2	35
East	Maoos	Bloekomspruit\3	BKOMS\3	36
East	Maoos	Middelburg	MBURG	37
East	Maoos	Petit M	PETITM	38
East	Reskz	Cedara	CEDAR	39
East	Reskz	Greytown P	GTOWN\P	40

East	Reskz	Greytown M\L	GTOWN\M\L	41
East	Reskz	Cedara GLS	CEDARG	42
East	Reskz	Döhne	DOHNE	43
East	Reskz	Khambula	KBULA	44
East	Reskz	Cedara 1	CEDAR 1	45
East	Reskz	Piet Retief D	PTIEFD	46
East	Reskz	Piet Retief S	PTIEFS	47
West	Vwnp	Delareyville	DVILLE	48
West	Vwnp	Warmbad	WBAD	49
West	Vwnp	Setlagole	SETLAG	50
West	Vwnp	Kameel	KAMEEL	51
West	Vwnp	SchweizerRenekeM	SRENEM	52
West	Vwnp	Glaudina	GDINA	53
West	Vwnp	Schweizer Reneke K	SRENEK	54
West	Western	Blesbokfontein	BBOKF	55
West	Western		GERDAU	56
West	Western	Koster	KOSTER	57
West	Western	Odendaalsrus	ODAL	58
West	Western	Potchefstroom A\1	POTCH\A\1	59
West	Western	Zoetmelksvallei	ZMVAL	60
West	Western	Wesselsbron	WBRON	61
West	Western	Rushof \A	RHOF\A	62
West	Western	Lichtenburg	LBURG	63
West	Western	Tweebuffels A\1	2BUF\A\1	64
West	Western	Leeudoringstad	LSTAD	65
West	Western	Rushof B	RHOFB	66
West	Western	Tweebuffels B\2	2BUFB\2	67
West	Western	Coligny	COLIG	68
West	Western	Nampo	NAMPO	69
West	Western	Hoopstad	HSTAD	70
West	Western	Losberg	LBERG	71
West	Western	Potchefstroom B\2	POTCHB\2	72
West	Western	Viljoenskroon\A\1	VKROO\A\1	73
West	Western	Viljoenskroon B\2	VKROOB\2	74
West	Western	Tweebuffels 3	2BUF3	75
West	Western	Boskop	BOSKOP	76
West	Western	Greenlands	GLANDS	77
West	Western	Ventersdorp	VDORP	78
West	Western	Viljoensdroon 3	VKROO3	79
West	Western	Witfontein	WITEIN	80

* Data supplied by Agricultural Research Council.

3.2.1 Analysis of variance (ANOVA)

An ANOVA was performed on the yield data of each of the individual trials, for each locality for each of the above mentioned tables. Thereafter, combined analyses of variance were performed on the pooled data of all the trials (using Tables 2, 3 and 4 as explained above) for each of the research regions respectively over the six year period.

3.2.2 Cultivar Superiority Measure

The data sets of each research region were analyzed according to the recommendations made by Linn and Binns (1988). The values estimated are the squares of the differences between an entry (genotype) mean and the maximum genotype mean at a location, summed and divided by twice the number of locations.

3.2.3 Wi-Ecovalence

The concept of ecovalence is defined as the contribution of each genotype to the genotype x environment interaction sum of squares (Wricke, 1962). Ecovalence (W_i) or the stability to the i^{th} genotype is its interaction with environments, squared and summed across environments, and expressed as

$$W_i = [\bar{Y}_{ij} - \bar{Y}_{i} - \bar{Y}_{j} - \bar{Y}_{..}]^2.$$

as explained in 2.4.2.2. Accordingly, genotypes with low ecovalence have smaller fluctuations from the mean across different environments and are therefore more stable.

3.2.4 Shukla’s procedure of stability variance

Shukla’s stability variance for each genotype across environments was determined. Stability variance (σ^2_i) of genotype i, was defined by Shukla (1972) as the variance across environments after the main effects of environmental means had been removed. The genotype main effect seems to be constant, therefore the stability variance is based on the residual ($GE_{ij} + e_{ij}$) matrix. The stability variance (σ^2_i) is estimated as follows:

$$\sigma_i^2 = \frac{1}{(G-1)(G-2)(E-1)} \left[G(G-1)\sum_{j}(Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y}_{..})^2 - \sum_{i}\sum_{j}(Y_{ij} - \bar{Y}_i - \bar{Y}_j + \bar{Y}_{..})^2\right]$$

3.2.5 Stability variance with locality as covariate

The same principles as for Shuckla's stability variance in 3.3.4 apply for this analysis. Except for localities mean yield that was used as covariate.

3.2.6 Rank differences , S(1), and variances, S(2)

Nassar and Huehn's (1987) non-parametric measure of stability use rank interactions and are distribution free and require no assumptions like: homogeneity of variance, normality and linearity of genotype and environmental effects. S1 is the mean absolute rank differences and S2 is the variance of ranks. Both these values of the genotypes across the tested environments were used as measurements of stability (Huehn, 1990). The S1 and S2 statistics are based on ranks of the genotypes across locations and the give equal weight to each location or environment. The more stable genotypes have less change in their ranking position (Becker and Leon, 1988). S1 are estimates of all possible pair-wise rank differences across locations for each cultivar, while S2 are variances of ranks for each cultivar across environments (Nassar and Huehn, 1987). Huehn (1990) preferred S1 to S2 for many practical applications (easier to calculate).

3.2.7 Eberhart and Russell stability regression model

Joint linear regression of the mean of the genotype on the environmental mean as an independent variable, was performed. Of importance are the regression coefficient (b), the deviation from regression for each genotype (S^2d) and the mean yield (kg ha^{-1}) of the genotype over all the environments. Eberhart and Russell (1966) developed a model which defines stability parameters that may be used to describe the performance of a genotype over a series of environments.

Their model:

$$Y_{ij} = \mu_i + \beta i I j + \delta_{ij}$$

Y_{ij} is the genotypes mean of the i^{th} genotype at the jth environment, μ is the i^{th} genotypes mean over all environments, β_i is the regression coefficient that measures the response of the ith genotype to varying environments, β_{ij} is the deviation from regression of the ith genotype at the j^{th} environment, and I_j is the environmental index.

3.2.8 AMMI

AMMI combines analysis of variance (ANOVA) into a single model with additive and multiplicative parameters. The model equation is:

$$Y_{ij} = \mu + G_i + E_j + (\sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + e_{ij})$$

where Y_{ij} is the yield of the i^{th} genotype in the j^{th} environment; μ is the grand mean; G_i and E_j are the genotype and environment deviations from the grand mean, respectively; λ_k is the eigenvalue of the PCA axis k; α_{ik} and γ_{jk} are the genotype and environment principal component scores for axis k; n is the number of principal components retained in the model and e_{ij} is the error term. The interaction is explained by using a graphical biplot where, PCA scores are plotted against each other and it provides visual illustration which can be used for interpretation and inspection of the GxE interaction. Genotypes can be grouped based on similarity of performance across diverse environments.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 ANALYSIS OF VARIANCE

The analysis of variance results for the irrigation region, western region and eastern region are given in Tables 4.1(i), 4.2(i) and 4.3(i) respectively. All three ANOVA's indicated highly significant differences between entries, localities and years. The only insignificant value is in Table 4.3(i) for years, entry by year and entry by year by loc which represents the different conditions over the three years was insignificant. Variance components (%) of the sum of squares for total sum of squares, ranged from 3-8 percent for genotype, from 25-33 percent for locality and from 3.5-5.4 percent for genotype x locality interaction. This indicates the overwhelming influence of the locality on yield performance of maize cultivars in the respective maize producing regions of South Africa.

The mean yield of 20-25 maize genotypes evaluated over three to six localities in the research regions Irrigation, Maoos (Eastern) and Western respectively are given in Tables 4.1(ii), 4.2(ii) and 4.3(ii). Irrigation research region represent the irrigation trials, Maoos represents the eastern region of South Africa and Western the western region. Under irrigation, CRN3760, PAN6777, CRN3505 and Phb3202 yielded significantly higher than the other genotypes. Phb30H22, PAN 6730, Phb30G03, CRN3549 and PAN6568 also yielded well. QS7608 and LS8507 were the worst performers for irrigated maize production in South Africa for 2001-2003. In the eastern part of South Africa (Maoos research region) under dry land conditions CRN3505, CRN3549, Phb30H22, Phb30G03 and SNK2472 yielded significantly higher than most of the other cultivars. CRN 3604 and Phb3442 had intermediate performance. At the bottom of the range there was once again LS8507 and QS7608. In the Western research region PAN6844, CRN3549, PAN 6146 and CRN3505 ranked much better according to yield performance than the rest of the 20 genotypes. PAN6734, SNK2472 and

CRN3760 also performed well. In this region QS7608 and Phb3203 had the lowest yields. Under dryland production the maize cultivars CRN3505 and CRN3549 did the best with SNK2472 in the third position. QS7608 performed by far the worst.

Table 4.1(i) Combined analyses of variance for 25 maize genotypes evaluated, under irrigation, over three localities in South Africa for the period 2001-2003.

Source	**Df**	**Sum of Squares x 1 000 000**	**Mean Squares x 1 000 000**	**F-value**
Total	647	2958.800		
Year	2	130.836	65.418**	46.07
Loc	2	847.373	423.686**	298.39
Year by Loc	4	471.164	117.791**	82.96
Entry	24	235.217	9.801**	6.90
Entry by Year	48	127.314	2.652**	1.87
Entry by Loc	48	118.585	2.471**	1.74
Entry by Year by Loc	96	146.572	1.527	1.08
Block in Year by Loc	18	306.682	17.038**	12.00
Residual	405	575.057	1.420	

**** $P \leq 0.01$**

Table 4.1(ii) Mean yield (ton ha^{-1}) of 25 maize genotypes evaluated, under irrigation, in three locations in South Africa for the period 2001-2003.

Genotype/Cultivar	**Mean yield (ton.ha^{-1})**	**Cv**	**Rank**
CRN 3760	9.84	22.2	1
PAN 6777	9.66	20.8	2
CRN 3505	9.52	28.4	3
Phb 3203	9.51	25.4	4
Phb 30H22	9.25	24.7	5
PAN 6730	9.23	21.22	6
Phb 30G03	9.15	22.4	7
CRN 3549	9.14	22.6	8
PAN 6568	9.10	22.2	9
SNK 2472	8.97	24.3	10
SNK 2778	8.97	22.6	11
PAN 6757	8.97	23.1	12
CRN 3604	8.69	24.9	13
PAN 6740	8.69	24.3	14
PAN 6614	8.60	25.5	15
Phb 3442	8.59	20.5	16
LS 8508	8.51	23.2	17
PAN 6479	8.48	21.6	18
PAN 6573	8.37	23.7	19
SNK 2969	8.37	29.3	20
SC 405	8.35	25.8	21
LS 8502	8.13	23.4	22
SNK 2900	8.07	23.5	23
QS 7608	7.39	21.9	24
LS 8507	5.46	31.4	25
LSD for entry = 0.5457			

Table 4.2(i) Combined analyses of variance for 25 maize genotypes evaluated, under dry land condition, over six localities in eastern South Africa for the period 2001-2003.

Source	**Df**	**Sum of Squares x 1 000 000**	**Mean Squares X 1 000 000**	**F-value**
Total	1295	5265		
Year	2	372	185.791**	269.47
Loc	5	1731	346.202**	502.13
Year by Loc	10	1770	177.032**	256.77
Entry	24	160	6.421**	9.31
Entry by Year	48	70	1.399**	2.03
Entry by Loc	120	186	1.492**	2.16
Entry by Year by Loc	240	243	0.973**	1.41
Block in Year by Loc	36	186	5.174**	7.50
Residual	792	546	0.689	

**** $P \leq 0.01$**

Table 4.2(ii) Mean yield (ton ha^{-1}) of 25 maize genotypes evaluated under dry land conditions, in six localities in eastern South Africa for the period 2001-2003

.Cultivar	Mean yield (ton ha^{-1})	Cv	Rank
CRN 3505	6.33	31.5	1
CRN 3549	6.32	33.5	2
Phb 30H22	6.25	38.0	3
Phb 30G03	6.19	35.0	4
SNK 2472	6.18	30.0	5
CRN 3604	6.04	35.4	6
Phb 3442	6.03	33.5	7
PAN 6740	5.91	34.5	8
CRN 3760	5.87	37.3	9
PAN 6730	5.86	29.8	10
PAN 6568	5.82	36.8	11
PAN 6757	5.81	33.8	12
PAN 6777	5.78	31.9	13
SNK 2969	5.74	33.9	14
Phb 3203	5.73	31.9	15
PAN 6573	5.72	36.0	16
SNK 2778	5.66	37.8	17
PAN 6615	5.63	31.0	18
LS 8508	5.61	38.2	19
PAN 6479	5.54	31.4	20
SNK 2900	5.45	26.9	21
SAFFIER	5.38	14.4	22
LS 8502	5.32	39.7	23
LS 8507	5.19	19.9	24
QS 7608	5.19	38.4	25
LSD ($p \leq 0.05$) for entry = 0.2739			

Table 4.3(i) Combined analyses of variance for 20 maize genotypes evaluated, under dryland conditions, over five localities in western South Africa for the period 2001-2003.

Source	**Df**	**Sum of Squares x 1 000 000**	**Mean Squares x 1 000 000**	**F-value**
Total	944	1361		
Year	2	0.517	0.259	0.07
Loc	4	341	85.354**	230.26
Year by Loc	8	483	60.319**	162.72
Entry	19	94	4.686**	12.64
Entry by Year	38	18	0.444	1.20
Entry by Loc	76	73	0.909**	2.45
Entry by Year by Loc	152	74	0.463*	1.25
Block in Year by Loc	30	56	1.866**	5.03
Residual	600	222	0.371	

**** P ≤ 0.01, * P ≤ 0.05**

Table 4.3(ii) Mean yield (ton ha^{-1}) of 20 maize genotypes evaluated, under dryland conditions, in five locations in western South Africa for the period 2001-2003.

Cultivar	**Mean yield (ton ha^{-1})**	**Cv**	**Rank**
PAN 6844	4.12	31.6	1
CRN 3549	4.11	36.1	2
PAN 6146	4.07	37.0	3
CRN 3505	4.01	30.1	4
PAN 6734	3.90	32.9	5
SNK 2472	3.87	28.7	6
CRN 3760	3.81	35.4	7
SNK 2682	3.76	28.0	8
PAN 6043	3.72	33.0	9
PAN 6730	3.68	32.3	10
SNK 2969	3.65	32.2	11
Phb 30H22	3.59	32.1	12
PAN 6615	3.59	31.8	13
Phb 30N35	3.59	27.2	14
PAN 6479	3.54	29.1	15
Phb 3442	3.53	31.4	16
SNK 2900	3.51	29.2	17
NS 9100	3.48	31.3	18
Phb 3203W	3.42	29.9	19
QS 7608	3.33	32.9	20
LSD ($p \leq 0.05$) for entry = 0.2115			

4.2 CULTIVAR SUPERIORITY MEASURE (Pi)

Table 4.4 indicates the Lin and Binns’ (1988) cultivar superiority measure for each genotype in the respective production research regions discussed in this thesis.

Table 4.4 The Lin and Binns' cultivar performance measure for 20 -25 genotypes included in the trials in the irrigation, eastern and western regions respectively, for the period 2001-2003.

Stability Range	**Irrigation Region**		**Eastern Region**		**Western Region**	
	GxE Statistic(P_i)	**Cultivar**	**GxE Statistic(P_i)**	**Cultivar**	**GxE Statistic(P_i)**	**Cultivar**
1	0.4229	CRN3760	0.4184	**CRN3549**	0.1931	PAN6146
2	0.8383	Phb3203W	0.4598	**CRN3505**	0.1981	**CRN3549**
3	1.1982	**CRN3505**	0.7100	Phb30G03	0.2005	PAN6844
4	1.2483	Phb30G03	0.7117	Phb3442	0.3539	**CRN3505**
5	1.2955	PAN6730	0.7124	**SNK2472**	0.4076	**SNK2472**
6	1.3827	**CRN3549**	0.7570	Phb30H22	0.4304	CRN3760
7	1.5200	**SNK2472**	0.7911	CRN3604	0.5439	PAN6730
8	1.5251	PAN 6568	0.8860	PAN6740	0.5546	PAN6043
9	1.5377	SNK2778	0.9546	PAN6757	0.5876	SNK2682
10	1.8665	CRN3604	0.9703	CRN3760	0.6209	SNK2969
11	1.9836	PAN6757	1.0501	PAN6730	0.6526	PAN6615
12	2.1965	PAN6740	1.0691	SNK2969	0.6815	Phb30H22
13	2.3516	LS 8508	1.1520	PAN6568	0.6952	PAN6734
14	2.4306	Phb3442	1.1709	SNK2778	0.7046	Phb3442
15	2.6461	PAN6615	1.2209	PAN6573	0.7469	Phb30N35
16	2.9938	PAN6479	1.2944	Phb3203W	0.8313	PAN6379
17	3.0934	SNK2969	1.3442	PAN6615	0.8376	SNK2900
18	3.1108	SC 405	1.4480	LS 8508	0.8457	NS 9100
19	3.5642	LS 8502	1.6060	PAN6479	0.8837	Phb3202W
20	3.5734	SNK2900	1.8148	SNK2900	1.0387	QS 7608
21	3.6269	PAN6573	2.0130	LS 8502	2.2652	SC 401
22	6.1227	QS 7608	2.2067	QS 7608		
23	17.4706	PAN6777	9.4281	PAN6777		
24	27.1096	Phb30H22	10.6719	SC 405		

In the irrigation region, consisting of the whole of South Africa's irrigation maize production regions, CRN3760, Phb3203W, CRN3505 and Phb30G03 had the lowest P_i values and therefore the best stability, while QS 7608, PAN6777 and Phb30H22 had the poorest stability. In the eastern part of South Africa (Maoos region) CRN3549, CRN3505, Phb30G03 and Phb3442 were the most stable genotypes, while QS7608, PAN6777 and SC405 were the most unstable cultivars. In the western region PAN6146, CRN3549, PAN6844 and CRN3505 were the cultivars with best stability, while Phb3202W, QS7608 and SC401 had the poorest stability.

According to Lin and Binns' (1988) definition of the cultivar performance measure (P_i), as stability statistic, CRN3549, CRN3505 and SNK2472 appeared to be the superior genotypes over the three regions as a whole. These three cultivars featured under the seven most stable genotypes in al three regions for al localities over the period 2001-2003. CRN3760 showed intermediate stability (included in 10 most stable genotypes for all three regions) and QS7608 and PAN6777 indicated poor stability.

4.3 WI-ECOVALENCE (W_i)

In Table 4.5 the Wricke's (1962) ecovalence values for each of the 20-25 genotypes, which were calculated over a total of 14 environments in the irrigation, eastern and western South African maize production region, are listed.

Table 4.5 Wricke's ecovalence values (W_i) for 20-25 cultivars over 14 environments across the irrigation, eastern and western regions respectively.

Stability Range	**Irrigation Region**		**Eastern Region**		**Western Region**	
	GxE Statistic(W_i)	**Cultivar**	**GxE Statistic(W_i)**	**Cultivar**	**GxE Statistic(W_i)**	**Cultivar**
1	1.9735	SNK2472	3.0424	PAN6757	1.1920	PAN6615
2	2.2535	LS8508	4.4716	SNK2778	1.2026	SNK2472
3	2.2695	Phb30G03	4.5646	CRN3549	1.5364	PAN6043
4	2.8078	SNK2778	4.6047	SNK2969	1.5511	Phb3442
5	4.1747	CRN3604	4.9056	Phb3442	1.7514	QS7608
6	4.2375	SNK2900	5.0832	CRN3760	1.9340	Phb3203W
7	4.4077	CRN3760	5.6648	PAN6615	1.9584	NS9100
8	4.5187	Phb3442	6.2598	PAN6730	2.0957	SNK2969
9	4.7206	PAN6740	7.1381	PAN6740	2.1642	PAN6844
10	4.8396	LS8502	7.5516	Phb3202W	2.3029	CRN3760
11	5.9444	CRN3549	7.5788	CRN3505	2.4652	PAN6730
12	6.7809	Phb3202W	7.6226	PAN6568	2.5667	SNK2900
13	7.1514	PAN6730	7.7210	CRN3604	2.9054	CRN3505
14	8.4802	SC405	7.9320	LS8502	2.9835	SNK2682
15	8.5344	PAN6568	7.9488	SNK2472	2.9939	Phb30H22
16	8.9462	PAN6615	8.0245	PAN6573	3.0129	Phb30N35
17	8.9749	SNK2969	8.0602	Phb30G03	3.0194	CRN3549
18	10.5765	PAN6757	10.0303	PAN6479	3.2195	PAN6479
19	11.4919	PAN6479	10.3072	LS8508	4.9607	PAN6146
20	12.0748	CRN3505	10.3828	SNK2900	5.1918	SC401
21	13.3073	QS7608	11.0418	Phb30H22	14.2851	PAN6734
22	14.7560	PAN6573	12.5569	QS7608		
23	226.2170	PAN6777	193.8286	SC405		
24	346.5421	Phb30H22	224.2691	PAN6777		

For the irrigation region in South Africa SNK2472, LS8508, Phb30G03 and SNK2778 were the genotypes with the lowest ecovalence and therefore the best stability (Wricke, 1962). SNK2900, CRN3604, CRN3769 and Phb3442 proved to have intermediate stability, while PAN 6777 and Phb30H22 had the poorest stability. In the eastern part of SA (Maoos), PAN6575, SNK2778, CRN3549 and CRN2969 appeared to be the more stable cultivars. Phb3442, CRN3760, PAN6615 and PAN6730 showed medium stability. The more unstable cultivars for this region were SC405 and PAN6777. PAN6615, SNK2742, PAN6043 and Phb3442 were the most stable genotypes for the western region with QS7608, Phb3203W, NS9100 and SNK2969 as the intermediate sector. The highest ecovalence values placed SC401 and PAN6734 in the position of poorest stability.

Over the whole of the SA region, the most stable genotypes appeared to be CRN3760 and Phb3442, while PAN6615, SNK2969 and Phb3203W were stable for the dry land regions only. The most unstable genotypes generally were QS7608, PAN6777 and Phb30H22. The results for the irrigation and eastern regions were very much the same, but the western region differed from these two. QS7608 was relatively stable in the western area.

4.4 SHUKLA'S PROCEDURE OF STABILITY VARIANCE

Table 4.6 shows Shukla's stability variance values (σ^2_i) (1977) as well as the ranking order of the cultivars stability.

Table 4.6 Stability variance (Shukla, 1972) results for the irrigation, eastern and western regions according to the ARC maize research database for the period of 2001-2003.

Stability Range	**Bespr**		**Maoos**		**Weste**	
	GxE Statistic(σ^2_i)	**Cultivar**	**GxE Statistic(σ^2_i)**	**Cultivar**	**GxE Statistic(σ^2_i)**	**Cultivar**
1	0.2693	SNK2472	0.3832	PAN6757	0.2455	PAN6615
2	0.3839	LS8508	0.6583	SNK2778	0.2480	SNK2472
3	0.3904	Phb30G03	0.6763	CRN3549	0.3271	PAN6043
4	0.6106	SNK2778	0.6840	SNK2969	0.3305	Phb3442
5	1.1698	CRN3604	0.7761	CRN3760	0.3780	QS7608
6	1.1955	SNK2900	0.7419	Phb3442	0.4212	Phb3203W
7	1.2651	CRN3760	0.8881	PAN6615	0.4270	NS9100
8	1.3105	Phb3442	1.0026	PAN6730	0.4595	SNK2969
9	1.3931	PAN6740	1.1717	PAN6740	0.4758	PAN6844
10	1.4418	LS8502	1.2513	Phb3203W	0.5086	CRN3760
11	1.8938	CRN3549	1.2565	CRN3505	0.5470	PAN6730
12	2.2360	Phb3203W	1.2650	PAN6568	0.5711	SNK2900
13	2.3875	PAN6730	1.2839	CRN3604	0.6513	CRN3505
14	2.9311	SC405	1.3245	LS8502	0.6698	SNK2682
15	2.9533	PAN6568	1.3278	SNK2472	0.6723	Phb30H22
16	3.1218	PAN6615	1.3423	PAN6573	0.6768	Phb30N35
17	3.1335	SNK2969	1.3492	Phb30G03	0.6783	CRN3549
18	3.7887	PAN6757	1.7285	PAN6479	0.7257	PAN6479
19	4.1632	PAN6479	1.7818	LS8508	1.1381	PAN6146
20	4.4017	CRN3505	1.7964	SNK2900	1.1943	SC401
21	4.9059	QS7608	1.9232	Phb30H22	3.3456	PAN6734
22	5.4985	PAN6573	2.2149	QS7608		
23	92.0053	PAN6777	37.1121	SC405		
24	141.2292	Phb30H22	42.9273	PAN6777		

According to Shukla (1972) the more stable genotypes, for irrigation maize production in SA, is SNK2472, LS8508, Phb30G03 and SNK2778, while PAN6777 and Phb30H22 the most unstable are. For the Maoos region PAN6567, SNK2778, CRN3549 and SNK2969 are the cultivars with the highest stability and SC405 and PAN6777 have the poorest stability. PAN6615, SNK2472, PAN6043 and Phb3442 are the most stable genotypes in the western part of SA, while SC401 and PAN6734 were the most unstable ones.

Over the whole SA maize production region, CRN3760 and Phb3442 indicated superior stability. If only the dryland productions are taken into consideration, SNK2969, PAN6615 and Phb3203W can be added to the above mentioned cultivars. PAN6777, QS7608 and Phb30H22 had the most unstable yields, although the western region differed somewhat from the other two regions, because the cultivars used in the western trials differed from the other two regions.

4.5 STABILITY VARIANCE WITH LOCALITY AS COVARIATE

Table 4.7 illustrates the results obtained from calculations for the GxE interaction by using the locality mean as covariate. Once again all the calculations were done for all three regions for the period of 2001-2003 (20-25 genotypes and 11 environments).

Table 4.7 The GxE statistic of stability variance with locality mean as covariate for the irrigation, eastern and western regions for the period of 2001-2003.

Stability Range	**Irrigation Region**		**Eastern Region**		**Western Region**	
	GxE Statistic	**Cultivar**	**GxE Statistic**	**Cultivar**	**GxE Statistic**	**Cultivar**
1	0.3574	SNK2472	0.4119	PAN6757	0.2553	CRN3760
2	0.4453	Phb30G03	0.5611	SNK2778	0.2608	PAN6615
3	0.5330	LS8508	0.5752	CRN3760	0.2685	SNK2472
4	0.6351	SNK2778	0.6495	PAN6615	0.3176	PAN6043
5	1.2128	CRN3604	0.7126	CRN3549	0.3384	PAN6844
6	1.2771	SNK2900	0.7175	SNK2969	0.3583	Phb3442
7	1.2775	Phb3442	0.7605	Phb3442	0.4035	QS7608
8	1.3081	CRN3760	0.9289	PAN6730	0.4231	Phb3203W
9	1.6399	LS8502	0.9929	SNK2900	0.4482	CRN3549
10	1.6708	PAN6740	1.1507	PAN6568	0.4626	NS9100
11	2.2103	Phb3203W	1.2287	Phb3203W	0.5002	SNK2969
12	2.2617	CRN3549	1.2408	PAN6740	0.5468	Phb30N35
13	2.4838	QS7608	1.2450	CRN3604	0.5897	PAN6730
14	2.6991	PAN6730	1.3342	Phb30G03	0.5912	SNK2900
15	3.3945	SC405	1.3379	CRN3505	0.5923	PAN6146
16	3.4604	PAN6568	1.3488	LS8502	0.6241	PAN6479
17	3.5260	SNK2969	1.3595	SNK2472	0.6707	SNK2682
18	3.6173	PAN6479	1.4206	PAN6573	0.6940	CRN3505
19	3.6520	PAN6615	1.4638	PAN6479	0.7302	Phb30H22
20	4.2196	CRN3505	1.4828	Phb30H22	0.8091	SC401
21	4.3017	PAN6757	1.7907	LS8508	3.4449	PAN6734
22	5.0871	PAN6573	2.3342	QS7608		
23	69.1587	PAN6777	39.4037	SC405		
24	151.6255	Phb30H22	45.1893	PAN6777		

From these results, it is clear that SNK2742, Phb30G03, LS8508 and SNK2778 were the most stable cultivars for the irrigation regions in SA. CRN3604, SNK2900 and Phb3442 showed intermediate stability while PAN6777 and Phb30H22 had the poorest stability for this region.

In the eastern region (Maoos), PAN6757, SNK2778, CRN3760 and PAN6615 were the better performers for yield. CRN3549, SNK2969 and Phb3442 had medium stability. On the lower yielding side were PAN 6777 and SC405.

CRM3760, PAN6615, SNK2472 and PAN6043 were the most stable genotypes for the western region for the period of 2001-2003. PAN6844 and Phb3442 were also relatively stable. In this region most of the genotypes were relatively stable with GxE statistics smaller than one. PAN6734 and SC401 had the poorest stability statistics.

Overall in South Africa SNK2778, Phb3442 and CRN3760 seemed to be the more stable genotypes and PAN6777 and Phb30H22 the less stable cultivars. For dry land conditions, PAN6615 and CRN3549 can be added to the list of more stable cultivars.

4.6 RANK DIFFERENCES (S1) AND VARIANCE DIFFERENCES (S2)

Nassar and Huehn’s (1987) non-parametric measures of stability for seed yield of 21-24 maize genotypes evaluated in 14 environments, separated into three regions, of South Africa are presented in Table 4.8. Both S1 (mean absolute rank differences) and S2 (variance of ranks) values of the genotypes across the tested environments were used as measurements of stability (Huehn, 1990). The S1 and S2 statistics are based on ranks of the genotypes across locations and the give equal weight to each location or environment. The more stable genotypes have less change in their ranking position (Becker and Leon, 1988). S1 values are estimates of all possible pair-wise rank differences across locations for each cultivar, while S2 are variances of ranks for each cultivar across environments (Nassar and Heuhn, 1987). Huehn (1990) preferred S1 to S2 for many practical applications (easier to calculate).

Table 4.8 Nassar and Huehn's (1987) non-parametric measures of stability for seed yield of 20-25 genotypes evaluated in three, six and five different localities, in three different regions, respectively.

Cultivar	**Irrigation region**			**EASTERN REGION**			**WESTERN REGION**		
	R	**S1**	**S2**	**R**	**S1**	**S2**	**R**	**S1**	**S2**
PAN6568	14	7.944	40.84	17	8.235	46.4			
SNK2778	5	6.778	28.54	6	7.144	37.5			
QS7608	**24**	10.500	67.8	19	8.654	52.44	**4**	6.419	27.58
CRN3760	15	7.944	41.8	7	7.314	37.46	9	7.181	35.02
SNK2900	**2**	5.556	20.67	16	8.170	48.47	**21**	8.495	49.31
Phb3442	12	7.778	37.28	9	7.366	36.98	6	6.895	31.96
CRN3604	16	8.167	41.33	20	8.706	51.89			
PAN6730	13	7.778	38.54	11	7.667	40.46	13	7.352	36.06
SNK2472	**1**	5.333	18.17	**2**	6.092	26.56	8	6.971	32.8
LS8508	**4**	5.889	21.78	**23**	9.039	55.57			
PAN6740	17	8.722	48.34	12	7.869	42.65			
Phb30H22	**2**	5.667	48.89	**24**	9.418	62.92	**3**	6.343	27.82
LS8502	8	7.278	34.03	15	7.987	45.1			
PAN6479	20	9.167	52.09	22	8.954	56.54	12	7.295	37.56
SNK2969	21	9.389	58.25	10	7.497	39.03	7	6.933	32.99
CRN3505	**23**	10.111	64.22	5	7.124	35.77	14	7.371	36.43
SC405	9	7.278	34.62	21	8.765	70.14			
Phb30G03	7	6.944	32.89	18	8.431	49.47			
PAN6777	6	6.889	48.89	**1**	5.915	36.58			
PAN6757	11	7.556	37.43	**3**	6.307	27.92			
CRN3549	10	7.333	34.25	**4**	6.346	29.36	16	7.733	40.29
PAN6615	18	8.778	47.33	13	7.948	43.44	**1**	5.657	21.85
Phb3202W	**22**	9.611	57.14	14	7.967	46.05	15	7.410	37.02
PAN6573	19	8.833	53.33	8	7.333	36.95			
NS9100							11	7.219	36.52
SC401							**20**	8.190	45.4
PAN6043							**2**	6.229	27.87
SNK2682							5	6.800	31.71
Phb30N35							10	7.200	35.33
PAN6844							19	8.076	43.69
PAN6734							17	8.038	43.73
PAN6146							18	8.038	46.3

S1 = mean absolute difference of ranks; S2 = variance of ranks; R = rank order of different estimates

According to these parameters, SNK2472, SNK2900, Phb30H22 and LS8508 had the smallest changes in ranks and were regarded as the most stable genotypes for irrigation maize production in South Africa. QS7608 and CRN3505 were unstable.

For the eastern region PAN6777, SNK2472, PAN6757 and CRN3549 were the more stable genotypes unlike Phb30H22 and LS8508 which were the unstable cultivars.

In the western part of South Africa's maize production area the genotypes differed from the other two regions. The western research regions climate is different from the other two regions. PAN6615, PAN6043, Phb30H22 and QS7608 had the best stability, while SNK2900 and SC401 were the most unstable genotypes.

SNK2778, SNK2472 and PAN6777 were the most stable genotypes over the whole maize production region of SA.

4.7 EBERHART AND RUSSEL STABILITY REGRESSION MEASURE

The Eberhart and Russel (1966) procedure involves the use of joint linear regression where the yield of each genotype is regressed on the environmental mean yield. Analysis of variance for the regression model is indicated by Table 4.9. Sums of squares due to environments and GxE are partitioned into environment (linear), GxE (linear) and deviations from the regression model. Each cultivar's performance across environments is interpreted in terms of three different parameters, the mean yield, the regression coefficient (b) and the deviation (S^2d) from the regression. A more stable genotype should have a high mean yield (μ), unit regression coefficient ($b=1.0$) and deviations from the regression as small as possible ($S^2d=0$). Therefore a stable cultivar is defined as a cultivar with $b = 1.0$ and $S^2d = 0$. The deviation from the regression is used as a measure of genotype stability across environments. In Table 4.9 the results of regression the genotype mean yield on the environment mean yield are indicated for the respective research regions.

Table 4.9 Analysis of variance for linear regressions of cultivar means in environmental mean yield for the irrigation, eastern and western maize production regions of the South Africa.

Source	**Irrigation Region**		**Eastern Region**		**Western Region**	
	Df	**SS**	**Df**	**SS**	**df**	**SS**
Total	647	11301.830	1295	1945.790	944	360.922
Cultivars (G)	23	89.960	23	101.064	20	31.243
E + in G x E	192	1211.870	408	1844.727	294	329.680
E in linear	1	485.889	1	1264.136	1	264.381
G x E (linear)	23	117.637	23	20.206	20	10.288
Pooled deviation	168	608.345	384	560.385	273	55.011
Residual	432	300.297	864	244.096	630	92.781
G = Genotype\Cultivars; E = Environment\Locality						

Table 4.10 The mean yield regression coefficient (b) and deviation from regression (S^2d) for 21-24 genotypes evaluated in the respective production regions of South Africa for the period of 2001-2003

Genotype	**Irrigation Region**			**Eastern Region**			**Western Region**		
	b	**S^2d**	**R**	**b**	**S^2d**	**R**	**B**	**S^2d**	**R**
PAN6568	0.9609	0.5196	16	1.1365	0.1325	10			
SNK2778	1.1310	-0.344	4	1.1164	-0.048	2			
QS7608	0.4165	0.2212	13	0.9503	0.4942	22	0.9448	-0.016	7
CRN3760	1.1584	-0.138	8	1.1544	-0.043	3	1.3050	-0.06	1
SNK2900	0.8588	-0.148	6	0.7073	0.0843	9	0.9032	0.0411	14
Phb3442	0.8162	-0.147	7	1.0572	0.0133	7	0.9650	-0.029	6
CRN3604	0.8462	-0.167	5	1.1084	0.1613	13			
PAN6730	0.8832	0.287	14	0.8844	0.0648	8	1.0420	0.0406	13
SNK2472	1.0727	-0.429	1	0.9262	0.1963	17	0.9613	-0.056	3
LS8508	1.0237	-0.375	3	1.1010	0.3281	21			
PAN6740	1.0471	-0.027	10	1.0329	0.1601	12			
Phb30H22	-0.022	45.79	24	1.2296	0.2340	20	1.0018	0.0830	19
LS8502	0.8934	-0.037	9	1.0783	0.1931	16			
PAN6479	0.6380	0.5676	18	0.8121	0.2282	19	0.7742	0.0510	16
SNK2969	1.1279	0.5397	17	0.9607	0.0002	6	1.0168	0.0137	11
CRN3505	1.3102	0.7516	20	0.9791	0.1897	15	1.0652	0.0721	18
SC405	1.0762	0.4995	15	1.0573	11.82	23			
Phb30G03	1.1031	-0.402	2	1.0996	0.1886	14			
PAN6777	2.9526	20.59	23	0.7898	13.59	24			
PAN6757	0.8838	0.7767	21	1.0159	-0.093	1			
CRN3549	1.0156	0.1534	12	1.0353	-0.001	5	1.2998	-0.002	9
PAN6615	0.9597	0.5782	19	0.8327	-0.021	4	1.0552	-0.059	2
Phb3202W	1.2168	0.1377	11	0.8997	0.1564	11	0.8930	-0.009	8
PAN6573	0.6299	1.0167	22	1.0349	0.2150	18			
NS9100							0.9669	0.0023	10
SC401							0.6120	0.1068	21
PAN6043							1.1128	-0.041	4
SNK2682							0.8670	0.0651	17
Phb30N35							0.7578	0.0277	12
PAN6844							1.2369	-0.035	5
PAN6734							0.7731	0.902	20
PAN6146							1.4463	0.041	15

R = Rank; b = Regression coefficient; S^2d = Deviation from the regression

For the irrigation maize production region, SNK2472, Phb30G03, LS8508 and SNK2778 showed the best stability, while CRN3604, SNK2900 and Phb3442 also had S^2d values smaller than 0, but regression coefficients considerably smaller than 1.0. Genotypes with the highest S^2d values were Phb30H22, PAN6777 and PAN6573.

In the eastern part of South Africa's maize production region, PAN6757, SNK2778, CRN3760 and PAN6615 were the most stable varieties. SNK2969, CRN3549 and Phb3442 also did well with S^2d value approaching zero, while PAN6777, SC405 and QS7608 were the most unstable genotypes.

For the western region CRN3760, PAN6615, SNK2472 and PAN6043 had the smallest S^2d values, therefore are the most stable genotypes. PAN6844, Phb3442 and QS7608 had intermediate stability, while PAN6734 and SC401 were the unstable genotypes.

Over all three the regions, the most stable genotypes were SNK2472, SNK2778, Phb3442, PAN6615. The unstable genotypes were PAN6777, PAN6734, SC401, PAN6573 and SC405.

4.8 ADDITIVE MAIN EFFECTS AND MULTIPLICATIVE INTERACTION (AMMI)

The additive main effect and multiplicative interaction (AMMI) model combines analysis of variance for the genotype and environment main effects with principal components analysis of the GxE interaction. The AMMI analysis of variance for grain yield of the 21-24 maize genotypes tested in three different research regions is given in Table 4.11. Between these three regions 14 localities were used for the trails done by the ARC. The best model for the irrigation region was AMMI 2, as IPCA1 and IPCA2 were highly significant ($Pr < 0.01$). These two axes declared 85.02% of the GxE interaction sum of squares while the remaining 14.98% were shared between the other IPCA's.

For the eastern region the AMMI 2 model was once again the best suited as ICPA1 and IPCA2 accounted for 79.08% of the total interaction. Both these axes were highly significant ($Pr < 0.01$). The remaining 20.92% consisted of the remaining IPCA's contribution to the interaction.

In the western part of South Africa's maize production region, AMMI2 model was the best fit as IPCA1, IPCA2 and IPCA3 were highly significant ($Pr < 0.01$) and contributed 65.59% of the GxE interaction.

All three research regions had R-squared values of 0.9 and lower, with CV values of 16.6% and smaller, which indicate relatively good trial accuracy. In all three regions IPCA1 and IPCA2 need to be interpreted and discussed while the other IPCA's may be discarded in the interpretation due to their relatively small contribution to the GxE sum of squares. In the western region, IPCA3 should also be investigated to elucidate meaningful and interpretable pattern.

Gauch and Zobel (1997) and Phurchase (1997) reported that the IPCA scores of genotypes in the AMMI analysis are an indication of the stability of a genotype across environments. The larger the IPCA scores, either negative or positive, as it is a relative value, the more specifically adapted a genotype is to certain environments. The closer the IPCA scores to zero, the more stable the genotype is over all environments sampled.

The other option is to calculate the AMMI stability value (ASV), by use of the formula:

$$\text{AMMI Stability Value (ASV)} = \sqrt{[\frac{IPCA1SumofSquares}{IPCA2\sum ofSquares}(IPCA1score)]^2 + [IPCA2score]^2} \tag{10}$$

This stability value was reported to be a balanced measurement between the two IPCA scores (Purchase, 1997).

Table 4.11 ANOVA of the cultivar evaluation trials for the irrigation (Model 2), eastern (AMMI 2) and western (AMMI 2) regions over the period of 2001-2003.

Source	Irrigation Region				Eastern Region				Western Region			
	df	SS	MS	Pr	df	SS	MS	Pr	df	SS	MS	Pr
Total	647	4806.3		0	1295	6569.66		0	944	1361		0
E	8	1457.6	182.21		17	3792.41	223.08		14	793	56.65	
Reps in E	18	304.09	16.89	0.48	36	186.27	5.17	0	30	56.1	1.87	0
G	23	269.88	11.73	0	23	303.19	13.18	0	20	93.7	4.69	0
GxE	184	2177.9	11.84	0	391	1741.77	4.46	0	280	196	0.70	0
IPCA 1	30	1109.9	36.99	0	39	798.86	20.48	0	33	57.9	1.76	0
IPCA 2	28	741.72	26.49	0	37	578.59	15.64	0	31	44.9	1.45	0
IPCA 3	26	152.46	5.86	0	35	77.56	2.20	0	29	25.7	0.89	0
IPCA 4	24	66.44	2.77	0.006	33	68.07	2.06	0	27	16.8	0.63	0.017
IPCA 5	22	38.81	1.76	0.223	31	53.16	1.72	0	25	14.8	0.59	0.033
IPCA 6	20	34.69	1.74	0.247	29	41.63	1.44	0	23	12.3	0.54	0.081
IPCA 7	18	19.83	1.10	0.743	27	27.66	1.02	0.037	21	8.58	0.41	0.340
IPCA 8	16	14.12	0.88	0.875	25	24.76	0.99	0.055	19	4.87	0.26	0.829
IPCA 9					23	20.40	0.89	0.129	17	3.81	0.22	0.889
IPCA 10					21	18.66	0.89	0.136	15	2.94	0.20	0.925
IPCA 11					19	10.25	0.54	0.687	13	1.69	0.13	0.983
IPCA 12					17	7.36	0.43	0.847	11	0.99	0.09	0.994
IPCA 13					15	6.40	0.43	0.836	9	0.35	0.04	0.999
IPCA 14					13	4.42	0.34	0.916	7	0.20	0.03	0.999
IPCA 15					11	2.22	0.20	0.985				
IPCA 16					9	1.73	0.19	0.977				
IPCA 17					7	0.56	0.08	0.997				
Residual	414	569.80	1.44		828	546.02	0.66		600	222	0.37	

E = Environments\Localities; G = Genotypes\Cultivars; GxE = Genotype Environment Interaction

Table 4.12 Mean yield ($ton.ha^{-1}$), rank, IPCA1 and IPCA2 scores and an AMMI stability value (ASV) of maize genotypes over 14 environments in the irrigation, eastern and western maize production regions in South Africa for the period of 2001-2003.

Cultivar	**Irrigation Region**						**Eastern Region**						**Western Region**					
	Yield	**R**	**IPCA1**	**IPCA2**	**ASV**	**R**	**Yield**	**R**	**IPCA1**	**IPCA2**	**ASV**	**R**	**Yield**	**R**	**IPCA1**	**IPCA2**	**ASV**	**R**
PAN6568	9.10	7	-0.470	-0.042	0.71	23	5.82	11	-0.039	0.1630	0.17	18						
SNK2778	8.97	9	-0.222	-0.103	0.35	16	5.66	16	0.0894	0.0398	0.13	10						
QS7608	7.39	23	0.0214	-0.693	0.69	3	5.19	22	0.4635	0.4108	0.76	3	3.33	20	-0.097	0.2165	0.25	9
CRN3760	9.84	1	-0.237	-0.122	0.38	18	5.87	9	0.1115	0.0251	0.16	9	3.81	7	-0.068	-0.496	0.50	8
SNK2900	8.07	21	-0.203	-0.334	0.45	14	5.45	20	-0.036	0.4363	0.44	17	3.51	17	-0.172	0.3599	0.42	14
Phb3442	8.59	14	-0.209	-0.251	0.40	15	6.03	7	0.0101	0.1871	0.19	14	3.53	16	0.2310	0.1623	0.34	4
CRN3604	8.82	11	0.0092	-0.252	0.25	4	6.04	6	0.1311	-0.079	0.20	8						
PAN6730	9.23	4	-0.166	-0.369	0.44	12	5.86	10	0.0498	0.3249	0.33	12	3.68	10	-0.004	-0.325	0.33	7
SNK2472	8.97	8	-0.053	-0.014	0.08	7	6.18	5	0.3047	0.4842	0.64	4	3.87	5	0.0869	-0.134	0.17	5
LS8508	8.51	15	-0.082	-0.031	0.13	8	5.61	18	0.5493	-0.057	0.76	2						
PAN6740	8.69	12	0.0225	-0.169	0.17	2	5.91	8	0.2179	0.2239	0.38	5						
Phb30H22	7.22	24	4.2436	0.0867	6.35	1	6.25	3	-0.282	-0.201	0.44	23	3.59	12	0.5504	0.3954	0.81	2
LS8502	8.13	20	-0.049	-0.124	0.14	6	5.32	21	0.1613	-0.009	0.22	6						
PAN6479	8.48	16	-0.298	-0.506	0.67	19	5.54	19	0.0070	0.4670	0.47	15	3.54	15	-0.419	0.2512	0.60	21
SNK2969	8.37	18	-0.321	0.0064	0.48	21	5.74	13	0.0618	0.3498	0.36	11	3.65	11	-0.148	-0.274	0.33	12
CRN3505	9.52	2	-0.479	0.0819	0.72	24	6.33	1	0.1364	0.6010	0.63	7	4.01	4	-0.160	-0.038	0.21	13
SC405	8.35	19	-0.149	-0.066	0.23	10	4.07	24	2.0338	-3.006	4.11	1						
Phb30G03	9.15	5	-0.106	0.0089	0.16	9	6.19	4	0.0296	0.1867	0.19	13						
PAN6777	7.57	22	-0.232	3.7771	3.79	17	4.96	23	-3.354	-1.701	4.93	24						
PAN6757	8.97	10	-0.159	-0.181	0.30	11	5.81	12	-0.140	0.2231	0.30	20						
CRN3549	9.14	6	-0.302	-0.118	0.47	20	6.32	2	-0.132	0.2076	0.28	19	4.11	1	-0.106	-0.768	0.78	10
PAN6615	8.60	13	-0.034	-0.155	0.16	5	5.63	17	-0.168	0.2004	0.31	21	3.59	13	-0.300	-0.083	0.40	17
Phb3202W	9.51	3	-0.333	0.0012	0.50	22	5.73	14	-0.195	0.0535	0.27	22	3.42	19	-0.195	0.3079	0.40	16
PAN6573	8.37	17	-0.192	-0.429	0.51	13	5.72	15	-0.010	0.4696	0.47	16						
NS9100													3.48	18	-0.145	0.2011	0.27	11
SC401													2.68	21	-0.368	0.9761	1.09	20
PAN6043													3.72	9	-0.349	-0.324	0.55	19
SNK2682													3.76	8	-0.179	0.4799	0.53	15
Phb30N35													3.59	14	-0.347	-0.094	0.46	18
PAN6844													4.12	1	0.0537	-0.192	0.20	6
PAN6734													3.90	5	1.7417	0.2986	2.27	1
PAN6146													4.07	3	0.3953	-0.919	1.05	3

According to the concept of Gauch and Zobel (1997) Phb30H22 was the most stable genotype followed by PAN6740, QS7608 and CRN3604 for the irrigation region. In contrast, CRN3505, PAN6568 and Phb3203W were adapted to specific environments. Figure 4.1 indicates the AMMI2 model biplot for the Irrigation region trials. Distinct patterns are identifiable with the higher potential environments predominating in quadrant II, such as Cradock and Upington and the lower potential environment in quadrant I, such as Krugersdorp. A high intensity variation around the mean yield of 8.65 ton ha^{-1} was noted for the genotypes. Purchase (1997) found that IPCA2 also plays a significant role in the GxE interaction. Therefore IPCA1 scores were plotted against IPCA2 scores to further test the stability of the 24 genotypes (Fig. 4.2). The closer the genotypes are to the centre or zero of this figure, the more stable they are. Most of the genotypes were less interactive with their environments and thus more stable, which is exactly what we expect of an irrigation trial, for there is very little change in environmental conditions. PAN6777 showed intensive interaction with the environment and are therefore considered to be unstable.

Figure 4.3 indicates the AMMI2 biplot of the eastern region trials. Again a distinct pattern was discernible with the majority of high potential environments, such as Delmas and Bloekomspruit, positioned in quadrant II. The eastern maize production region of South Africa is generally high potential regions. According to the biplot PAN6573, Phb30H22 and PAN6730 were the most stable genotypes, while SC405 is adapted to lower potential environments and PAN6777 specifically adapted to higher potential environments. Most of the cultivars used for the trials in this region were relatively stable, for they are concentrated around the average mean yield and zero IPCA1 value (centre of figure). If we look at Fig.4.4 which illustrates the biplot of IPCA1 and IPCA2 values of the Maoos region, most of the cultivars seem to be relatively stable for they are centred around the origin. PAN6777 and CRN3505 were further from the centre and were the genotypes experiencing a big influence from the environmental conditions.

The AMMI2 biplot of the western region cultivar evaluation trials is presented in Figure 4.5. Once again, the high potential areas dominate in quadrant II, such as Wesselsbron and Rushof. However, the low potential environments, such as Blesbolfontein and

Zoetmelksvallei were predominantly distributed just beneath the IPCA1 score of zero in quadrant IV. According to the biplot (yield plotted against IPCA1), CRN3760, SNK2472, PAN6730, SNK2969 and SNK2682 were the most stable cultivars, while PAN6734 were specifically adapted to unfavourable environments. Figure 4.6 represents the biplot of the IPCA1 and IPCA2 values for this region. According to this biplot, most of the genotypes were relatively stable. However PAN6734, Phb30H22, SC401 and PAN6164 were adapted to specific environments.

From the respective AMMI biplots for the three different research regions, it is clear that the genotypes were arranged in a fairly specific and similar order, according to the IPCA1 scores. In the interpretation of the AMMI analysis, the genotype main effect (yield) should also be considered. The hybrids CRN3505 was rated 2, 1 and 4 respectively in the different regions, while CRN3549 ranked 6, 2 and 1 respectively (Table 4.12)

Despite discernible differences in adaptation over regions, it generally appears that the cultivars were specifically adapted to favourable conditions. The adaptation of the cultivars for the irrigation and eastern regions were similar, but the western region differed from these two.

Table 4.13 Cultivars and environments represented by alphabetical letters in the three different regions biplot as illustrated by AMMI2. Each locality has three letters representing the three different years. (See Figures 4.1-4.6)

Irrigation Region				**Eastern Region**				**Western Region**			
Alphabetic letter and Cultivar		**Alphabetic letter and Locality**		**Alphabetic letter and Cultivar**		**Alphabetic letter and Locality**		**Alphabetic letter and Cultivar**		**Alphabetic letter and Locality**	
a	PAN6568	A	CDOCK	a	PAN6568	A	NCASTL	a	QS7608	A	BBOKF
b	SNK2778	B	KDORP	b	SNK2778	B	BVILLE	b	CRN3760	B	KOSTER
c	QS7608	C	UTON	c	QS7608	C	BKOMS	c	Phb3442	C	ZMVAL
d	CRN3760	D	CDOCK	d	CRN3760	D	BSPRUIT	d	SNK2900	D	WBRON
e	SNK2900	E	KDORP	e	SNK2900	E	DELM1	e	SNK2472	E	RHOF
f	Phb3442	F	UTON	f	Phb3442	F	DELMA2	f	PAN6730	F	BBOKF
g	CRN3604	G	CDOCK	g	CRN3604	G	NCASTL	g	Phb30H22	G	KOSTER
h	PAN6730	H	KDORP	h	PAN6730	H	BVILLE	h	NS9100	H	ZMVAL
i	SNK2472	I	UTON	i	SNK2472	I	BKOMS	i	PAN6479	I	WBRON
j	LS8508			j	LS8508	J	BSPRUIT	j	SNK2969	J	RHOF
k	PAN6740			k	PAN6740	K	DELM1	k	SC401	K	BBOKF
l	Phb30H22			l	Phb30H22	L	DELMA2	l	CRN3505	L	KOSTER
m	LS8502			m	LS8502	M	NCASTL	m	PAN6043	M	ZMVAL
n	PAN6479			n	PAN6479	N	BVILLE	n	SNK2682	N	WBRON
o	SNK2969			o	SNK2969	O	BKOMS	o	CRN3549	O	RHOF
p	CRN3505			p	CRN3505	P	BSPRUIT	p	Phb30N35		
q	SC405			q	SC405	Q	DELM1	q	PAN6615		
r	Phb30G03			r	Phb30G03	R	DELMA2	r	Phb3203W		
s	PAN6777			s	PAN6777			s	PAN6844		
t	PAN6757			t	PAN6757			t	PAN6734		
u	CRN3549			u	CRN3549			u	PAN6146		
v	PAN6615			v	PAN6615						
w	Phb3202W			w	Phb3202W						
x	PAN6573			x	PAN6573						
A-C=2003; D-F=2002; G-I=2001				A-F=2003; G-L=2002; M-R=2001				A-E=2003; F-J=2002; K-O=2001			

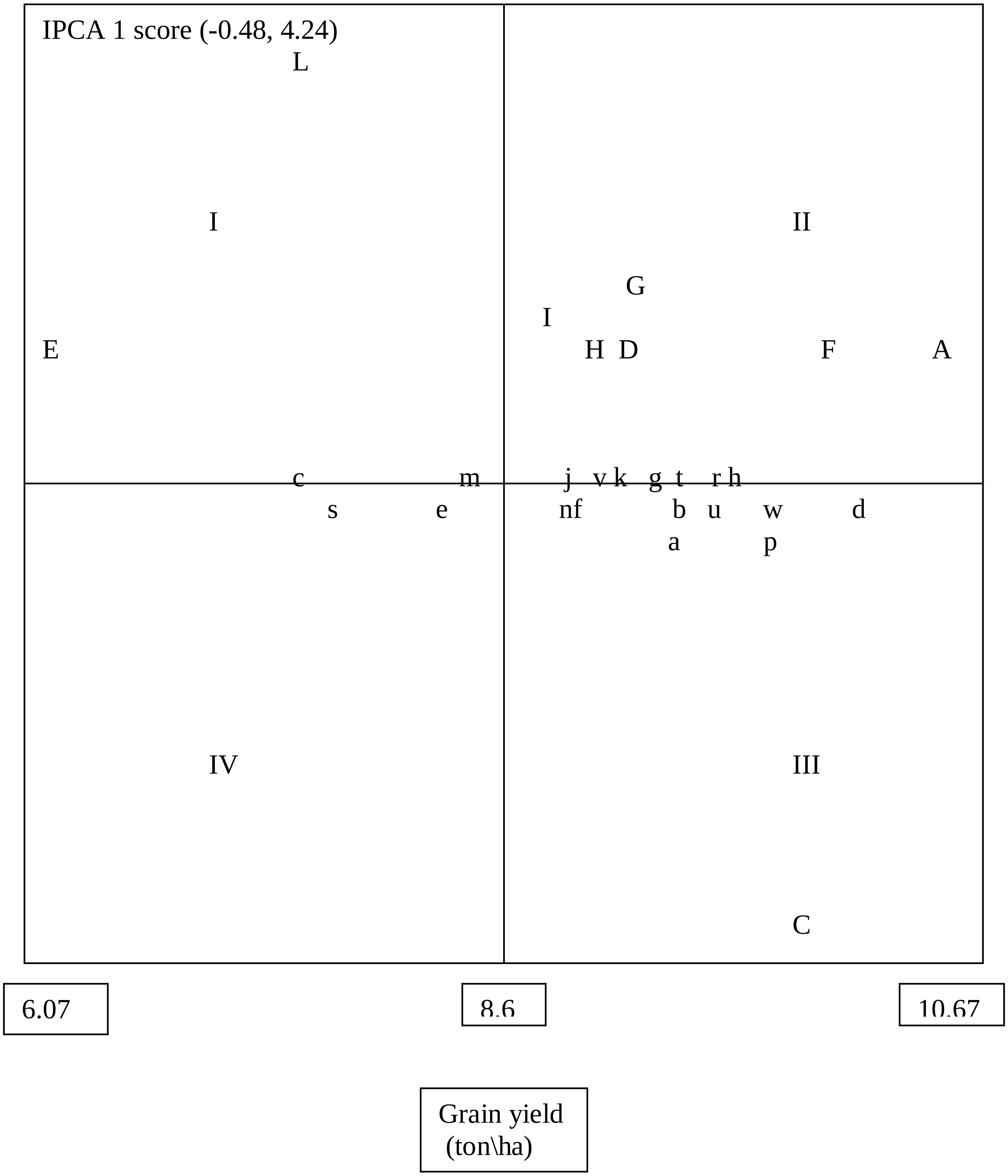

Figure 4.1 AMMI model 2 biplot for grain yield of 24 maize genotypes tested in 3 environments under irrigation in South Africa for the period of 2001-2003. The alphabetic letters of all genotypes and environments indicate the correct spot on the biplots, as listed in table 4.13.

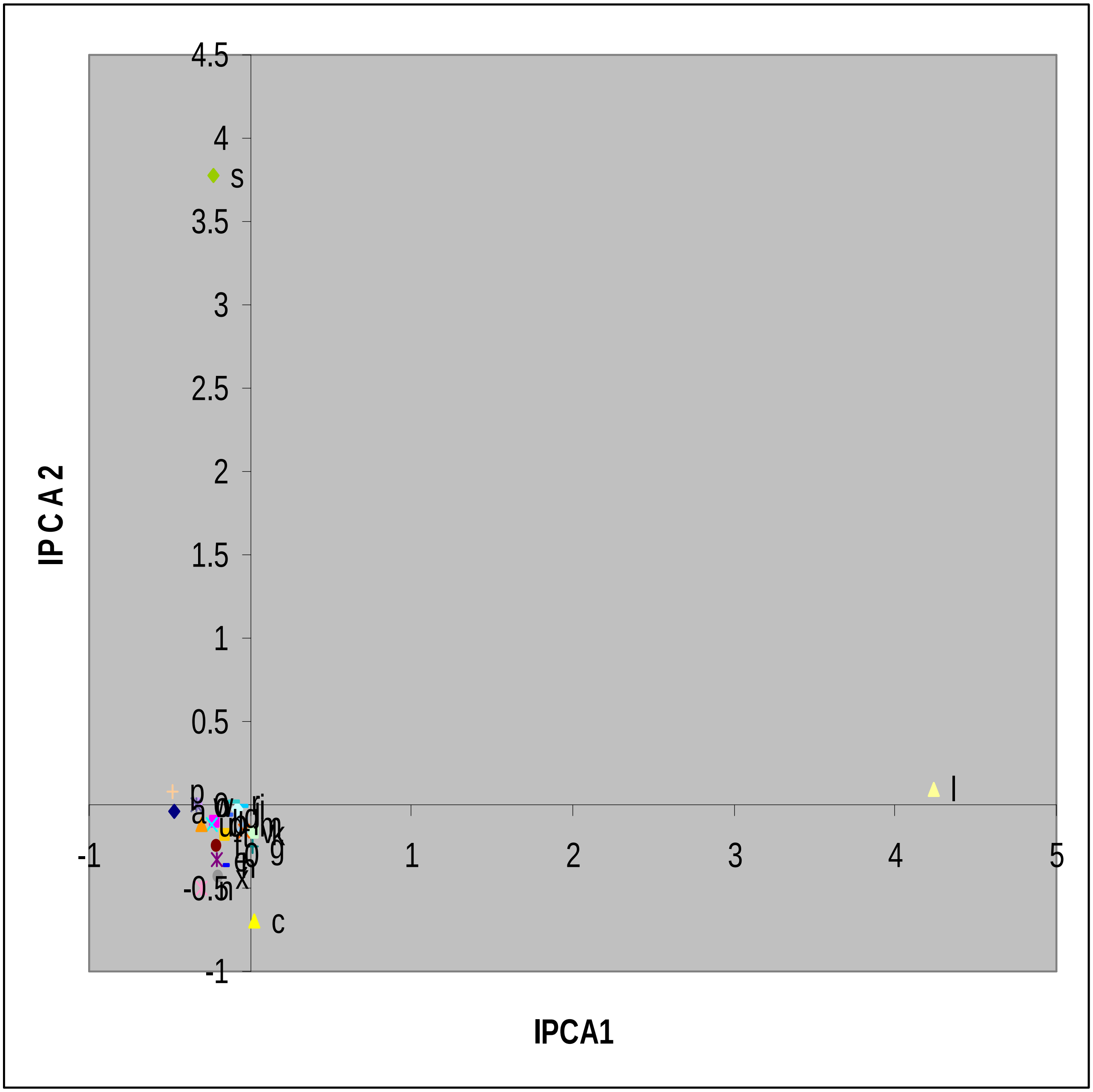

Figure 4.2 Plotted IPCA1 and IPCA2 scores of 24 maize genotypes tested in three environments under irrigation in South Africa for the period of 2001-2003.

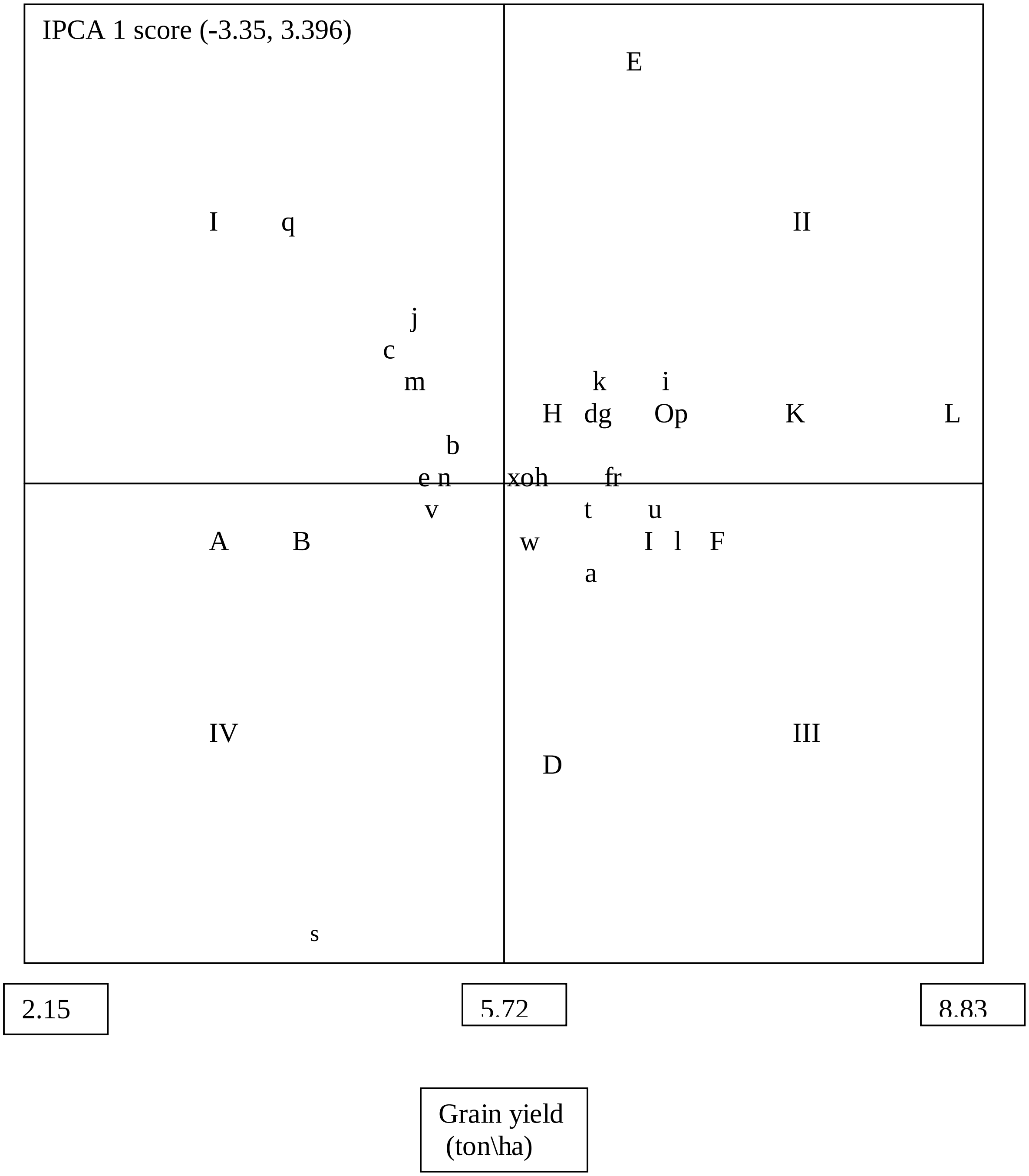

Figure 4.3 AMMI model 2 biplot for grain yield of 24 maize genotypes tested in 6 environments in the eastern maize production region of South Africa for the period of 2001-2003. The alphabetic letters indicates genotypes and environments positions on the biplot, as listed in Table 4.13.

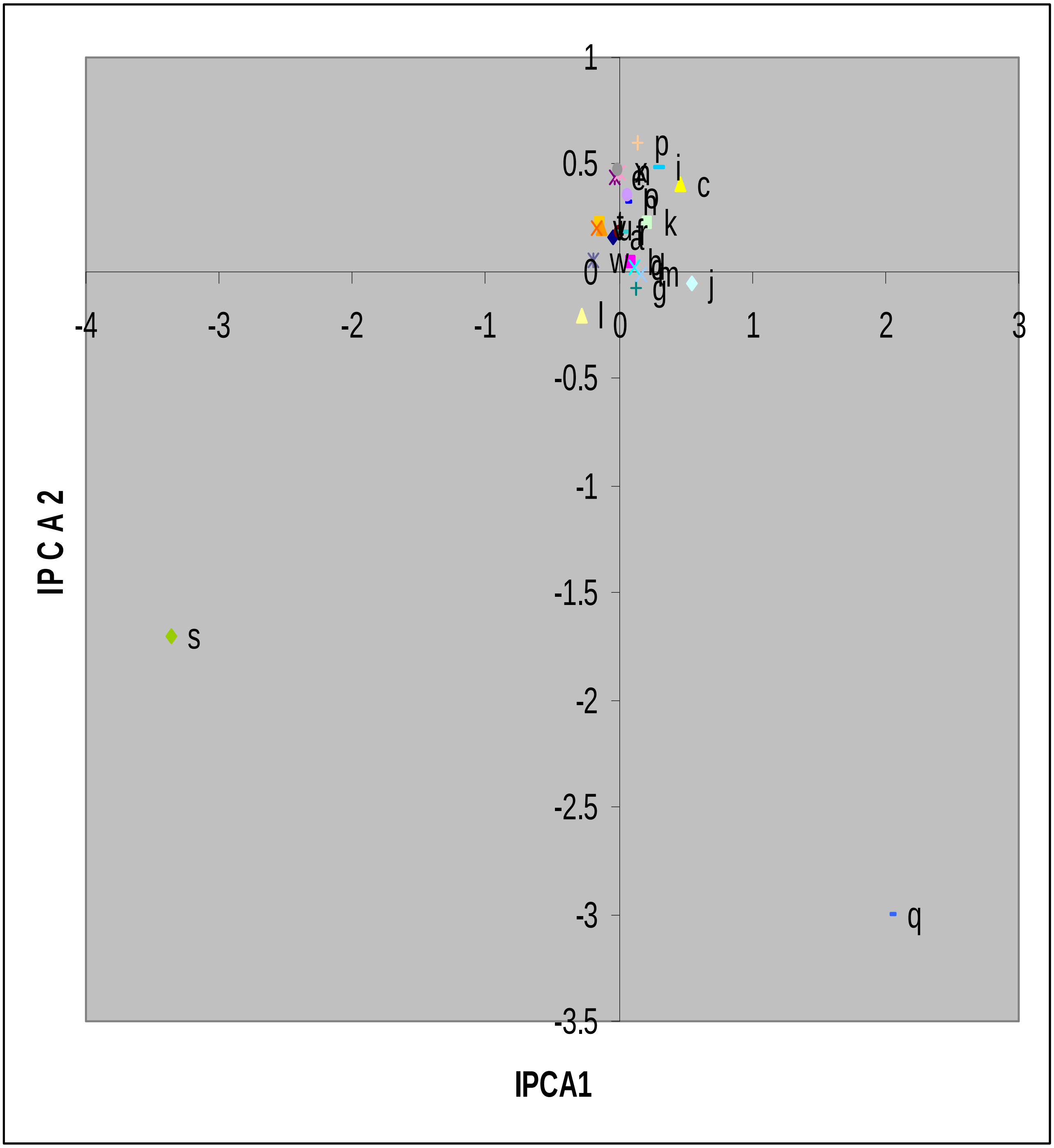

Figure 4.4 Plotted IPCA1 and IPCA2 scores of 24 maize genotypes tested in 6 environments in the eastern region in South Africa for the period of 2001-2003.

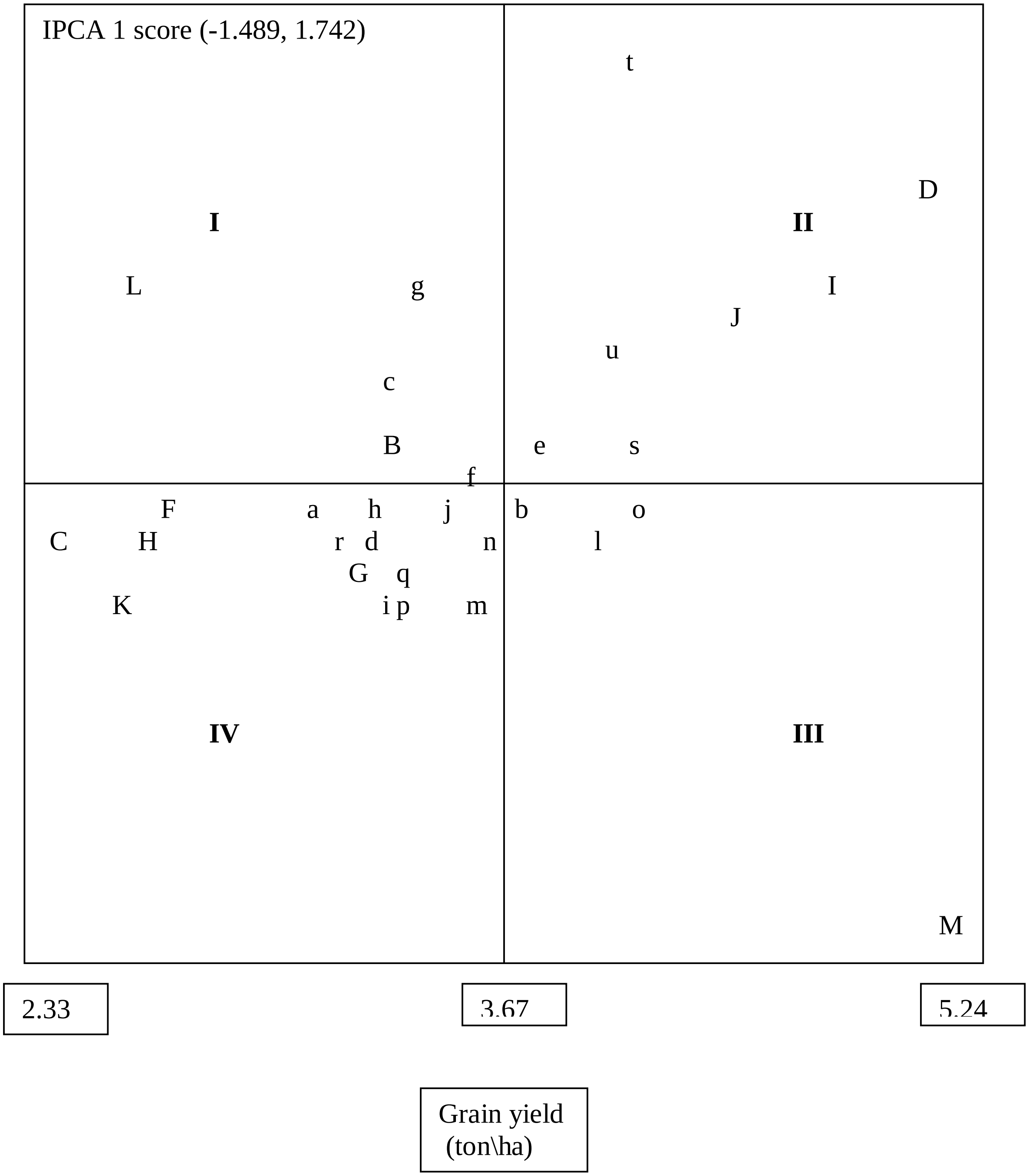

Figure 4.5 AMMI model 2 biplot for grain yield of 21 maize genotypes tested in 5 environments in the western maize production region of South Africa for the period of 2001-2003. The alphabetic letters indicates genotypes and environments positions on the biplot, as listed in Table 4.13.

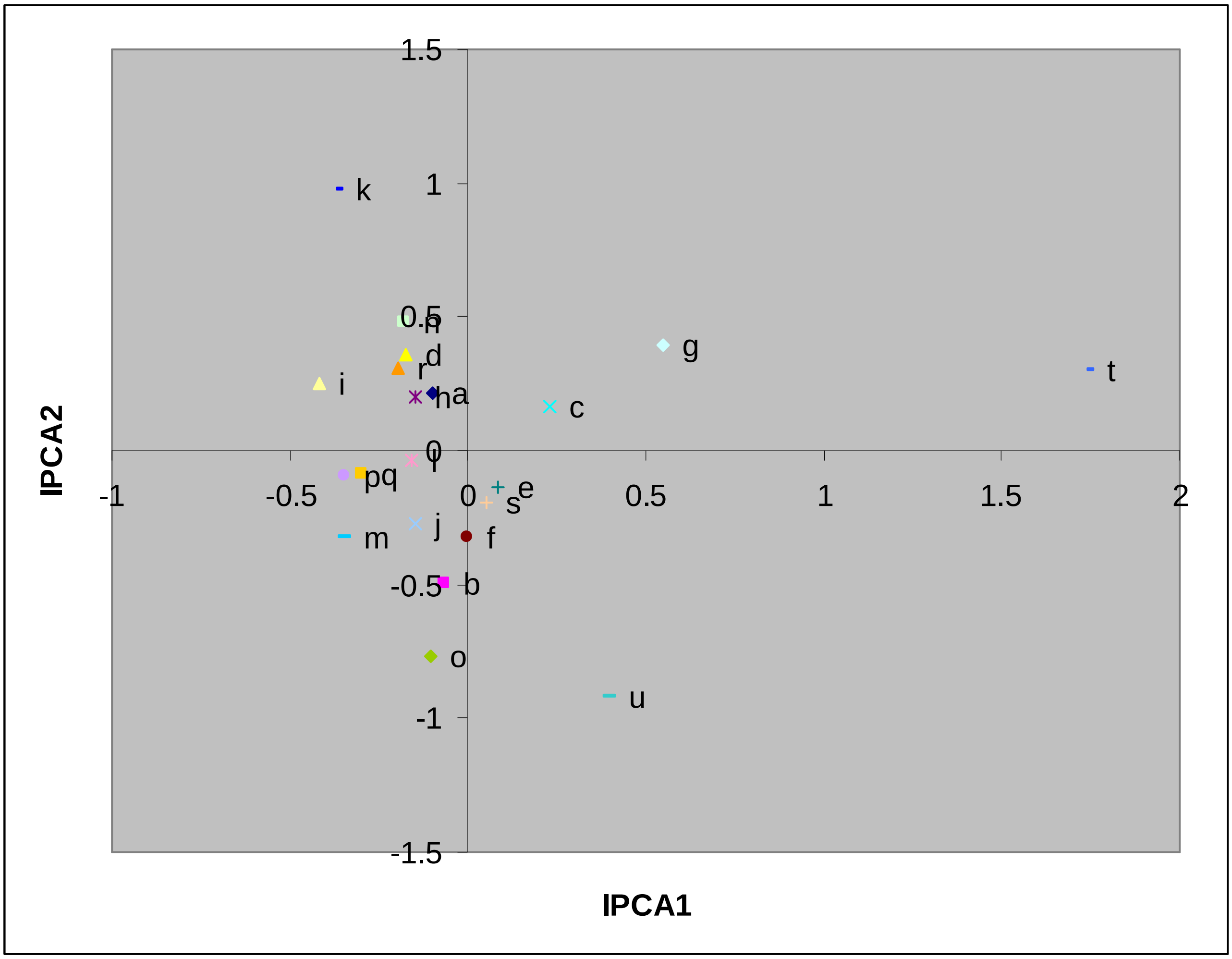

Figure 4.6 Plotted IPCA1 and IPCA2 scores of 21 maize genotypes tested in 5 environments in the western region in South Africa for the period of 2001-2003.

4.9 COMPARISON OF STABILITY PARAMETERS

Tables 4.14, 4.15 and 4.16 indicate the ranking order for stability of the 21-24 maize genotypes, according to the eight different genotype x environment interaction statistical analysis procedures, for respectively the irrigation, eastern and western maize production regions in South Africa. Purchase (1997) did a similar study on wheat trails in the Free State and found that Shukla's stability analysis procedure correlated highly significantly with those of Eberhart and Russel, Wricke and the AMMI model, while the same held true for Eberhart and Russel with Wricke and AMMI, as well as for Wricke with the AMMI. However, no correlation was found in the pair wise comparison of Lin and Binns' (Cultivar Superiority Measure) procedure with the other procedures, which indicates that Lin and Binns procedure is significantly different from the other procedures (see tables 4.15, 4.17 and 4.19).

Lin and Binns' definition of stability (the deviation of a specific genotype's performance from the performance of the best cultivar in a trial) implies that a stable cultivar is one that performs in correlation with the environment. Therefore, cultivars with high mean yield values would always be classified as stable for their mean yield would always be close to the highest performer for that environment. Cultivars with lower potential would always be classified as unstable (Purchase, 1997). This procedure appears to be more of a genotype performance measure, than a stability measure over different environments. Mean yield can rather be used to determine a superior yield performing genotype.

Table 4.14 contains the stability analysis values for the irrigation region. The most significant correlations were visible between Wi-Ecovalence, Shukla's stability variance, Stability Variance with locality as co-variate, Rank Difference and Variance Difference and Eberhart and Russel procedures. AMMI procedure differs from these procedures. According to the correlations SNK2778, SNK2472, LS8508 and Phb30G03 were the most stable genotypes respectively. The most unstable cultivars are Phb30H22 and PAN6777.

As indicated in Table 4.15, the value of Wi-ecovalence, Shukla's stability variance and Eberhart and Russel procedures found PAN6757, SNK2778, CRN3549 and SNK2969 as the most stable genotypes in the eastern region. Only variation from the ranking order of these procedures were the Rank Difference and Variation Difference’s as well as the AMMI model’s ranking order. PAN6777 and SC405 were found to be the most unstable genotypes by the dominating procedures.

For the western region, the stability analysis correlated the same as for the eastern region. The AMMI model‘s results was different from the other four procedures. PAN6615, SNK2472, PAN6043 and Phb3442 were ranked as most stable cultivars by five of the eight stability analysis. SC401 and PAN6734 were rated as the most unstable cultivars.

Genotypes that were used for the trials in the western region were a little bit different from those used in the irrigation and eastern regions. The western part of South Africa has a lower mean yield, due to the lower potential rianfall.

The AMMI model can be described as a multivariate analysis method as it integrates analysis of variance and principal components analysis into a unified approach. Purchase (1997) suggested that if a single method of describing GxE interaction and the stability of a genotype had to be selected, the AMMI model would be the more appropriate. Becker and Leon (1988) stated that multivariate methods are too sophisticated to provide any simple measure of yield stability which allow ranking of genotypes.

The Eberhart and Russel procedure showed highly significant correlation with the procedures of Wricke, Shukla (no co-variate and locality as co-variate) as well as Rank Difference (S1) and Variance Difference (S2). Their definition of stability is based on a genotype’s average sensitivity to environmental fluctuations and is determined by using joint linear regression analysis in which the average deviation from the regression is determined. Using the regression approach could assist in identifying and recommending the best genotypes for specific environments.

Wricke’s ecovalence, Shukla’s stability analysis and Eberhart and Russel’s procedures correlated highly significantly. However, no correlation was found in the pair wise comparison of Lin and Binns’ (1988) (Cultivar Superiority Measure) procedure with the other procedures and very little correlation was found in the pair wise comparison of the AMMI model and the other procedures. The more holistic approach of AMMI is particularly effective in clarifying GxE interactions. Using the IPCA1 and IPCA2 scores to determine an AMMI stability value, superiority ranking of genotypes can easily be done. The AMMI model can summarize patterns and relationships of genotypes and environments successfully as well as offers a valuable prediction assessment. For this reason, it is recommended that this model is used for analyzing GxE interaction of maize genotypes in South Africa. The Lin and Binns procedure appears to be more of a cultivar performance measure than a stability measure, which explains its correlation with the mean yield of the genotypes. The Eberhart and Russel, Wricke’s ecovalence and Shukla’s stability analysis showed highly significant correlation and are recommended to be used to describe genotype stability of maize genotypes rather than to be used to describe GxE interactions, due to the limitations of these techniques.

Table 4.14 Mean yield (ton ha^{-1}), different stability measurements and rankings for the maize genotypes tested in three environments under irrigation for the period of 2001-2003 (Irrigation region).

Cultivar	GxE Stability Analysis Procedures															
	Combined ANOVA		Cult. Superiority Measure		Wi-Ecovalence		Shukla Stability Variance		Stability Variance-Locality Covariate		Rank Difference Variance Difference		Eberhart & Russel		AMMI	
	MEAN YIELD	R	Pi	R	Wi	R	$\sigma^2 i$	R	GxE STAT.	R	S1	R	$S^2 d$	R	ASV	R
PAN6568	9.10	9	1.53	8	8.53	15	2.95	15	3.46	16	7.944	14	0.5196	16	0.71	23
SNK2778	8.97	11	1.54	9	2.81	4	.61	4	0.64	4	6.778	5	-0.344	4	0.35	16
QS7608	7.39	24	6.12	22	13.31	21	4.91	21	2.48	13	10.500	24	0.2212	13	0.69	3
CRN3760	9.84	1	0.42	1	4.41	7	1.27	7	1.31	8	7.944	15	-0.138	8	0.38	18
SNK2900	8.07	23	3.57	20	4.24	6	1.2	6	1.28	6	5.556	2	-0.148	6	0.45	14
Phb3442	8.59	16	2.43	14	4.52	8	1.31	8	1.28	7	7.778	12	-0.147	7	0.40	15
CRN3604	8.82	13	1.87	10	4.17	5	1.17	5	1.21	5	8.167	16	-0.167	5	0.25	4
PAN6730	9.23	6	1.30	5	7.15	13	2.39	13	2.70	14	7.778	13	0.287	14	0.44	12
SNK2472	8.97	10	1.52	7	1.97	1	0.27	1	0.36	1	5.333	1	-0.429	1	0.08	7
LS8508	8.51	17	2.35	13	2.25	2	0.38	2	0.53	3	5.889	4	-0.375	3	0.13	8
PAN6740	8.69	14	2.19	12	4.72	9	1.39	9	1.67	10	8.722	17	-0.027	10	0.17	2
Phb30H22	9.25	5	27.11	23	346.54	24	141.23	24	151.63	24	5.667	2	45.79	24	6.35	1
LS8502	8.13	22	3.56	19	4.84	10	1.44	10	1.64	9	7.278	8	-0.037	9	0.14	6
PAN6479	8.48	18	2.99	16	11.49	19	4.16	19	3.62	18	9.167	20	0.5676	18	0.67	19
SNK2969	8.37	20	3.09	17	8.97	17	3.13	17	3.53	17	9.389	21	0.5397	17	0.48	21
CRN3505	9.52	3	1.2	3	12.07	20	4.40	20	4.22	20	10.111	23	0.7516	20	0.72	24
SC405	8.35	21	3.11	18	8.48	14	2.93	14	3.39	15	7.278	9	0.4995	15	0.23	10
Phb30G03	9.15	7	1.25	4	2.27	3	0.39	3	0.45	2	6.944	7	-0.402	2	0.16	9
PAN6777	9.66	2	17.47	24	226.22	23	92.01	23	69.16	23	6.889	6	20.59	23	3.79	17
PAN6757	8.97	12	1.98	11	10.58	18	3.79	18	4.30	21	7.556	11	0.7767	21	0.30	11
CRN3549	9.14	8	1.38	6	5.944	11	1.89	11	2.26	12	7.333	10	0.1534	12	0.47	20
PAN6615	8.60	15	2.65	15	8.95	16	3.12	16	3.65	19	8.778	18	0.5782	19	0.16	5
Phb3203W	9.51	4	.84	2	6.78	12	2.24	12	2.21	11	9.611	22	0.1377	11	0.50	22
PAN6573	8.37	19	3.63	21	14.76	22	5.5	22	5.08	22	8.833	19	1.0167	22	0.51	13

4.15 Spearman's coefficients of rank correlation for seven GxE stability analysis procedures conducted on 24 cultivars evaluated over three sites in the irrigation maize production region of South Africa.

Statistical procedure	**Mean Yield**	**Superiority Measure**	**Wricke's ecovalence**	**Shukla's Stability Measure**	**Stability Measure Locality Co-variate**	**Rank Difference Variance Difference**	**Eberhart & Russel**
Superiority Measure	0.5991**						
Wricke's ecovalence	-0.0243	0.4904*					
Shukla's Stability	-0.0243	0.4904*	1.0000**				
Stability Locality Co-variate	-0.1130	0.4122	0.9591**	0.9591**			
Rank Difference Variance Difference	0.0780	-0.1461	0.4384*	0.4384*	0.3591		
Eberhart & Russel	-0.1130	0.4122	0.9591**	0.9591**	1.0000**	0.3591	
AMMI	-0.3278	-0.3861	0.1365	0.1365	0.1765	0.2823	0.1765

*** P ≤ 0.05, ** P ≤ 0.01**

Table 4.16 Mean yield (ton ha^{-1}), different stability measurements and rankings for the maize genotypes tested in three environments for eastern research region for the period of 2001-2003.

Cultivar	**GxE Stability Analysis Procedures**															
	Combined ANOVA		**Cult. Superiority Measure**		**Wi-Ecovalence**		**Shukla Stability Variance**		**Stability Variance-Locality Covariate**		**Rank Difference Variance Difference**		**Eberhart & Russel**		**AMMI**	
	MEAN YIELD	**R**	**Pi**	**R**	**Wi**	**R**	**$\sigma^2 i$**	**R**	**GxE STAT.**	**R**	**S1**	**R**	**$S^2 d$**	**R**	**ASV**	**R**
PAN6568	5.82	11	1.15	13	7.62	12	1.27	12	1.15	10	8.235	17	0.1325	10	0.17	18
SNK2778	5.66	17	1.17	14	4.47	2	0.66	2	0.56	2	7.144	6	-0.048	2	0.13	10
QS7608	5.19	25	2.20	22	12.56	22	2.21	22	2.33	22	8.654	19	0.4942	22	0.76	3
CRN3760	5.87	9	0.97	10	5.08	6	0.78	6	0.58	3	7.314	7	-0.043	3	0.16	9
SNK2900	5.45	21	1.81	20	10.38	20	1.80	19	0.99	9	8.170	16	0.0843	9	0.44	17
Phb3442	6.03	7	0.71	4	4.91	5	0.74	5	0.76	7	7.366	9	0.0133	7	0.19	14
CRN3604	6.04	6	0.79	7	7.72	13	1.28	13	1.25	12	8.706	20	0.1613	13	0.20	8
PAN6730	5.86	10	1.05	11	6.26	8	1.00	8	0.93	8	7.667	11	0.0648	8	0.33	12
SNK2472	6.18	5	0.71	5	7.95	15	1.33	14	1.36	18	6.092	2	0.1963	17	0.64	4
LS8508	5.61	19	1.49	18	10.31	19	1.78	20	1.79	21	9.039	23	0.3281	21	0.76	2
PAN6740	5.91	8	0.87	8	7.14	9	1.17	9	1.24	12	7.869	12	0.1601	12	0.38	5
Phb30H22	6.25	3	0.76	6	11.04	21	1.92	21	1.48	20	9.418	24	0.2340	20	0.44	23
LS8502	5.32	23	2.01	21	7.93	14	1.32	15	1.35	17	7.987	15	0.1931	16	0.22	6
PAN6479	5.54	20	1.61	19	10.03	18	1.73	18	1.46	19	8.954	22	0.2282	19	0.47	15
SNK2969	5.74	14	1.07	12	4.60	4	0.68	4	0.72	6	7.497	10	0.0002	6	0.36	11
CRN3505	6.33	1	0.46	2	7.58	11	1.26	11	1.34	15	7.124	5	0.1897	15	0.63	7
SC405	4.84	26	10.67	24	193.83	23	37.11	23	39.40	23	8.765	21	11.82	23	4.11	1
Phb30G03	6.19	4	0.71	3	8.06	17	1.34	17	1.33	14	8.431	18	0.1886	14	0.19	13
PAN6777	5.78	13	9.42	23	224.27	24	42.97	24	45.19	24	5.915	1	13.59	24	4.93	24
PAN6757	5.81	12	0.95	9	3.04	1	0.38	1	0.41	1	6.307	3	-0.093	1	0.30	20
CRN3549	6.32	2	0.42	1	4.56	3	0.68	3	0.712	5	6.346	4	-0.001	5	0.28	19
PAN6615	5.63	18	1.34	17	5.66	7	0.89	7	0.65	4	7.948	13	-0.021	4	0.31	21
Phb3203W	5.73	15	1.29	16	7.55	10	1.25	10	1.23	11	7.967	14	0.1564	11	0.27	22
PAN6573	5.72	16	1.22	15	8.02	16	1.34	16	1.42	16	7.333	8	0.2150	18	0.47	16

4.17 Spearman's coefficients of rank correlation for seven GxE stability analysis procedures conducted on 24 cultivars evaluated over six sites in the eastern maize production region of South Africa.

Statistical procedure	**Mean Yield**	**Superiority Measure**	**Wricke's ecovalence**	**Shukla's Stability Measure**	**Stability Measure Locality Co-variate**	**Rank Difference Variance Difference**	**Eberhart & Russel**
Superiority Measure	0.9298**						
Wricke's ecovalence	0.3470	0.5078*					
Shukla's Stability	0.3602	0.5200*	0.9983**				
Stability Locality Co-variate	0.2547	0.4022	0.9065**	0.9161**			
Rank Difference Variance Difference	0.3611	0.3165	0.5270*	0.5443**	0.4222		
Eberhart & Russel	0.2525	0.4009	0.9096**	0.9191**	0.9970**	0.4278*	
AMMI	-0.2218	-0.0713	-0.1417	-0.1530	-0.2883	-0.1904	-0.2730

*** P ≤ 0.05, ** P ≤ 0.01**

Table 4.18 Mean yield (ton ha^{-1}), different stability measurements and rankings for the maize genotypes tested in five environments in the western research region for the period of 2001-2003.

Cultivar	GxE Stability Analysis Procedures															
	Combined ANOVA		Cult. Superiority Measure		Wi-Ecovalence		Shukla Stability Variance		Stability Variance-Locality Covariate		Rank Difference Variance Difference		Eberhart & Russel		AMMI	
	MEAN YIELD	R	Pi	R	Wi	R	$\sigma^2 i$	R	GxE STAT.	R	S1	R	$S^2 d$	R	ASV	R
QS7608	3.33	20	1.04	20	1.75	5	0.38	5	0.40	7	6.419	4	-0.016	7	0.25	9
CRN3760	3.81	7	0.43	6	2.30	10	0.51	10	0.26	1	7.181	9	-0.06	1	0.50	8
SNK2900	3.51	17	0.84	12	2.57	12	0.57	12	0.59	14	8.495	21	0.0411	14	0.42	14
PAN3442	3.53	16	0.70	15	1.55	4	0.33	4	0.36	6	6.895	6	-0.029	6	0.34	4
PAN6730	3.68	10	0.54	7	2.47	11	0.55	11	0.59	13	7.352	13	0.0406	13	0.33	7
SNK2472	3.87	6	0.41	5	1.2	2	0.25	2	0.27	3	6.971	8	-0.056	3	0.17	5
Phb30H22	3.59	12	0.68	13	2.99	15	0.67	15	0.73	19	6.343	3	0.0830	19	0.81	2
PAN6479	3.54	15	0.83	17	3.22	18	0.73	18	0.62	16	7.295	12	0.0510	16	0.60	21
SNK2969	3.65	11	0.62	10	2.10	8	0.46	8	0.50	11	6.933	7	0.0137	11	0.33	12
CRN3505	4.01	4	0.35	4	2.91	13	0.65	13	0.69	18	7.371	14	0.0721	18	0.21	13
CRN3549	4.11	2	0.20	2	3.02	17	0.68	17	0.45	9	7.733	16	-0.002	9	0.78	10
PAN6615	3.59	13	0.65	11	1.19	1	0.25	1	0.26	2	5.657	1	-0.059	2	0.40	17
Phb3202W	3.42	19	0.88	19	1.93	6	0.42	6	0.42	8	7.410	15	-0.009	8	0.40	16
NS9100	3.48	18	0.85	18	1.96	7	0.43	7	0.46	10	7.219	11	0.0023	10	0.27	11
SC401	2.68	21	2.27	21	5.20	20	1.19	20	0.81	20	8.190	20	0.1068	21	1.09	20
PAN6043	3.72	9	0.55	8	1.54	3	0.33	3	0.32	4	6.229	2	-0.041	4	0.55	19
SNK2682	3.76	8	0.59	9	2.98	14	0.67	14	0.67	17	6.800	5	0.0651	17	0.53	15
Phb30N35	3.59	14	0.75	16	3.01	16	0.68	16	0.55	12	7.200	10	0.0277	12	0.46	18
PAN6844	4.12	1	0.20	3	2.16	9	0.48	9	0.34	5	8.076	19	-0.035	5	0.20	6
PAN6734	3.90	5	0.70	14	14.29	21	3.35	21	3.44	21	8.038	17	0.902	20	2.27	1
PAN6146	4.07	3	0.19	1	4.96	19	1.14	19	0.59	15	8.038	18	0.041	15	1.05	3

4.19 Spearman’s coefficients of rank correlation for seven GxE stability analysis procedures conducted on 21 cultivars evaluated over five sites in the western maize production region of South Africa.

Statistical procedure	**Mean Yield**	**Superiority Measure**	**Wricke’s ecovalence**	**Shukla’s Stability Measure**	**Stability Measure Locality Co-variate**	**Rank Difference Variance Difference**	**Eberhart & Russel**
Superiority Measure	0.9078**						
Wricke’s ecovalence	-0.1948	-0.0078					
Shukla’s Stability	-0.1948	-0.0078	1.0000**				
Stability Locality Co-variate	0.0519	0.2117	0.8130**	0.8130**			
Rank Difference Variance Difference	-0.1481	-0.1104	0.5831**	0.5831**	0.4000		
Eberhart & Russel	0.0727	0.2208	0.8117**	0.8117**	0.9987**	0.4039	
AMMI	0.4494	0.3675	-0.0325	-0.0325	0.0013	-0.0571	0.0260

*** $P \leq 0.05$, ** $P \leq 0.01$**

4.10 STABILITY ANALYSIS OF SIX YEAR DATA

There were six, six and seven genotypes and three, six and five localities that were common over the period of 1998-2003 for the irrigation, eastern and western regional trials, respectively. Wricke's stability parameter was used to determine the most stable cultivars over all six years over all localities for all three regions. Table 4.20 illustrates these results. SNK2778 was the most stable genotype for the irrigation maize production region in South Africa for a six year period. In the eastern region, Phb3442 was the most stable cultivar with the lowest Wi value, while NS9100 was the most stable cultivar in the western region. The genotypes planted in the western region are different from those planted in the eastern and irrigation regions. This is caused by the difference in climatic conditions. The western region is much dryer and warmer, and therefore needs genotypes that are more stable under these extreme conditions. PAN6479 had one of the lowest mean yields at all three regions and was found to be relatively unstable in all the analysis. CRN3760 had a good mean yield and intermediate stability trough all three regions over the period 1998-2003.

Table 4.20 Mean yield (ton ha^{-1}) and Wricke's stability measurement and rankings for the maize genotypes tested in three different maize production regions of South Africa for the period of 1998-2003.

Source	Irrigation Region				Eastern Region				Western Region			
	Mean Yield	R	Wi	R	Mean Yield	R	Wi	R	Mean Yield	R	Wi	R
SNK2778	9.12	3	2..9476	1	6.30	4	8.1996	5				
CRN3760	9.95	1	4.5438	3	6.66	2	5.4202	3	4.30	2	1.9450	2
Phb3442	9.00	5	8.8537	6	6.24	5	3.9233	1	3.63	7	3.1306	5
CRN3604	9.06	4	3.9161	2	6.36	3	4.3334	2				
Phb30H22	9.61	2	7.3641	4	6.76	1	11.7839	6	3.93	4	2.5557	4
PAN6479	8.86	6	8.4378	5	6.09	6	7.6854	4	3.75	6	6.6765	7
NS9100									3.89	5	0.9489	1
SNK2682									4.00	3	2.1391	3
PAN6146									4.56	1	4.2246	6

R = rankings; W_i = Wi-ecovalence stability value

4.11 YIELD PROGRESS OVER SIX YEARS

The data collected from 80 genotypes planted at Cradock over a period of six years (1998-2003) were used to determine if there was any progress or patterns visible in the mean yield over this period. Table 4.21 illustrates the mean yield of all the cultivars for each year. Year 1998 had the lowest mean yield of all years as well as for each cultivar on its own. Year 2000 had the highest mean yield for the year and the respective cultivars. No specific pattern in yield progress was visible, except for the fact that only six of these cultivars were planted for all six years. There were many new genotypes released in the industry which had higher mean yield than the older cultivars used in the earlier years.

Table 4.22 Mean yield for each genotype at Cradock (locality 1), mean yield for each year as well as mean yield for each cultivar for the period of 1998-2003.

CULTIVAR	**MEAN YIELD PER YEAR AT LOCALITY 1**						**CULTIVAR MEAN**
	2003	**2002**	**2001**	**2000**	**1999**	**1998**	
PAN 6568	9.08	10.55	9.25				9.63
SNK 2778	9.33	11.17	9.09	12.87	8.94	7.6	9.83
QS 7608	6.2	8.98	7.5				7.56
CRN 3760	9.17	12.19	10.76	14.26	10.04	7.77	10.70
PAN 6966	10.38	12.3					11.34
SNK 2900	7.97	9.97	8.7				8.88
Phb 3442	9.74	9.6	9.24	13.79	10.15	5.92	9.74
CRN 3604	7.77	10.06	9.1	13.18	9.56	6.67	9.39
PAN 6730	9.16	10.88	9.1				9.71
SNK 2472	9.01	10.64	9.64				9.76
LS 8508	8.09	9.93	9.57				9.20
DKC 80-10	11.08						11.08
PAN 6740	9.7	10.73	9.93				10.12
NS 5914	9.33	11.08					10.21
Phb 30H22	9.16	11.48	11.18	14.01	9.05	6.42	10.22
SNK 8520	10.1						10.10
CAP 611	7.41						7.41
PAN 6026	10.04						10.04
DKC 63-20	8.67						8.67
LS 8502	9.99	9.07	8.62				9.23
SYNCERUS	10.03						10.03
NS 9100	6.54		8.26	13.44	9.82	6.13	8.84
PAN 6479	7.94	10.41	8.41	13.53	9.89	6.5	9.45
SNK 2969	8.29	11.8	9.64				9.91
SC 401	5.9	9.28					7.59
PAN 6029	9.66						9.66
CRN 3505	9.77	11.89	10.31				10.66
LS 8507	10.32	9.79					10.06
SC 405	8.96	9.76	7.21				8.64
PAN 6939	7.82	11.47					9.65
SNK 2911	10.24	11.05					10.65
PANTHERA	7.6	10.87					9.24
Phb 30D05	8.86	10.52					9.69
SC 407	7.42						7.42
PAN 6839	9.12						9.12
LS 8525	9.03						9.03
Phb 30G03	8.82	11.6	9.28				9.90
PAN 6777	10.38	12.4	8.59				10.46
SAFFIER	7.95						7.95
SNK 2551	7.64						7.64
PAN 6757	8.71	11	7.1				8.94
CRN 3549	9.38	10.26	8.99				9.54
SC 403	8.4	9.26					8.83

PAN 6615	9.49	9.55	9.54				9.53
Phb 3203W	9.49	10.83	11.33				10.55
SC 621	9.03	9.33					9.18
PAN 6573	8.68	11.32	6.8				8.93
SC 625	8.9						8.90
PAN 6927	10.57						10.57
CRN 4070B		10.71					10.71
PAN 6734		11.62					11.62
SC 602		10.74	9.49				10.12
PAN 6146		11.06	9.3	14.32	9.3	7.33	10.26
PAN 6710		10.66	9.17				9.92
SNK 2972		11.71	10.18				10.95
PAN 6480		11.51	8.3				9.91
PAN 6844		11.21	8.75				9.98
DK 2551		10.24					10.24
LS 8501		32.65	7.43				20.04
PAN 6845		12.1					12.10
SC 709		10.02	7.73				8.88
PAN 6234		10.1					10.10
PAN 6825		9.47					9.47
Phb 30N35		10.87	7.82				9.35
CRN 3414			8.13	14.69	9.51	7.54	9.97
PAN 6256			9.48				9.48
CRN 3815				13.21	8.18	6.42	9.27
PAN 6242			9.66	12.25	10.38	7.43	9.93
Phb 31R88			10.12				10.12
SNK 2962B			8.48				8.48
PAN 6414			7.75				7.75
SNK 2682			9.36	12.11	9.89	5.48	9.21
PAN 6364			8.26	13.87	9.56	7.1	9.70
SNK 2626			9.03				9.03
SNK 2942			9.94				9.94
PAN 6335			9.84	14.89	10.84	7.41	10.75
SC 627			7.23				7.23
PAN 6633			10.17				10.17
SNK 2721			7.8	14.75	9.29	6.9	9.69
PAN 6243			7.37	12.19	10.48	7.56	9.40
CRN 3524				14.72	8.51	6	9.74
CRN 3818				13.89	9.29	5.97	9.72
PAN 6332				13.22	9.44	8.36	10.34
SNK 2021				14.1	9.9	6.54	10.18
CRN 3631					10.57	6.67	8.62
YEAR MEAN	8.90449	11.13653	8.937347	13.6645	9.647143	6.84381	

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Maize is one of South Africa's most important agricultural products. With the current situation where maize is trading at the South African Forward Exchange Council, the price that producers get for their product is very versatile. Therefore it is of utmost importance to enable the producers to plant genotypes which perform with great stability and high mean yield. The interaction of genotypes with the environment (GxE) is significant in maize. GxE interaction results in different rankings in different environments, therefore testing of the genotypes needs to be conducted at different locations. Performances of genotypes at different locations were not consistent from year to year and needs to be tested across years. To maximize yield throughout a crop's heterogeneous growing region, despite differences in cultivar rankings from place to place due to GxE interactions, frequently it is necessary to subdivide a growing region into several homogeneous mega-environments, like the irrigation, eastern and western regions in South Africa. Analytical methods that effectively take account of the GxE interactions and the efficient use of the resources available are essential for a successful variety evaluation program.

From the results of this study it was concluded that Wi-Ecovalence, Shukla's stability variance and Eberhart and Russel procedures, correlated highly significantly and are the best fitted parameters for determination of stable genotypes. Further, it is recommended that each area be analyzed separately due to the big difference in environmental conditions. From all the cultivars planted over the period 2001-2003, SNK2472 was the most stable and PAN6777 the most unstable genotypes. There were many more white maize cultivars under the most stable genotypes than yellow maize cultivars. For industrial purposes, it is important to have stable cultivars for both yellow and white maize. Once again, the price that the producers get for their product is the determining factor. If the yellow maize price is lower than the white maize price, a farmer needs the option of planting a stable yellow cultivar and the other way around. It is also important for the farmer to produce a balanced set of products (white and yellow maize) to spread the risk factors. Therefore it is recommendable to the maize breeding companies to concentrate on developing a balanced white and yellow maize portfolio.

SNK2778 was the most stable yellow cultivar and Phb30G03 the white genotype with best stability for the irrigation region. In the eastern region the white cultivar with best stability was PAN6757 and SNK2778 the yellow maize cultivar. For the western region the stability analysis found PAN6615 as the most stable white genotype and SNK2472 as the most stable yellow genotype.

AMMI combines the analysis of variance and the principal component analysis in one model, thus it was found useful in describing GxE interactions. Since information on GxE interactions and stability of varieties are essential for farmers, breeders and other agricultural experts, the data on stability analysis need to be made available to users whenever new varieties are proposed for commercial release, whether they are recommended for specific regions or whether they are broadly adapted.

CHAPTER 6
SUMMARY

1. This study was undertaken to compare various statistical methods of analysis to determine the most suitable procedure to evaluate maize genotype performance under the variable production conditions in South Africa, as well as to assess the suitability of these statistical procedures for characterizing yield stability. The main objective of this study was to recommend the most appropriate statistical procedure(s) to estimate maize genotype performance and stability more accurately and to investigate the GxE interaction and stability performance of genotypes in various environments by applying different statistical methods of analysis in order to make useful recommendations for future utilization.

2. Ninety four genotypes were planted at 80 localities in South Africa for the period 1998 to 2003. These trails, which were done by the Agricultural Research Counsel, were divided into six research regions. Three of these regions were used for the purpose of this study. Twenty four cultivars were planted at three sites under irrigation for the Irrigation research region, 24 cultivars at six sites for the Eastern region and 21 genotypes at five sites for the Western region for the period of 2001 to 2003. Both the Eastern and Western region are dryland maize production regions. Grain yield was determined and genotypes were evaluated for performance and yield stability in all three regions according to eight statistical procedures, which were (i) Combined Analysis of Variance, (ii) Cultivar Superiority Measure (P_i), (iii) Wi-Ecovalence (W_i), (iv) Shukla's procedure of stability variance, (v) Stability Variance with Locality as Covariate, (vi) Rank differences (S1) and Variance differences (S2), (vii) Eberhart and Russell Regression Model, (viii) Additive Main Effects and Multiplicative Interaction (AMMI). The procedure proposed by Purchase (1997) to determine the absolute stability measure for the AMMI model was used as well. Comparisons between results from all statistical procedures as well as recommendations from Phurcase (1997) were used to determine the best suited procedure.

3. The combined analysis of variance ranked cultivars according to their mean grain yield measured in ton ha^{-1}. CRN3505, CRN3549, PAN6844, Phb30H22 and CRN3760 indicated good mean yield over all three different regions. On the other hand QS7608, SC405, LS8508 and SC401 delivered the lowest mean yield values over all three regions. This procedure is no indication of the stability for yield of the genotypes.

4. Lin and Binns cultivar superiority measure indicated good yield stability, according to their definition and procedure, for especially the genotypes CRN3505, CRN3549, SNK2472, PAN6146. The worst performers were PAN6777, QS7608 and SC401. There was considerable correspondence in the performance of the genotypes over the Irrigation and Eastern regions as well as the Eastern and Western (dryland condition) regions.

5. Wricke's ecovalence, Shukla's stability variance and stability variance with locality as covariate procedures had approximately the same results. They showed different genotypes to be more stable in different regions. These three procedures found SNK2472, LS8508, SNK2778 and Phb30G03 to be the most stable cultivars and Phb30H22 and PAN6777 to the most unstable cultivars in the Irrigation region. For the eastern region PAN6757, CRN3549, SNK2778 and SNK2969 were the most stable genotypes while PAN6777 and SC405 were the unstable genotypes. Phb3442, SNK2472, PAN6615 and PAN6043 were the most stable cultivars in the western region with PAN6734 and SC401 the most unstable ones.

6. Rank difference and variance difference procedure correlated the best with the AMMI model. This procedure found SNK2472, LS8508, SNK2778 and NS2900 as the most stable genotypes in the irrigation region, while QS7608 and CRN3505 were the unstable genotypes. These results were very much the same as the previous three procedure's results. But for the eastern region the results were different for the previous three procedures. PAN6777, SNK2472, PAN6757 and

CRN3549 were the most stable cultivars and Phb30H22 and LS8508 were the unstable genotypes. In the western region, PAN6615, PAN6043, QS7608 and Phb30H22 were the most stable genotypes while SNK2900 and SC401 were the most unstable genotypes.

7. The Eberhart and Russel procedure, based on deviation from the regression in regression analysis, showed exactly the same results as Stability variance with locality as covariate and therefore had exactly the same rankings for all three regions as Wricke's ecovalence, Shukla's stability variance and stability variance with locality as covariate.

8. For the AMMI method, a procedure combining the IPCA1 and IPCA2 scores was used to determine an absolute AMMI value. According to this analysis, Phb30H22, PAN6740, QS7608 and CRN3604 were the most stable genotypes in the irrigation region. This differs totally from the results found by the other procedures. PAN6568 and CRN3505 were the most unstable genotypes. For the eastern region SC405, LS8508, QS7608 and SNK2472 were the most stable cultivars and Phb30H22 and PAN6777 were the most unstable cultivars. In the western region PAN6734, PAN6146, Phb30H22 and Phb3442 were the most stable genotypes and PAN6043 and PAN6479 were the most unstable genotypes.

9. Wricke's ecovalence, Shukla's stability analysis and Eberhart and Russel's procedures correlated highly significantly. However, no correlation was found in the pair wise comparison of Lin and Binns' (Cultivar Superiority Measure) procedure with the other procedures and very little correlation was found in the pair wise comparison of the AMMI model and the other procedures. The more holistic approach of AMMI is particularly effective in clarifying GxE interactions. Using the IPCA1 and IPCA2 scores to determine an AMMI stability value, superiority ranking of genotypes can easily be done. The AMMI model can summarize patterns and relationships of genotypes and environments successfully and offers a valuable prediction assessment. For this reason, it is recommended

that this model is used for analyzing GxE interaction of maize genotypes in South Africa. The Lin and Binns procedure appears to be more of a cultivar performance measure than a stability measure which explains its correlation with the mean yield of the genotypes. The Eberhart and Russel, Wricke's ecovalence and Shukla's stability analysis showed highly significant correlation and are recommended to be used to describe genotype stability of maize genotypes rather than to be used to describe GxE interactions, due to the limitations of these techniques.

10. There were six genotypes and three localities that were common over the six year period for the irrigation region and six genotypes with six localities for the eastern region and seven genotypes with five localities for the western region. Wricke's stability parameter was used to determine the most stable cultivars over all six years over all localities for all three regions. SNK2778 was the most stable genotype for the irrigation maize production region in South Africa for a six year period. In the eastern region, Phb3442 was the most stable cultivar with the lowest Wi value, while NS9100 was the most stable cultivar in the western region. The genotypes planted in the western region are different from those planted in the eastern and irrigation regions. This is due to the difference in climatic conditions. The western region is much dryer and warmer and therefore needs genotypes that are more stable under these extreme conditions. PAN6479 had one of the lowest mean yields throughout all three regions and was found to be relatively unstable in all the analyses. CRN3760 had a good mean yield and intermediate stability throughout all three regions over the period 1998-2003.

11. In the yield progress study, no significant progress was visible. Eighty cultivars planted for a six year period at Cradock were used for this analysis. Year 1998 had the lowest mean yield and 2000 the highest mean yield. The cultivars that were tested in the later part of the period 1998-2003, had overall higher mean yield, which proves that progress has been made by breeding companies in genotype yield increase.

OPSOMMING

1. Hierdie studie is onderneem om die wye verskeidenheid statistiese metodes van analisering van genotipes se prestasies, te vergelyk en sodoende die mees geskikte prosedure te bepaal waarmee mielie genotipes se prestasies onder veranderlike produksie omstandighede in Suid Afrika geevalueer kan word, sowel as die assesering van die statistiese prosedures tov geskiktheid vir die karakterisering van opbrengs stabiliteit. Die primêre doel van hierdie studie was die aanbeveling van die mees gepaste statistiese prosedure(s) om die mielie genotipes se prestasies te kan bepaal so wel as die akkurate bepaling van stabiliteit en die bestudering van GxE interaksies en stabiliteits prestasies van genotipes in verskillende omgewings. Dit is gedoen deur die toepassing van 'n verskeidenheid van verskillende statistiese metodes vir analises om sodoende waardevolle aanbevelings vir toekomstige toepassings te maak.

2. Vier en negentig genotipes was in 80 verskillende lokaliteite in Suid Afrika geplant van 1998 tot 2003. Hierdie proewe is deur die Landbou Navorsings Raad gedoen. Data is versamel vir ses verskillende navorsings streke. Drie van hierdie streke se inligting is vir hierdie betrokke studie gebruik. Vier en twintig kultivars was by drie lokaliteite onder besproeiing geplant, 24 kultivars in die oostelike mielie produksie streek van Suid Afrika by 6 verskillende lokaliteite en 21 kultivars in die westelike streek by 5 verskillende lokaliteite. Beide die oostelike en westelike streke is droëland mielie produksie streke. Graan opbrengs was bepaal en die genotipes was geevalueer tov prestasie en opbrengs stabiliteit in al drie streke. Die analises was gedoen mbv agt verskillende statistiese prosedures, nl. (i) Gekombineerde Analise van Variansie, (ii) Kultivar Superioriteits Bepaling (P_i), (iii) Wricke se ekovalensie (W_i), (iv) Shukla se prosedure van stabiliteitsvariansie, (v) Stabiliteitsvariansie met Lokaliteit as Ko-variant, (vi) Rangorde verskille (S1) en Variansie verskille (S2), (vii) Eberhart and Russell Regressie Model, (viii) AMMI stabiliteitsmodel. Die prosedure wat deur Purchase (1997) voorgestel is vir die bepaling van die absolute stabiliteits meting vir die

AMMI model is ook toegepas. Vergelykings tussen al die toegepaste statistiese prosedures se resultate en aanbevelings van Purchase (1997) is gebruik om die mees geskikte prosedure(s) te bepaal.

3. Die gekombineerde analise van variansie het die kultivars se rangorde bepaal tov die kultivars se gemiddelde graan opbrengs gemeet in ton ha^{-1}. CRN3505, CRN3549, PAN6844, Phb30H22 en CRN3760 het hoë gemiddelde opbrengste gehad in al drie van die verskillende navorsings streke. QS7608, SC405, LS8508 en SC401 het die laagste gemiddelde opbrengs waardes gehad oor al drie streke. Hierdie prosedure is egter geen aanduiding van die stabiliteit vir opbrengs van die kultivar nie.

4. Lin en Binns se kultivar superioriteits meting het goeie opbrengs stabiliteit bepaal, volgens hulle definisie, vir die genotypes CRN3505, CRN3549, SNK2472, en PAN6146. Die swakste presteerders was PAN6777, QS7608 en SC401. Daar was ‘n betekenisvolle ooreenkoms tussen die prestasie van die genotipes in die besproeiing en oostelike droëland produksie streke sowel as die oostelike en westelike droëland produksie streke.

5. Wricke se ekovalensie, Shukla se stabiliteitsvariansie and stabiliteitsvariansie met lokaliteit as ko-variant se prosedures het ongeveer dieselfde resultate opgelewer. Verskillende genotipes was meer stabiel in die verskillende navorsings streke. Hierdie drie prosedures het SNK2472, LS8508, SNK2778 en Phb30G03 as die mees stabiele kultivars bepaal en Phb30H22 en PAN6777 as die mins stabiele kultivars, vir die besproeiings streek. Vir die oostelike streek was PAN6757, CRN3549, SNK2778 en SNK2969 die mees stabiele genotipes terwyl PAN6777 en SC405 die mees onstabiele genotipes was. Phb3442, SNK2472, PAN6615 en PAN6043 was die mees stabiele kultivars in die westelike streek met PAN6734 en SC401 as die mins stabiele kultivars.

6. Rangorde verskille en variansie verskille se prosedure het die beste gekorreleer met die AMMI model se resultate. Hiedie prosedure het SNK2472, LS8508, SNK2778 en NS2900 as die mees stabiele genotipes bepaal in die besproeiings area, terwyl QS7608 en CRN3505 die mees onstabiele genotipes was. Die resultate vir die besproeiings area het baie ooreengestem met die vorige drie prosedures se resultate. Maar die oostelike streek se resultate het verskil van die vorige drie prosedures se resultate. PAN6777, SNK2472, PAN6757 en CRN3549 was die mees stabiele kultivars en Phb30H22 en LS8508 was die mees onstabiele genotipes. In die westelike area was PAN6615, PAN6043, QS7608 en Phb30H22 die meer stabiele genotipes terwyl SNK2900 en SC401 die mins stabiele genotipes was.

7. Die Eberhart en Russel prosedure is gebaseer op die deviasie van die regressie in regressie analise en het presies dieselfde resultate gehad as die stabiliteitsvariansie met lokaliteit as ko-variant en het dus dieselfde rangorde opgelewer as Wricke se ekovalensie, Shukla se stabiliteitsvariansie en stabilitietsvariansie met lokaliteit as ko-variant.

8. Vir die AMMI model is die prosedure wat die kombinasie van die IPCA1 en IPCA2 waardes bepaal, gebruik om die absolute stabiliteits waardes vir AMMI te bepaal. Volgens hierdie analise was, Phb30H22, PAN6740, QS7608 en CRN3604 die mees stabiele genotipes in die besproeiings area. Hierdie resultate verskil totaal van die ander prosedures se resultate. PAN6568 en CRN3505 was die mees onstabiele genotipes. Vir die oostelike streek was SC405, LS8508, QS7608 en SNK2472 die mees stabiele kultivars en Phb30H22 en PAN6777 die mins stabiele kultivars. In die westelike streek was PAN6734, PAN6146, Phb30H22 en Phb3442 die mees stabiele genotipes en PAN6043 en PAN6479 die mees onstabiele genotipes.

9. Wricke se ekovalensie, Shukla se stabiliteits analise en Eberhart en Russel se prosedures het hoogs betekenisvol gekorreleer met mekaar. Geen korrelasie kon

gevind word tussen die vergelykings van Lin en Binn se kultivar superioriteits meting prosedure en die ander prosedures nie, terwyl daar baie min korrelasie was tussen die AMMI model se resultate en die ander prosedures se resultate. Die meer oorsiggewende benadering van die AMMI model is in besonder effektief in die ontleding van GxE interaksies. Deur gebruik te maak van die IPCA1 en IPCA2 waardes om die AMMI stabiliteits waarde te bepaal kan die superioriteits rangordes van kultivars ook bepaal word. Die AMMI model kan patrone en interaksies van genotipes en omgewings suksesvol opsom. Daarom word dit aanbeveel dat hierdie model gebruik word vir die analisering van GxE interaksies van mielie genotipes in Suid Afrika. Die Lin en Binns prosedure blyk meer van ‘n kultivar prestasie metings te wees as ‘n stabiliteits bepaling, wat ook die korrelassie met die gemiddelde opbrengs van die genotipes verduidelik. Die Eberhart en Russel, Wricke se ekovalensie and Shukla se stabiliteits analise het hoogs betekenisvolle korrelasies getoon en word ook aanbeveel vir die beskrywing of bepaling van mielie genotipes se stabiliteit eerder as vir die analisering van GxE interaksie, agv die beperkings wat hierdie tegnieke het.

10. Daar was ses genotipes en drie lokaliteite wat gemeenskaplik oor ‘n ses jaar periode in die besproeiings area voorkom. Ses genotipes en ses lokaliteite in die oostelike streek en sewe genotipes met vyf lokaliteite vir die westelike streek. Wricke se stabiliteits analise was gebruik om die mees stabiele kultivars oor die ses jaar periode te bepaal vir al drie streke. SNK2778 was die mees stabiele genotipe vir die besproeiings area. In die oostelike streek was, Phb3442 die mees stabiele kultivar met die laagste Wi waarde, terwyl NS9100 die mees stabiele kultivar in die westelike streek was. Die genotipes wat in die westelike streek geplant word verskil van die wat beter in die oostelike en besproeiings gebiede presteer. Dit is ‘n oorsaak van die verskil in klimaats toestande. Die westelike streek is baie droër en warmer as die ander twee streke, dus word kultivars wat aangepas is vir hierdie uiterste omstandighede vir hierdie area benodig. CRN3760 het ‘n goeie gemiddelde opbrengs en middelmatige stabiliteit in al drie streke gehad, vir die tydperk van 1998-2003.

11. In die opbrengs progressie studie was geen betekenisvolle vorderings sigbaar. Agt kultivars wat vir ‘n ses jaar periode by Cradock geplant was, was vir hierdie analise gebruik. 1998 het die laagste gemiddelde opbrengs gehad en 2000 die hoogste gemiddelde opbrengs. Die kultivars wat tydens die laaste drie jaar van die betrokke tydperk nuut by die proewe ingesluit was het oor die algemeen hoër gemiddelde opbrengste gehad, wat ‘n bewys is van die vordering wat gemaak is deur telings organisasie tov mielie kultivars se opbrengs eienskappe.

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