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Genotype x environment analysis in sunflower (*Helianthus annuus*) in South Africa

by

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Thesis presented in accordance with the requirements for the degree
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CHAPTER 1

INTRODUCTION

Sunflower is the most important oilseed crop in South Africa. The sunflower oil market has shown a steady increase of approximately three percent per year in the past few years, with a current demand of 600 000 tons of seed for oil extraction (Pakendorf, 1998).

In the past, sunflower in South Africa was considered to be an alternative crop to maize, i.e. if a maize crop could not be successfully produced due to drought or any other constraint. This led to a situation where sunflower cultivation was not done under optimal conditions, leading to low and erratic yields and consequently gaining a reputation of being uneconomical compared to maize.

The areas planted during the 2002/2003 season were, Free State 275 000 ha, Mpumalanga 40 000 ha, Limpopo 37 000 ha, Gauteng 10 000 ha and North West 220 000 ha with a total of approximately 582 000 ha (Beukes, 2003). It is evident that the largest concentration of sunflower is in the Free State and North West province. This is generally the drier or western part of South Africa with more sandy soils. However in the Limpopo province most of the sunflower is planted very late in Arcadia type soils with very high clay content. Another factor typical to these areas is that the evaporation is up to three times the value of the annual rainfall. Economics is an important factor that influences the expansion of sunflower. In areas where maize has a low average yield, sunflower is a good alternative crop (Parkendorf, 1998).

The above-mentioned areas of cultivated sunflower vary considerably in soil, climate and elevation. Although it is widely accepted that sunflowers have a good general adaptability, the planting date and rainfall have an influence on the performance of hybrids. The instability of hybrids creates difficulty in selection in breeding programs. Most decisions are based on limited information from one or two years with a normal

ANOVA and cross site analysis. No effects of environment x genotype interaction are taken into consideration.

According to Becker and Leon (1988) successful new varieties must show good performance for yield and other essential agronomic traits. Their superiority should be reliable over a wide range of environmental conditions. Plant breeders generally agree on the importance of high yield stability, but there is fewer consensuses on the most appropriate definition of "stability" and on methods to measure and to improve yield stability.

The basic cause of differences between genotypes in their yield stability is the wide occurrence of genotype x environment interactions, i.e. the ranking of the genotype depends on the particular environmental conditions where it is grown. Very few researchers use statistical measures of yield stability in their breeding programs. A deeper insight into the relation among the numerous stability parameters and their similarity may be obtained by comparing the resulting stability rank orders of different genotypes which are derived by applying different concepts of phenotypic stability (Huehn, 1990).

The aim of this study was to compare various statistical procedures

- For assessing genotype x environmental interaction and yield stability of South African sunflowers.
- To determine the most suitable parametric procedure to evaluate and describe sunflower genotype performance under dryland conditions in South Africa.
- To recommend to breeders the most appropriate procedure to estimate genotype performance and stability most accurately.

Individuals and seed companies plant the trials co-coordinated by the Agricultural Research Council (ARC) as a trade for participation to the research. This trial system ensures good quality hybrids in the market since intercompany competition is very active and the advantage of having hybrids with good yields and good ranking in this trial setup would ensure good sales. Part of the system requirements is to have all entries registered on the cultivar list after a Difference in Uniqueness System (DUS) test run by the Registration Department in Roodeplaat. This, in turn, ensures the quality of the seed reaching the millers and the oil press. The independent evaluation of data run by the ARC, gives the farmer an advantage of a choice of improved hybrids, proven to have good yields without extra cost.

In the map of general agricultural regions (Fig.1) it is evident that the Free State is mostly utilized for cereal production and to the west for mixed farming. In the areas of cereal cultivation, sunflowers are used in rotation with wheat and maize. The western areas are traditionally maize areas. During the last five years the percentage of sunflower hectares has greatly increased in the North West and decreased in the Mpumalanga province.

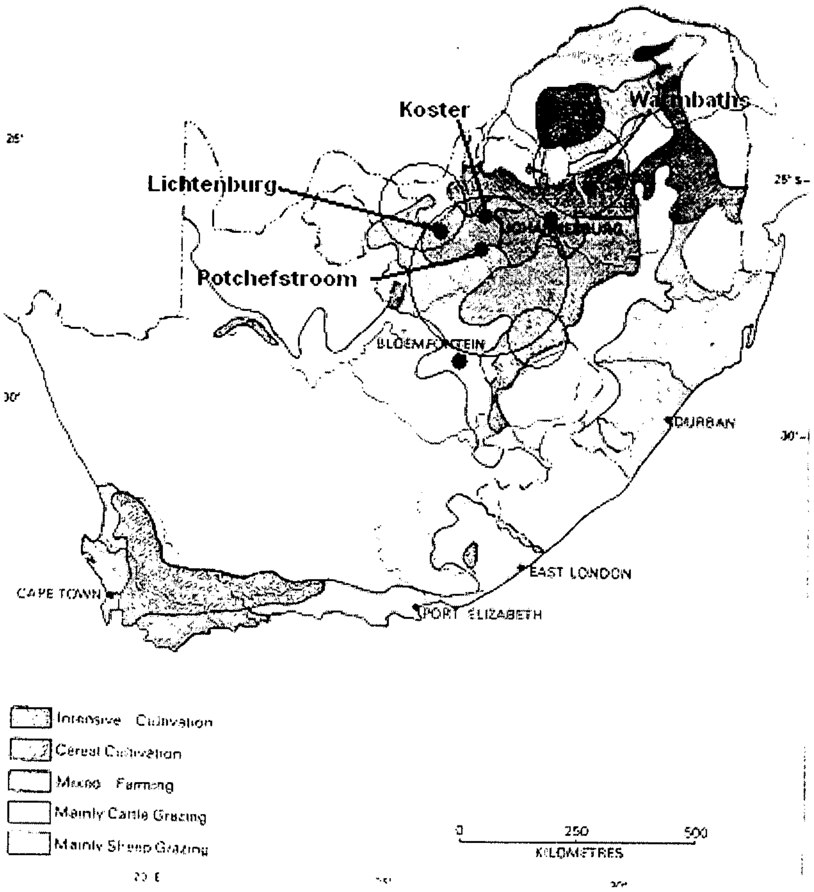

Fig. 1 Map of agricultural activities. The main sunflower production areas are indicated (o) and the test sites by (•) (Dept. of Foreign Affairs and Information, 1982)

The large circle depicts the area actually planted in the Free State and part of the adjoining North West and contains two of the ARC trial sites namely Potchefstroom and Koster. The bottom smaller circle would be the very early plantings in the southern Free State. The circle above Johannesburg represent the area with the dark Arcadia type soils known as the "Springbok flats" with the Warmbaths site and the circle west of Johannesburg would represent the North West province and contains the Lichtenburg site.

CHAPTER 2

LITERATURE REVIEW

2.1 The ANOVA

The ANOVA is essentially an arithmetic process for partitioning the total sum of squares into components associated with recognized sources of variation. Significance tests from combined analyses of variance are valid if error terms from different environments are homogeneous. It is therefore also used specifically for multiple environments. If Bartlett's test indicates heterogeneous variances, then regrouping the environments into subsets with homogeneous variances is recommended (Steele and Torrie, 1980). For any two-factor mixed model (fixed genotypes and random environments), the most commonly used combined analysis of variance is shown in Table 2.1.

Table 2.1 Mixed model (fixed genotype and random environment) analysis of variance for *g* genotypes at *e* locations with *r* replications

Source of variation	*Degrees of freedom*	*Mean squares*	*Expected mean squares*	*F-ratios*
Total	$erg-1$			
Environ (E)	$e-1$	MS1	$\sigma_e^2 + g\sigma_{R(E)}^2 + rg\sigma_E^2$	MS1/MS2
Rep./E[a]	$e(r-1)$	MS2	$\sigma_e^2 + g\sigma_{R(E)}^2$	MS2/MS5
Genotypes (G)	$g-1$	MS3	$\sigma_e^2 + g\sigma_{GE}^2 + er\phi_G^2$	MS3/MS4
GxE	$(e-1)(g-1)$	MS4	$\sigma_e^2 + g\sigma_{GE}^2$	MS4/MS5
Error	$e(g-1)(r-1)$	MS5	σ_e^2	

[a] If replicates within environments are not separated from the error term, the environment main effect should then be tested against the error mean square.

Means adequately describe the potential of environments and the performance in a trial when G x E is not significant. However, when the interaction is significant, main effects should be interpreted with caution and the nature of the interaction should be examined, as means often mask cases where genotypes perform well or poorly in subsets of sites. In analyses of variance, magnitudes of sums of squares of relevant terms as well as variance components are used to quantify sources of variation. Sums of squares attributable to a source of variation confound: (1) the nature of the factor considered with respect to its ability to elicit variation, (2) the number of levels of the factor, e.g. the number of sites in a trial. However, variance components corrected for the number of levels of factors allows direct comparisons of estimates from sources with divergent numbers of sites and genotypes (Ramagosa and Fox, 1993)

2.2 Partitioning of G x E interactions

Wricke (1962) proposed using the G x E interaction effects for each genotype, squared and summed across all environments, as a stability measure. This statistic, termed ecovalence (Wi), is by far more simpler to compute and is more directly related to the G x E interactions than statistics by Plaisted and Peterson (1959) and may be estimated as follows:

$$W_i = \sum_j \left[Y_{ij} - \bar{Y}_i. - \bar{Y}._j + \bar{Y}..\right]^2,$$

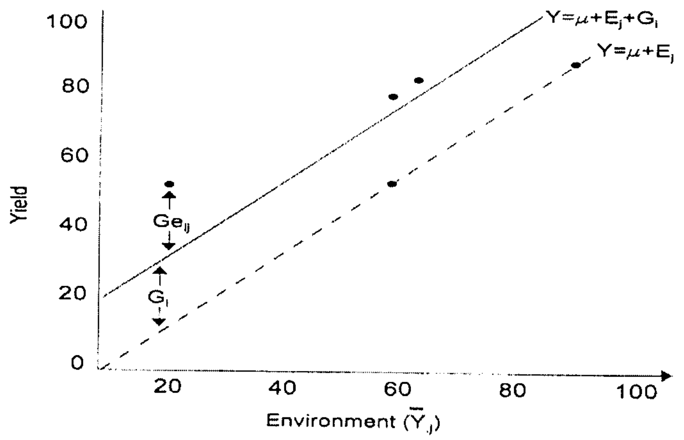

Fig. 2 Graphical representation of G X E interactions: the stability statistic ecovalence (Wi) is the sum of squares of deviations from the upper straight line (Becker and Leon, 1988)

Because ecovalence measures the contribution of a genotype to the G x E interaction, a genotype with Wi = 0 is regarded as stable. According to the meaning of the word ecovalence, this stable genotype possesses a high ecovalence. Fig 2 presents a numerical example of yields of genotype (I) in various environments against the respective means of environments. The lower straight line estimates the average yield of all genotypes simply using the information about the general mean (μ) and the environmental effects (ej), while the upper straight line additionally takes into account the genotypic effect (gi) and therefore estimates the yield of the genotype i. Deviations of yields from the upper straight line are the G x E interaction effects of the genotype I and these deviations, squared and summed across environments constitute the ecovalence.

2.3 Joint linear regression

Another important model for analyzing and interpreting the non-additive structure (interaction) of two-way classification data is the joint linear regression method. This approach has been extensively used in genetics, plant breeding, and agronomy for determining yield stability of different genotypes or agronomic treatments (Crossa, 1990).

Applying the usual biometrical model, it is assumed that the effects are independent of each other. This assumption is fulfilled when regarding all the genotypes together and when no covariance exists between the effects of environments and of G x E interactions. Considering each genotype separately, however, this covariance may be different from zero. The regression coefficient is a standardized description of this covariance (Becker and Leon, 1998).

The same example as presented in Fig. 2 has been analyzed by the regression in Fig. 3. The deviations between actual and predicted values now decrease by the amount of covariance between environmental and G x E interaction effects.

The straight line $Y = \mu + b_i e_j + g_i$ fits the data better than does the line $Y = \mu + e_j + g_i$.

The effects of G x E interaction may be expressed as follows:

$GEij = \beta_i E_j + \delta_{ij}$

Where B_i is a linear regression coefficient for the i th genotype and δ_{ij} a deviation.

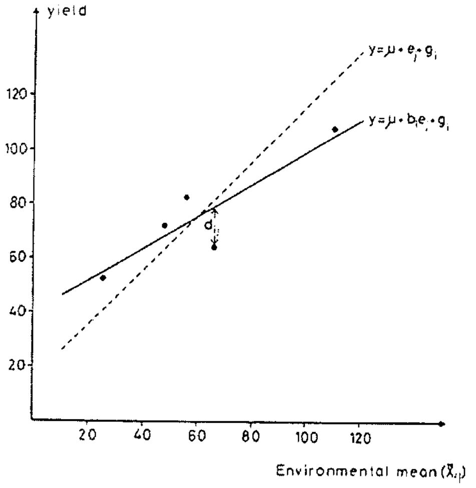

Fig. 3 Graphical representation of the regression approach (Becker and Leon, 1988)

In addition to the coefficient of regression, the deviation mean squares (s^2d_i) describe the contribution of genotype I to the G x E interactions (Eberhart and Russell, 1966).

coefficient of regression:

$$b_i = 1 + \frac{\sum_j (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})(\bar{X}_{.j} - \bar{X}_{..})}{\sum_j (\bar{X}_{.j} - \bar{X}_{..})^2}$$

deviation mean squares:

$$s^2_{di} = \frac{1}{E-2} [\sum_j (X_{ij} - \bar{X}_{i.} - \bar{X}_{.j} + \bar{X}_{..})^2 - (b_i - 1)^2 \sum_j (\bar{X}_{.j} - \bar{X}_{..})^2]$$

Both statistics are used in different ways to assess the reaction of genotypes to the varying environmental conditions. While s^2d_i is strongly related to the remaining unpredictable part of variability of any genotype and is therefore considered as a stability parameter, the coefficient of regression, bi, characterizes the specific response of genotypes to environmental effects and may be regarded as a response parameter. Genotypes that do not react to varying environmental factors show zero bi-values and would be stable according to the statistical concept. On the other hand, genotypes possessing an average response to changing environmental conditions show bi-values of one. For ranking purposes the choice of desired bi-value depends on the specific goal, while independent of the objective, deviation mean squares of stable genotypes are zero (Becker and Leon, 1988).

Part of the genotype's performance across environments or genotypic stability is expressed in terms of three parameters: the mean performance, the slope of the regression line, and the sum of squares deviation from the regression. Although joint regression has been principally used for assessing the yield stability of genotypes in a plant-breeding program, it may also be used for agronomic treatments (Crossa 1990).

Methods involving the linear regression approach and related stability parameters cannot be recommended, nor can the defects of these methods be overcome by the use of either cluster analysis or principal component analysis (Wescott, 1986). The use of the particular cluster strategy in cluster analysis could lead to a result in different cluster groups and the acceptance or rejection of any particular choice may be difficult to justify. The chief difficulty of the principal component analysis is the interpretation of the resulting principal components, which may not bear any obvious relation to the environmental conditions. The biggest defect of linear regression would be the fact that the stability statistics of a variety may be unduly influenced by its performance in only one or two environments.

2.4 Other measurements of yield stability

Lin and Binns (1988) defined the cultivar performance measure (P_i) and defined P_i of genotype I as the mean squares of distance between the i^{th} genotype and the genotype with maximum response as

$P_i = [n\,(Y_{i.} - M_{.})^2 + (Yij - Y_{i.} + M_j + M_{.})^2]/2n$

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 the maximum response among all genotypes in the j^{th} location, and n is the number of locations. The first term of the equation represents the genotype sum of squares; the second term is the genotype-environment sum of squares. The smaller the value of P_i, the less its distance to the genotype with maximum yield and the better the genotype. A pairwise genotype x environment interaction mean square between the maximum and each genotype is also determined and is similar to the method used by Plaisted and Peterson (1959). The difference is that (1) the stability statistic is based on both the average genotypic effects and genotype x environment interaction effects, and (2) each genotype is compared only with the one maximum response at each environment (Crossa, 1990).

Several nonparametric measures of stability have been proposed. These are based on the ranks of phenotypes in each environment. The rank stability measures are similar in concept to the genotype x environment interaction measures in that they define stability or the ability of a genotype to stabilize itself in different environments. Measures based on ranks are distribution-free (Nasser and Huehn, 1987).

2.5 AMMI analysis

The additive main effects and multiplicative interaction method use the standard ANOVA procedure, where after the AMMI model separates the additive variance from the multiplicative variance (interaction), and then applies PCA to the interaction (residual) portion from the ANOVA analysis to extract a new set of coordinate axes which account more effectively for the interaction patterns (Shaffi *et al*, 1992).

The AMMI method is used for three main purposes. The first is model diagnosis. AMMI is more appropriate in the initial statistical analysis of yield trials, because it provides an analytical tool for diagnosing other models as sub cases when these are better for a particular data set. The second use of AMMI is to clarify G x E interactions. AMMI summarizes patterns and relationships of genotypes and environments. The third use is to improve the accuracy of yield estimates that are equivalent to increasing the number of replicates by a factor of two to five. Such gains may be used to reduce costs by reducing the number of replications, to include more treatments in the experiment, or to improve the efficiency in selecting the best genotypes (Crossa, 1990).

It has proven useful for understanding complex genotype x environment interactions. The results can be graphed in a very informative biplot that shows both main and interaction effects for both genotypes and environments. Also, AMMI can partition the data into a pattern rich model and discard noise rich residual to gain accuracy (Gauch and Zobel, 1996). Where there is no interaction, a single sunflower hybrid would have an equal ranking in all trials and therefore only one trail would be needed for universal results. Without noise the results would be exact, removing the need for replication.

AMMI combines analysis of variance (ANOVA) and principal component analysis (PCA) into a single model with additive and multiplicative parameters.

The AMMI model equation is:

$$Y_{ij} = \mu + g_i + l_j + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{jk} + E_{ij},$$

Where μ is the overall mean, G_i and E_j are genotypic and environmental main effects, N is the number of PCA axes considered, λ_n is the singular value of the n^{th} PCA axis and ϵ_{ij} are scores for the i^{th} genotype and the jth environment on the nth PCA axis and ϵ_{ij} is the residual term which includes the experimental error (Gauch and Zobel, 1996).

2.6 Major agronomic traits and their response to environments

Objectives in sunflower breeding vary with specific programs but generally emphasize high seed yield and high oil content. Seed yield and to a lesser extent oil content, depends on many factors including suitable agronomic type, tolerance to agronomic stress environments, and resistance to disease, insects and other pests. Many of the latter traits also become important objectives when breeding improved cultivars (Fick and Miller, 1997).

According to Nel (1998) vigor of pre-emergent sunflower seedlings is reduced when daily peak soil temperatures exceed 44 °C, resulting in poor emergence. Seed of three sunflower cultivars was used to compare response to heat shock of two hours at 50 °C in untreated incubated seed. Germination percentages differed significantly between cultivars, with Hysun 333 having the highest germination percentage and a smaller decrease with high temperature than CRN 1435 and SNK 37. Hypocotyls of seed pre-exposed to 40 °C were shorter than untreated seed, indicating the inability of sunflower to acquire thermo tolerance.

In Spain a genetic analysis was performed on yield and related traits of 36 hybrids produced in a factorial cross of six male sterile lines and six restorer lines. The parents and their hybrids were evaluated in eight environments in the Cordoba and Seville area. Based on estimates of heritability with information from analysis combined across environments the variation for yield was higher than other traits (Alza and Fernandez-Martinez, 1997).

Wilson and McClurg (1997) reported on the resistance of the cultivated sunflower germplasm to the sunflower moth *Homoeosoma electellum*. Using 680 cultivated sunflower accessions from the North Central Regional Plant Introduction Station it was found that 51 proved resistant to moth feeding. Twenty-seven of these accessions were obtained from Turkey.

Deibert (1989) performed a tillage trial on sunflowers in North Dakota using conventional plough, sweep, intertill and no-till. The yield, oil concentration and oil yield was not significantly different among the different tillage systems. Hybrids performed similarly in the seed parameters measured, although the late maturity hybrids consistently produced smaller seed.

Gross and Hanzel (1991) studied morphological traits in sunflower that confer resistance to birds. These traits include long bracts, horizontally oriented heads, concave heads and long head to stem distances. Measurements were done at R7 stage. The genotype, environment and genotype x environment effects were all significant. The results of this study indicated that performance of hybrids possessing these traits could be expected to be stable across a wide area.

Laishram and Sing (1995) determined the adaptability of sunflower in the state of Manipur by phenotypic analysis. Eleven genotypes were tested in three artificially created environments for two seasons. Different fertilizer doses were used: (i) 90:90:45 kg N:P:K kg/ha, (ii) 60:60:30 N:P:K kg/ha and (iii) 30:30:15 N:P:K kg/ha. Analysis was performed on plant height, days to 50% flowering and maturity, head diameter, 100 seed weight, percent seed filled per head, seed yield per plant and oil content. The results showed that both linear and nonlinear components were important in all characters, except plant height and seed filling in which only nonlinear component was predominant.

A study on sunflowers under dryland conditions on Vertisol soil was done to determine the most suitable hybrids evaluating seed yield, plant height, head diameter, number of leaves per plant day to maturity and days to 50% flowering. Genotypes reacted considerably with the environmental conditions except for days to 50% flowering. A major portion of G x E interaction variance was explained by the linear component (deviation) and was significant for all characters except yield (Muppidathi et al., 1996)

2.7 Data analysis

Multilocation trials play an important role in plant breeding and agronomic research. Data from such trials have three main agricultural objectives: (a) to accurately estimate and predict the yield based performance on limited experimental data: (b) to determine yield stability and the pattern of response of genotypes or agronomic treatments across environments; and (c) to provide reliable guidance for selecting the best genotypes or agronomic treatments for planting in future years and at new sites.

Agronomists who compare combinations of agronomic factors, such as fertilizer levels and plant density, to make recommendations to farmers, use mostly multilocation trials. Breeders compare different genotypes to identify the superior ones. Variation in yield responses to genotypes and agronomic treatments, when evaluated in different environments is known as interaction. Assessing any genotype or agronomic treatment without including its interaction with the environment is incomplete and limits the accuracy of yield estimates. A significant portion of the resources of crop breeding is devoted to determining this interaction through replicated multilocation trials.

Data from the multilocation trials are complex and have three fundamental aspects:(a) structural patterns; (b) nonstructural noise; and (c) relationships among genotypes, environments, and genotypes and environments considered jointly. Pattern implies that a number of genotypes respond to certain environments in a systematic, significant and interpretable manner, whereas noise suggests that the responses are unpredictable and uninterruptible (Crossa, 1990).

The function of the experimental design and statistical analyses of multilocation trials is to eliminate as much as possible of the unexplainable and extraneous variability or noise contained in the data. When the data's structure agrees moderately well with the model, the analysis achieves three goals;(a) parsimony, because the model contains relatively few of the total degrees of freedom, (b) effectiveness, because the model contains most of the total SS, leaving a residual with most degrees of freedom but few SS, and (c) meaningfulness, in that the model provides agronomical meaningful insights into the data structure (Zobel *et al*, 1988).

CHAPTER 3

MATERIALS AND METHODS

Results of trials from the Agricultural Research Council compiled in their annual reports were used for the comparisons in analysis. These trials include the elite commercial hybrids from all the companies marketing sunflower hybrids in South Africa. Data from these trials are mainly used for promotional purposes since all the hybrids need to be in, or post registration, to enter into the trials. The commercial seed companies plant the majority of trials. Currently four hybrids per company are allowed in the trials, resulting in a quick turnover of hybrids for the four places. The limited number of hybrids that are common during the three years are a direct result of this quick turnover.

Yield data were subjected to statistical analysis using Agrobase 2000 (Agronomix Software Inc, 2000) at the University of the Free State. Separate analyses of variance were performed on six locations over three years using Agrobase 2000. A combined analysis of variance was then performed on year 1, year 2, year 3, years 1 and 2, years 2 and 3 and across three years. Stability analysis was performed using Lin and Binns (1988) cultivar superiority measure, Shukla's (1972) method of stability variance, Wricke's (1962) ecovalence analysis and Eberhart and Russell's (1966) joint regression model. Lastly AMMI analysis was performed.

3.1 Test environments

This experiment was executed at six different locations over three years, 1998, 1999 and 2000. The trial plot size was between 8.46 and 27 m^2. The Agricultural Research Council conducts the main testing from Potchefstroom. Two experiments were conducted at Potchefstroom namely, *Potchefstroom early* representing a normal or early planting and the *Potchefstroom late* planting after normal maize planting is completed. This site represents the red soils high in clay that occur from Viljoenskroon to Delmas. It should be noted that supplement irrigation was used for both plantings. This is noticeable in the absence of correlation between the yield and the rainfall and rainfall and Coefficient of variation (CV) for the three months growing season in Table 3.2.

Table 3.1 Rainfall during 1998, 1999 and 2000 seasons

			1998			
Planting date	Location	Mean yield (t/ha)	Rain during growth period (mm)			CV (%)
			Month 1	Month 2	Month 3	
4-11-1998	Bloemfontein	1.512	102.8	90.2	67.7	8.79
26-11-1998	Koster	2.202	215	179	87	18.5
22-10-1998	Potchefstroom early	2.258	54	117	44	20.38
24-11-1998	Potchefstroom late	2.255	117	44	32	9.37
19-01-1999	Warmbaths	0.219	48	48	35	26.73
10-12-1998	Lichtenburg	1.763	189	93	93	14.93

			1999			
Planting date	location	mean yield t/ha	rain during growth period			CV
			Month 1	Month 2	Month 3	
7-12-1999	Bloemfontein	1.925	141	111	29	15.82
13-01-2000	Koster	1.403	64	204	133	15.62
5-11-1999	Potchefstroom early	2.611	29	80	90	11.53
14-12-1999	Potchefstroom late	2.042	80	90	67	10.46
24-1-2000	Warmbaths	2.249	395	376	134	11.5
29-12-1999	Lichtenburg	1.989	226	161	87	13.39

			2000			
Planting date	location	mean yield t/ha	rain during growth period			CV
			Month 1	Month 2	Month 3	
22-11-2000	Bloemfontein	2.628	37	77	63	20
27-10-2000	Koster	1.665	106	58	100	10.24
14-11-2000	Potchefstroom early	1.482	73	114	40	22.08
30-11-2000	Potchefstroom late	2.994	114	40	93	12.43
25-01-2001	Warmbaths	2.775	57	316	54	14.35
01-12-2000	Lichtenburg	2.521	123	24	145	6.36

The *Bloemfontein* location was planted on a Bainsvlei type soil. This soil has good water retention properties caused by a clay layer below the sand. This quality causes the buildup of moisture before planting. According to Table 3.2 the best season was 1998 with a good average rainfall spread over the three months. However in 1999 and 2000 a lower rainfall resulted in poorer CV's of trials but better yields. This could be due to carryover moisture correlating with uneven soil conditions or other environment interactions.

The *Koster* location has a similar soil type to *Potchefstroom* with a higher rainfall. This could result in better yields but higher disease prevalence. During the seasons 1998 and 1999 the yield was good, but the CV was high. The rainfall during 1998 was lower during the later part of the season that gave the earlier hybrids an advantage and enlarged the variation between hybrids. The 1999 season received less rain in the earlier part of the season giving the late hybrids the advantage of utilizing the moisture to their advantage, but giving rise to higher CV's.

The *Lichtenburg* location has a lower rainfall than Potchefstroom but similar soil type. Although this site had little rain during the mid season in 2000, the average yield remained good as well as the CV. A strong possibility exists that a very localized rainstorm could have passed over the site and not over the weather station.

The *Warmbaths* site was planted on dark Arcadia type soil with "self crumbling" characteristics. This soil needs a constant rain pattern otherwise it would result in a high runoff without soil penetration. The 1998 season did not receive more than 50mm per month and the yield as well as the CV was poor. The seasons 1999 and 2000 were good and above the norm for this area.

Table 3.1 Altitude, latitude and longitude of the test sites

Location	Altitude meter above sea level	Latitude ° South	Longitude ° East
Bloemfontein	1304	-28.950	26.334
Koster	1524	-25.984	26.550
Potchefstroom early	1345	-26.734	27.083
Potchefstroom late	1345	-26.734	27.083
Settlers	1116	-24.883	28.283
Lichtenburg	1489	-26.150	26.167

3.2 Experimental design and cultural practices

A randomized complete block design (RCBD) with three replications was used. Each trial was sent to the co-operator already randomized and the seed prepacked in three packets of 250 g each. Trials were planted using different methods, depending on the co-operator. Hand planting was not unusual since thinning for a good population was used. A population of 31 000 - 44 000 plants/ha was an acceptable norm. Plot size depended on space available or planting system used by the co-operator. Seeding rates and row width depended on the optimal rate used in that area.

Complimentary to the seed, a manual is sent out to the co-operators. Parameters discussed in this manual are; plot size, terrain, time of planting, seeding rate, method of planting, herbicide application and bird damage. Data recording of yield, moisture, planting date and size of plot was compulsory. The data on days to 50% flowering, days to emergence, disease presence and percentage off types was voluntary. After harvesting the trial, one kilogram of harvested seed per plot were returned to the ARC to determine oil and protein content.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Separate analysis of variance

Season of 1998

The separate analysis of variance for 1998 yield data in Table 4.1 indicates a highly significant (P<0.01) variance for replication at Bloemfontein, Potchefstroom early, Potchefstroom late and Warmbad. In Table 4.1 the total variance was between 70 – 89% for replications at Bloemfontein, Potchefstroom early and Warmbad indicating a higher heterogeneity in environmental conditions at these sites. Variance due to genotype was highly significant at all the localities and between 66 and 78% of total variance was accounted for by genotypes at Koster and Lichtenburg. The Warmbad site had an exceptionally low yield due to late planting with a nearly nonexistent rainfall (see Table 3.2). Where sites have a low coefficient of variance (CV), but a high variation attributable to replication effects, further analyses is needed.

In Table 4.2. indicating ranking in 1998 at six locations, the ranking amongst the lower yielders (HYSUN325 and PNR 6340) did not vary, since the shorter maturity caused a lower yield in general. However, amongst the high yielding hybrids, large variation occurred. This variation was due to fluctuation of genotypes in their response to the different environments and years. In general the PAN hybrids had a better yield that might be attributable to the use of similar genetical background coming from the same company. Of the SNK hybrids, SNK 78 had the best ranking that could be attributed to a longer maturity period. Making decisions based on the average ranking is impossible and it would therefore be advisable to do further analyses.

The combined ANOVA for 1998 showed highly significant (P<0.01) differences among environments, replications, genotypes and G x E interactions for yield (Table 4.7). This indicates differential responses of the entries to environments of the six localities in 1998. The biggest contributor to variance was the environments complicating selection of hybrids. This would necessitate the need for stability analysis. Zobel et al. (1988) reported that AMMI provides a more appropriate first statistical analysis of yield trials that may have a high G x E interaction.

Table 4.1 Mean squares of yield for separate ANOVA for seed yield for six locations in 1998

1998	Bloemfontein		Koster		Potchefstroom early		Potchefstroom late		Warmbaths		Lichtenburg	
	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation
Replication	0.333**	70.25	0.082	22.22	3.353**	81.72	0.631**	48.2	0.181**	89.16	0.012*	3.58
Genotype	0.118**	24.89	0.245**	66.39	0.538**	13.11	0.563**	43	0.017**	8.37	0.266**	78.69
Error	0.023	4.85	0.042	11.38	0.212	5.17	0.115	8.78	0.005	2.46	0.057	16.86
CV (%)		8.79		18.5		20.38		9.37		26.73		14.93
R-squared (%)		76		75		67		73		78		70
Mean yield (t/ha)		1.747		1.101		2.258		3.618		0.264		1.596

*, ** Significantly different at p = 0.05 and p = 0.01 levels respectively

Table 4.2. Ranking of sunflower hybrids tested in the 1998 season at six locations

	Bloem	Koster	Potch early	Potch late	Warmbaths	Lichten	
Location	1	2	3	4	5	6	Average ranking
PAN7371	1	9	11	5	6	2	1
PAN7351	5	8	10	2	2	3	2
PAN7355	2	7	13	1	3	10	3
PAN7392	3	1	9	7	10	4	4
SNK78	4	6	14	9	18	1	5
CRN1470	13	3	1	20	1	8	6
HV3037	10	12	3	6	15	14	7
SUNSTRIPE	6	4	12	10	11	13	8
PNR6338	8	19	2	4	5	16	9
ADV1003	11	10	7	13	17	6	10
PNR6500	7	2	4	17	7	11	11
AGSUN8751	14	5	5	11	9	20	12
HYSUN345	15	14	15	12	13	7	13
CRN1435	9	13	8	15	14	15	14
SNK80	16	16	18	3	12	9	15
HYSUN333	20	17	6	14	8	12	16
SNK77	12	11	19	8	4	17	17
SNK50	18	18	17	16	16	5	18
CRN1080	19	15	16	18	20	18	19
HYSUN325	21	20	20	19	19	21	20
PNR6340	17	21	21	21	21	19	21
C V	8.79	18.5	20.38	9.37	26.73	14.9	

Ranking based on mean yield as indicated in table 4,9

Season of 1999

The separate analysis of variance for 1999 in Table 4.3 indicates a highly significant (P<0.01) variance for replication at Koster, Potchefstroom early and Lichtenburg with the highest variance percentages of 33%, 35% 49% and 70%. The contribution to variance by the genotypes was highly significant for Koster, Potchefstroom early, and Potchefstroom late, Warmbaths and Lichtenburg locations (P<0.01). The highest values of variation due to genotypes were at Warmbaths and Potchefstroom late. The good yields indicated a stable rainfall during the growing season. Bloemfontein had an exceptional high error and poor repeatability of the trial.

In the ranking table for the 1999 season (Table 4.4) the hybrids AGSUN 5551 and CRN 1414 showed a good ranking for average yield and of the low yielders, the hybrid LG 5630 showed consistent ranking across different locations. The other hybrids like SNK 50 had three poor rankings and two good ones resulting in a better ranking than would be acceptable. HYSUN350 shows inconsistency by having a rank of 19 as well as two number one rankings. Further analysis of stability is therefore needed.

In the combined analysis for 1999 (Table 4.7) the environments, replications, genotypes and G x E interaction were highly significant. The biggest contributor of variance was the environments with 98.01% of the total. Large differences between replications would mean that the trial area was not homogenous. This could have been due to differences in soil, poor cultivation practices, diseases, insect pressure or moisture gradients between replications. If a hybrid with good general adaptability were sought, then this would be a good test. The interaction between genotypes and environment was significant and could be attributed to the differences in environments and the different reactions of hybrids to these environments.

Table 4.3 Mean squares of yield for separate ANOVA for seed yield for six locations in 1999

1999	Bloemfontein		Koster		Potchefstroom early		Potchefstroom late		Warmbaths		Lichtenburg	
	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation	MS	%of variation	MS	% of variation
Replication	0.236	18.09	0.437 **	49.54	1.106 **	70.17	0.12	33.42	0.065	15.36	0.520 **	35.28
Genotype	0.148	11.35	0.397 **	45.01	0.379 **	24.68	0.194 **	54.03	0.290 **	68.55	0.244 **	16.55
Error	0.92	70.55	0.048	5.1	0.091	5,77	0.045	12.53	0.068	16.07	0.71	48.16
CV (%)		15.82		15.65		11.56		10.43		11.5		13.41
R-squared (%)		48		82		73		70		68		68
Mean yield (t/ha)		1.925		1.403		2.611		2.042		2.249		1.989

*, ** Significantly different at p = 0.05 and p = 0.01 levels respectively

Table 4.4 Ranking of sunflower hybrids tested in the 1999 season at six locations

	Bloem	Koster	Potch early	Potch late	Warmbaths	Lichten	
Hybrid	1	2	3	4	5	6	Average ranking
AGSUN5551	15	6	2	7	7	1	1
CRN1424	16	1	1	10	14	12	2
CRN1414	2	4	8	5	6	14	3
HYSUN333	4	15	10	2	1	5	4
PAN7355	13	2	15	6	2	3	5
AGSUN8751	18	5	4	9	11	6	6
HV3037	10	8	11	4	8	11	7
HYSUN345	8	13	14	11	5	2	8
HYSUN350	1	19	13	1	12	4	9
SNK77	17	3	6	14	15	9	10
PAN7371	7	10	17	13	4	8	11
PAN7351	5	9	16	12	3	15	12
SNK50	6	16	3	16	10	16	13
PHB6488	11	18	5	3	17	17	14
CRN1435	12	12	7	19	13	13	15
PAN7392	3	11	19	18	9	10	16
SNK73	14	7	12	17	19	7	17
PHB6500	9	17	9	8	16	19	18
LG5630	19	14	18	15	18	18	19
C V	15.9	15.6	11.5	10.4	11.58	13.4	

Ranking based on mean yield as indicated in table 4,11

Season of 2000

In the separate analysis of variance for the 2000 season (Table 4.5) there was no significant variation between replications. There was significant variation between genotypes at Koster and Lichtenburg with contribution to variance of between 86% and 90%. Taking these observations into consideration, it would seem that the season of 2000 had the best conditions for testing.

In Table 4.6 very little conclusions could be made from the stability in ranking across environments for any of the hybrids. This indicates a big difference in reaction of hybrids to the environments they were tested in or very unstable hybrids.

As shown in the combined analysis of variance (Table 4.7), mean squares for environments, replications, interaction of environments and genotypes were significant. There was no significant difference between the genotypes. Since this was only done on seed yield it means there is little difference in yields amongst hybrids.

Table 4.5 Mean squares yield for the separate ANOVA for seed yield for six locations in 2000

2000	Bloemfontein		Koster		Potchefstroom early		Potchefstroom late		Warmbaths		Lichtenburg	
	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation	MS	% of variation
Replication	0.705	74.84	0.021	5.8	1.714	57.15	0.19	33.27	0.13	11.1	0.025	4.82
Genotype	0.123	13.05	0.312**	86.19	0.785	26.17	0.242	42.38	0.543	50.36	0.468**	90.17
Error	0.117	12.42	0.029	8.01	0.5	16.67	0.139	24.34	0.498	42.53	0.026	5.01
CV (%)		20		10.24		22.08		12.43		14.35		6.36
R-squared (%)		47		84		50		49		36		90
Mean yield (t/ha)		2.628		1.665		1.482		2.994		2.775		2.521

*, ** Significantly different at p = 0.05 and p = 0.01.

Table 4.6 Ranking of sunflower hybrids tested in the 2000 season at six locations

	Bloem	Koster	Potch early	Potch late	Warmbaths	Lichten	
Hybrid	1	2	3	4	5	6	Average ranking
PAN7355	15	10	6	1	2	7	1
HYSUN350	12	14	10	2	10	1	2
PAN7351	5	1	16	3	9	15	3
HYSUN338	3	9	14	5	4	14	4
SNK74	11	12	5	8	3	12	5
PHB6488	8	8	2	16	8	10	6
SNK77	17	7	1	10	5	9	7
AGSUN5551	7	6	8	15	12	6	8
CRN1424	6	4	9	17	14	3	9
CRN1414	14	3	15	13	17	2	10
AGSUN8751	2	13	18	6	11	13	11
PHB65A02	13	2	3	4	7	18	12
HV3037	1	5	13	18	15	8	13
HYSUN345	9	18	17	14	6	4	14
PAN7371	10	15	11	12	1	17	15
SNK79	18	11	7	9	13	11	16
PAN7001	4	16	4	7	18	16	17
HYSUN333	16	17	12	11	16	5	18
C V	20	10.2	22.1	12.43	14.4	6.4	

Ranking based on mean yield as indicated in table 4,12

Table 4.7 Mean squares of yield from the combined analysis of variance across six locations in, 1998, 1999 and 2000

Source	df	1998 MS	df	1999 MS	df	2000 MS
Environments	5	80.627**	5	59.024**	5	20.785**
Reps	12	0.765**	12	0.414**	12	0.386**
Genotypes	20	0.834**	18	0.478**	17	0.163
G X E	100	0.183**	90	0.235**	85	0.298**
Error	240	0.076	216	0.07	204	0.123

*, ** Significanty different at p = 0.05 and p = 0.01 level

4.2 Combined analysis of variance over years and environments

The mean squares for year, environment, year x environment, G x E, G x E x Y and rep x Y x E were highly significant for all three sets of data (Table 4.8). The genotype effect was significant in 1998/99 and highly significant in 1998/99/00, and significant in 1999/00. This interaction could suggest that some of the genotypes were not stable, reacting differently to the environments.

According to Kang and Gorman (1989) the G x E interactions would greatly reduce the significance of the correlation between phenotypic and genotypic values. When interaction is due to variation caused by unpredictable environmental factors (rainfall variation) the breeder should develop widely adaptable varieties. These conclusions could be applied to the 1999 and 2000 combined analysis as well as the combined analysis of 1998, 1999 and 2000 seasons in Table 4.8. In the 1999 and 2000 analysis no significant variance was shown for genotype, therefore the hybrids did not differ much for these seasons. Across the three seasons all the interactions were significant.

Table 4.8 Mean squares of yield from combined ANOVA over years and environments for the six locations

Source	1998/99 MS	1999/00 MS	1998/99/00 MS
Year	3.993**	4.317**	8.307**
Environment	20.001**	8.521**	19.820**
Year x Environment	18.896**	6.330**	15.106**
Genotype	0.143*	0.167	0.264**
Genotype x Year	0.266**	0.192*	0.199**
G x E	0.169**	0.291**	0.241**
G x Y x E	0.139**	0.189**	0.183**
Rep in Y x E	0.187**	0.172**	0.189**
Residual	0.067	0.091	0.083

*, ** Significantly different at the p = 0.05 and p = 0.01 levels .

4.3 Stability analysis

4.3.1 Joint regression model

4.3.1.1 Regression analysis across locations

According to Finlay and Wilkinson (1963) mean yield of entries across all environments and regression coefficients are important indicators of cultivar adaptation. They showed that a regression coefficient approximating 1.0 indicated an average stability, and in association with high yield, the entry possesses general adaptability. However, entries with a low yield would be poorly adapted to the environment. Regression coefficient values increasing above 1.0 describe genotypes with increasing sensitivity to environmental change, thus below average stability. Regression coefficients decreasing below 1.0 provide a measure of greater resistance to environmental change, thus above average stability. However, regression coefficients must also be associated and interpreted with genotype mean yields to determine adaptability. In addition to the regression coefficient, Eberhart and Russell (1966) added deviation from the regression as a measure of stability, where an entry would be considered stable with a deviation close to 0.

In Table 4.9 the hybrids SNK 77, ADV 1003, CRN 1435 and HYSUN 333 had the best stability in 1998. According to the ranking and mean yield the hybrids SNK 77, CRN 1435 and Hysun 333 were all poorly adapted across the test environments, but ADV1003 had better yield and thus had better general adaptability. The hybrids with values below 1 generally had low yields, but CRN 1470 and PNR6500 had high yields that indicate a good adaptation of these hybrids to low yielding environments by resisting fluctuations associated with poor environments and thus had good average stability value.

Table 4.9. Stability analysis for 1998 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i) and environment as a covariate (s_i^2)

Hybrid	Rank on yield	Yield t/ha	*bi*	Rank	*S2di*	Rank	*Pi*	Rank	*Wi*	Rank	σ^2_i	Rank	s_i^2	Rank
PAN7371	1	2.01	1.0571	10	-0.0009	1	0.0456	1	0.1691	9	0.0978	8	0.1083	8
PAN7351	2	1.99	1.0834	12	-0.0188	10	0.0517	2	0.114	7	0.066	7	0.0491	2
PAN7355	3	1.99	1.1861	15	0.01	5	0.0543	3	0.4064	18	0.2599	18	0.1446	10
PAN7392	4	1.98	1.043	8	-0.0169	9	0.0594	4	0.089	4	0.0494	4	0.0554	3
SNK78	5	1.94	1.0294	7	0.0702	19	0.0744	5	0.2146	10	0.1327	10	0.1647	11
CRN1470	6	1.87	0.805	20	0.1094	21	0.0858	6	0.8256	20	0.5379	20	0.4742	20
HV3037	7	1.86	1.1278	13	-0.0047	3	0.098	7	0.2304	12	0.1432	12	0.0958	6
SUNSTRIPE	8	1.85	1.0281	6	-0.0111	6	0.1059	8	0.1051	6	0.0601	6	0.0744	5
PNR6338	9	1.85	1.1739	14	0.0702	20	0.1157	9	0.6187	19	0.4007	19	0.334	18
ADV1003	10	1.85	1.0116	2	-0.0149	7	0.1311	10	0.0858	3	0.0473	3	0.619	21
PNR6500	11	1.83	0.8804	19	0.027	12	0.1392	11	0.3441	16	0.2186	16	0.2008	12
AGSUN8751	12	1.82	1.0571	9	0.0491	17	0.1526	12	0.3622	17	0.2306	17	0.2743	16
HYSUN345	13	1.75	1.0191	5	-0.0221	11	0.1531	13	0.0587	1	0.0293	1	0.381	19
CRN1435	14	1.75	0.9817	4	-0.0157	8	0.1735	14	0.084	2	0.0461	2	0.0593	4
SNK80	15	1.72	1.0832	11	0.0375	15	0.1781	15	0.3389	15	0.2151	15	0.2356	14
HYSUN333	16	1.7	1.0125	3	0.0048	4	0.1839	16	0.165	8	0.0998	9	0.1274	9
SNK77	17	1.7	1.0115	1	0.0462	16	0.2063	17	0.3305	14	0.2096	14	0.2647	15
SNK50	18	1.61	0.9102	16	0.0288	14	0.2632	18	0.3114	13	0.1969	13	0.2068	13
CRN1080	19	1.51	0.9016	17	-0.0283	13	0.314	19	0.0934	5	0.0523	5	0.0176	1
HYSUN325	20	1.32	0.8852	18	-0.0022	2	0.4976	20	0.2204	11	0.1366	11	0.1042	7
PNR6340	21	1.18	0.7121	21	0.062	18	0.7311	21	0.9231	21	0.6026	21	0.3171	17

bi = 1 most stable

The hybrids PAN 7371 and PAN 7355 in Table 4.9 had the highest yields as well as low deviation from regression, but ADV 1003 had adapted the best to the environment by having the second best regression coefficient, high yield, and deviation and yield in the fourth place. Hybrids like HYSUN 333 and HYSUN 325 had a good deviation, but low yield, showing a constant low rank for yield.

In Table 4.10, showing the 1999 season data, the hybrids HV 3037 and Hysun 345 showed the best regression coefficient with high yields, indicating very stable hybrids. PAN 7351 had good stability but was low yielding in comparison and below the unity level indicating poor adaptability in low yielding environments. Hybrids like CRN 1414, Pan 7355 and CRN 1424 gave good yields in the low yielding environmental conditions and had resistance to fluctuating environmental conditions. Hybrids like AGSUN 5551 and HYSUN 333 were more sensitive to fluctuations. The regression deviation was lowest for the hybrids HV 3037 and CRN 1414. The hybrid HV 3037 would be the most stable although not the best yielding hybrid. The hybrid CRN 1414 with low deviation only had seventh place in the regression coefficients on the scale below 1, giving good general adaptability.

Table 4.10. Stability analysis for 1999 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i) and environment as a covariate (s_i^2)

Hybrid	Rank on yield	yield	b_i	Rank	S^2d_i	Rank	P_i	Rank	W_i	Rank	σ^2_i	Rank	s_i^2	Rank
AGSUN5551	1	2.29	1.2724	12	0.044	10	0.0899	1	0.3515	10	0.2219	10	0.2309	10
CRN1424	2	2.26	0.6568	15	0.2185	19	0.1066	2	1.0840	19	0.7130	19	0.8159	19
CRN1414	3	2.22	0.8008	7	0.0005	1	0.1083	3	0.1504	3	0.0870	3	0.0852	3
HYSUN333	4	2.2	1.2960	14	0.0575	14	0.1808	8	0.4162	13	0.2653	13	0.2762	14
PAN7355	5	2.18	0.5238	18	0.0226	4	0.1250	4	0.3866	12	0.2454	12	0.1590	5
AGSUN8751	6	2.1	1.1402	5	0.0411	9	0.1601	5	0.2970	6	0.1853	6	0.2213	9
HV3037	7	2.09	0.9913	1	-0.0103	3	0.1807	7	0.0759	2	0.0370	2	0.0490	2
HYSUN345	8	2.09	1.0680	2	0.0349	8	0.2066	9	0.2602	5	0.1606	5	0.2005	8
HYSUN350	9	2.08	1.1322	4	0.1078	18	0.2680	11	0.5618	18	0.3629	18	0.4448	18
SNK77	10	2.04	0.7850	8	0.0825	17	0.1800	6	0.4833	16	0.3103	16	0.3599	17
PAN7371	11	2.01	0.8729	6	0.0496	12	0.2543	10	0.3282	9	0.2063	9	0.2498	13
PAN7351	12	1.98	0.9505	3	0.0488	11	0.2749	12	0.3141	7	0.1968	7	0.2471	11
SNK50	13	1.96	1.4934	19	0.027	7	0.2890	15	0.4177	14	0.2663	14	0.1740	7
PHB6488	14	1.93	1.3610	17	0.0813	16	0.3319	16	0.5452	17	0.3518	17	0.3560	16
CRN1435	15	1.93	1.2914	13	0.001	2	0.2826	13	0.1880	4	0.1122	4	0.0867	4
PAN7392	16	1.91	0.7295	11	0.0704	15	0.3347	17	0.4563	15	0.2921	15	0.3194	15
SNK73	17	1.91	0.6414	16	0.0262	6	0.2835	14	0.3234	8	0.2030	8	0.1712	6
PHB6500	18	1.9	1.2254	9	0.0496	13	0.3397	18	0.3553	11	0.2244	11	0.2496	12
LG5630	19	1.61	0.7679	10	-0.023	5	0.5368	19	0.0673	1	0.0313	1	0.0061	1

bi = 1 most stable

For the 2000 season, shown in Table 4.11, the hybrids SNK 74, PAN7351 and PAN 7001 had the best regression coefficients. The highest yielders, PAN 7355 and HYSUN350 had very high regression coefficients, indicating sensitivity of the hybrids to environmental fluctuations. The hybrids with coefficients below 1, giving average stability, resisting fluctuations with good yields were CRN1414, AGSUN 5551, CRN 1424 and PHB 6488.The deviation column in Table 4.10 showed the hybrids SNK 74 and SNK 79 to be the most stable. Taking the ranking of yield into consideration, SNK 74 would be the most stable with AGSUN 5551 second best if general stability is important. HYSUN 338 had good S^2d_i value, but had a sensitive b_i value.

Table 4.11 Stability analysis for 2000 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i), and environment as a covariate (s_i^2)

Hybrid	**Rank on yield**	**Yield t/ha**	*bi*	**Rank**	*S2di*	**Rank**	*Pi*	**Rank**	*Wi*	**Rank**	σ^2_i	**Rank**	s_i^2	**Rank**
PAN7355	1	2.54	1.204	11	0.0379	9	0.0742	1	0.415	8	0.2615	8	0.2634	9
HYSUN350	2	2.46	1.2471	13	0.0627	13	0.103	2	0.5518	15	0.3539	14	0.3473	13
PAN7351	3	2.44	1.0546	2	0.0661	14	0.133	4	0.4353	9	0,2874	17	0.3586	14
HYSUN338	4	2.42	1.1572	8	0.0113	3	0.1336	5	0.2763	5	0.1679	5	0.1738	5
SNK74	5	2.4	0.9826	3	-0.0111	2	0.1289	3	0.1397	1	0.0757	1	0.0983	3
PHB6488	6	2.39	0.7237	14	-0.0274	7	0.1525	7	0.2206	3	0.1303	3	0.043	1
SNK77	7	2.38	0.7014	16	0.0296	8	0.1628	8	0.4735	11	0.301	10	0.2355	8
AGSUN5551	8	2.38	0.8424	9	-0.0147	5	0.1361	6	0.1725	2	0.0978	2	0.086	2
CRN1424	9	2.38	0.7927	12	0.0607	12	0.1679	10	0.5089	12	0.3249	11	0.3404	12
CRN1414	10	2.34	0.9155	4	0.0978	16	0.163	9	0.5883	16	0,3785	18	0.4656	16
AGSUN8751	11	2.32	1.2898	15	0.0118	4	0.1838	11	0.3924	6	0.2462	6	0.1755	6
PHB65A02	12	2.3	0.6997	18	0.2433	18	0.2951	18	1.3302	18	0.8793	16	0.9568	18
HV3037	13	2.3	0.8479	7	0.0769	15	0.2177	14	0.5355	13	0.3429	12	0.3951	15
HYSUN345	14	2.25	1.3614	17	0.0263	6	0.2058	12	0.5399	14	0.3458	13	0.2243	7
PAN7371	15	2.24	1.149	6	0.0428	10	0.2457	15	0.3973	7	0.2495	7	0.28	10
SNK79	16	2.24	0.8565	5	0.0083	1	0.2116	13	0.2563	4	0.1544	4	0.1637	4
PAN7001	17	2.23	1.0028	1	0.1419	17	0.2652	17	0.7509	17	0.4883	15	0.6144	17
HYSUN333	18	2.18	1.1716	10	0.0505	11	0.2543	16	0.4423	10	0.2799	9	0.3062	11

4.3.1.2 Regression analysis across locations and years

Combining the seasons 1998 and 1999 in Table 4.12 the hybrids PAN 7351 and AGSUN 8751 showed the best regression coefficient and HYSUN 345 and PAN 7355 showed the lowest deviation ($S^2d_i = 0$) or were the most stable. The most stable hybrid from both tables and models would be PAN 7351 having a little higher deviation but still a below zero regression coefficient for general stability.

In the seasons 1999 and 2000 (Table 4.13), PAN 7355 and PAN 7351 were the closest to unity. The hybrids with the lowest deviation for 1999 and 2000 were PAN 7371 and HYSUN 345. The most stable hybrid would be PAN7355 with the regression coefficient closest to unity and fourth lowest deviation value.

In the regression coefficient (Table 4.14) for the seasons 1998 and 2000 the hybrid PAN7371 had the best stability with high yield and a coefficient close to unity. The hybrid ranking first would be the most sensitive to environmental effects with specific stability. The hybrid HYSUN 333 would be stable but not well adapted to the specific environment with resulting low yield. In the deviation column for the 1998 and 2000 seasons PAN 7355 ranked first and had the lowest deviation value, but as a sensitive hybrid PAN 7351 would be more stable even with a fourth rank position for regression coefficient and a third lowest deviation, as it had a good yield.

Across 1998, 1999 and 2000 the coefficient in Table 4.15 indicated that PAN 7351 and HYSUN 333 would be the most stable. In the deviation column the hybrids HYSUN345 and PAN 7355 had the lowest deviation or best stability. The hybrid with the better general stability, HV 3037, had a general yield rank of 4, a coefficient rank of 3 and also the third best deviation score.

Table 4.12 Stability analysis for 1998 and 1999 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i), and environment as a covariate (s_i^2)

Hybrid	**Rank on yield**	**Yield t/ha**	*bi*	**Rank**	*S2di*	**Rank**	*Pi*	**Rank**	*Wi*	**Rank**	σ^2_i	**Rank**	s_i^2	**Rank**
PAN7355	1	2.24	1.0625	8	0.0119	3	0.0393	1	0.4233	3	0.1265	3	0.1270	3
PAN7351	2	2.14	0.9919	2	0.0198	4	0.0716	4	0.4708	4	0.1438	4	0.1587	4
PAN7371	3	2.09	0.9657	6	0.0226	5	0.1299	8	0.5079	5	0.1573	5	0.1699	5
HV3037	4	2.09	1.0485	5	-0.0088	2	0.0926	6	0.2037	1	0.0467	1	0.0443	1
AGSUN8751	5	2.08	1.0025	1	0.0451	7	0.0647	2	0.7232	7	0.2356	7	0.2598	7
SNK77	6	2.04	0.9367	7	0.0642	8	0.0920	5	0.9471	8	0.3170	8	0.3362	8
HYSUN345	7	2.03	0.9795	4	-0.0009	1	0.0689	3	0.2666	2	0.0696	2	0.0758	2
HYSUN333	8	2.03	1.0126	3	0.0401	6	0.1017	7	0.6749	6	0.2180	6	0.2400	6

Table 4.13 Stability analysis for 1999 and 2000 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i), and environment as a covariate (s_i^2)

Hybrid	**Rank on yield**	**Yield t/ha**	*bi*	**Rank**	*S2di*	**Rank**	*Pi*	**Rank**	*Wi*	**Rank**	σ^2_i	**Rank**	s_i^2	**Rank**
HYSUN345	7	2.17	1.1886	7	0.0132	1	0.1522	8	0.5870	2	0.1742	2	0.1493	1
PAN7371	8	2.19	1.0337	3	0.0142	2	0.1507	7	0.4841	1	0.1368	1	0.1532	2
HV3037	5	2.21	0.8320	6	0.0255	3	0.1264	5	0.6854	4	0.2099	4	0.1983	3
PAN7355	1	2.36	1.0094	1	0.0262	4	0.0517	1	0.6002	3	0.1790	3	0.2010	4
PAN7351	3	2.13	1.0266	2	0.0460	6	0.1192	4	0.8005	6	0.2518	6	0.2083	5
AGSUN8751	4	2.20	1.1338	5	0.0344	5	0.1124	3	0.7405	5	0.2300	5	0.2338	6
HYSUN333	6	2.21	1.0816	4	0.0538	7	0.1485	6	0.8977	7	0.2871	7	0.3114	7
SNK77	2	2.21	0.6942	8	0.0612	8	0.1066	2	1.2563	8	0.4175	8	0.3411	8

Table 4.14 Stability analysis for 1998 and 2000 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i), and environment as a covariate (s_i^2)

Hybrid	**Rank on yield**	**Yield t/ha**	*bi*	**Rank**	*S2di*	**Rank**	*Pi*	**Rank**	*Wi*	**Rank**	σ^2_i	**Rank**	s_i^2	**Rank**
HYSUN345	7	2.00	1.0207	8	0.0171	2	0.1124	3	0.5870	2	0.1742	2	0.1493	1
PAN7371	3	2.13	0.9958	1	0.0328	6	0.1448	6	0.4841	1	0.1368	1	0.1532	2
HV3037	4	2.08	0.9803	2	0.0420	7	0.1314	5	0.6854	4	0.2099	4	0.1983	3
PAN7355	1	2.26	1.1126	6	0.0079	1	0.0449	1	0.6002	3	0.1790	3	0.2010	4
PAN7351	2	2.21	0.9673	4	0.0174	3	0.0597	2	0.8005	6	0.2518	6	0.2083	5
AGSUN8751	5	2.07	1.0346	7	0.0243	4	0.1613	7	0.7405	5	0.2300	5	0.2338	6
HYSUN333	8	1.94	0.9744	5	0.0255	5	0.1942	8	0.8977	7	0.2871	7	0.3114	7
SNK77	6	2.02	0.6141	7	0.0534	8	0.1288	4	1.2563	8	0.4175	8	0.3411	8

Table 4.15 Stability analysis for 1998, 1999 and 2000 with rank on yield, regression coefficient (b_i), deviation from regression (S^2d_i), cultivar superiority (P_i), ecovalence (W_i), no covariate (σ^2_i), and environment as a covariate (s_i^2)

Hybrid	**Rank on yield**	**Yield t/ha**	*bi*	**Rank**	*S2di*	**Rank**	*Pi*	**Rank**	*Wi*	**Rank**	σ^2_i	**Rank**	s_i^2	**Rank**
PAN7355	1	2.24	1.0795	7	0.0137	2	0.0453	1	0.8055	2	0.1558	2	0.1490	2
PAN7351	2	2.14	0.9982	1	0.0273	5	0.0793	2	0.9534	5	0.1906	5	0.2035	5
PAN7371	3	2.09	0.9692	6	0.0233	4	0.1313	6	0.8995	4	0.1780	4	0.1875	4
HV3037	4	2.09	0.9828	3	0.0198	3	0.1122	5	0.8367	3	0.1632	3	0.1735	3
AGSUN8751	5	2.08	1.0374	5	0.0317	6	0.1339	7	1.0391	6	0.2108	6	0.2211	6
SNK77	6	2.04	0.8981	8	0.0616	8	0.1066	3	1.6167	8	0.3467	8	0.3405	8
HYSUN345	7	2.03	1.0303	4	0.0110	1	0.1112	4	0.7013	1	0.1313	1	0.1380	1
HYSUN333	8	2.03	1.0045	2	0.0407	7	0.1489	8	1.1674	7	0.2410	7	0.2570	7

4.3.2 Lin and Binns' cultivar superiority measure

4.3.2.1 Analysis across locations

According to Lin and Binns (1988), the superiority measure (Pi) of cultivars is estimated by the squares of differences between an entry mean and maximum entry mean, summed and divided by twice the number of locations. Cultivars with the lowest Pi values are considered the most stable. Accordingly, in Table 4.9 the superiority measure of the tested entries revealed that hybrids PAN 7351, PAN 7355, PAN 7371, PAN 7392 and SNK 78 had the highest stability and PNR 6340 and HYSUN 325 had the lowest stability. There is a good similarity between the mean yield ranking and the superiority ranking for the 1988 season.

During the 1999 season shown in Table 4.10 the hybrids AGSUN 5551, CRN 1424 and CRN 1414 had the best stability and PHB 6500 and LG5630, on the low yield side, had the lowest stability. On average ranking of superiority, this correlates very well with the average yield ranking.

The superiority measure for the 2000 season is shown in Table 4.11. The hybrids PAN 7355 SNK74 and HYSUN 350 had the best stability. SNK 74 had better stability than the yield ranking would place it. PNR 65A02 lost its stability with this measure to drop to last place compared to twelfth place in the yield ranking.

4.3.2.2 Superiority measure analysis across locations and years

For the multiple year analysis of 1998 and 1999 in Table 4.12 the superiority measure had less similarity to the mean yield rank. The best hybrid, PAN7355, did correlate with the mean yield rank, but the other hybrids had no correlation to the mean yield rank. In Table 4.13 of the 1999-2000 season the cultivar superiority measure had a better correlation to the mean yield ranking in the first six hybrids. PAN 7355 had the best stability (0.517). The last two hybrids HYSUN 333 and PAN 7371 had the lowest stability.

For the years 1998 and 2000 (Table 4.14) a similar pattern arose as in the 1998 and 1999 analysis. Although PAN 7355 (0.0449) and PAN 7351 (0.0597) had the best stability, the rest correlated with the mean yield rankings. There seems to be an unpredictable factor in the 1998 season with SNK 77 (0.1288) and HYSUN 345 (0.1124) moving down in stability. Since the one site had very low yields in 1998 this might have had an influence.

The multiple year analysis in Table 4.15 for the 1998,1999 and 2000 seasons show that the first two hybrids, PAN7355 (0.0454) and PAN7351 (0.0793) had the best stability with the other hybrids in a similar situation to the 1998-2000 analysis in Table 4.14. HYSUN 333 was the least stable. The PAN hybrids had similar yield ranking in all the combined analyses where the 1998 season was combined with other seasons.

4.3.3 Wricke's ecovalence

4.3.3.1 Analysis across locations

Wricke's ecovalence (1962) is an alternative method that is frequently used to determine stability of genotypes based on the G x E interaction effects. It indicates the contribution of each genotype to the G x E interaction. The cultivars with the lowest ecovalence contributed the least to the G x E interaction and are therefore more stable.

Although Table 4.9 for the 1998 season showed little similarity to the mean yield rank, the hybrid PAN 7392 (0.089) of good stability, correlated to the mean yield. PNR 6340 (0.9231) had similar ranking to the yield rank but had the highest *Wi* value and was thus the least stable. HYSUN 345 (0.0587) and CRN 1435 (0.084) had the best stability but had poor yield ranking and were therefore not well adapted to the test environments.

The 1999 season analysis showed reasonable correlation with mean yield rank in Table 4.10 with hybrids like CRN 1414 (0.1504) and AGSUN 8751 (0.2970) showing good stability and correlation to the mean yield. The least stable CRN1424 (1.0840) showed no similarity to mean yield ranking. The hybrid LG 5630 was the most stable with the lowest yield rank, indicating poor adaptability to test environments. Ecovalence on its own is therefore not a good indicator of a stable genotype.

For the 2000 season (Table 4.11) the analysis showed SNK 74 (0.1397) and PHB 6488 (0.4735) to be the most stable but with poor mean yield ranking. The other end of the stability ranks show PAN 7001 and PHB 65A02 (1.3302) to be very unstable. Both of these hybrids did not rank amongst the first 11 hybrids on mean yield.

4.3.3.2 Analysis across locations and years

For the 1998 and 1999 seasons (Table 4.12) the hybrids with the best stability were HV 3037 and HYSUN345, but their yield rank for showed stable yet poor yields. The hybrids PAN 7355 and PAN 7351 both had good stability and yield showing good adaptability to their test environments. The least stable hybrids were SNK77 and AGSUN8751with HYSUN better, but having a poor yield.

In Table 4.13 the analysis for the 1999 and 2000 seasons showed PAN 7371 to be the most stable, with HYSUN 345 second with the best yield. The third hybrid, PAN 7355, had poorer yield and stability. The hybrid with the lowest stability was SNK77 and HYSUN333 with a low yield.

In the combined analysis of the 1998 and 2000 seasons in Table 4.14 the hybrids PAN 7371 and HYSUN 345 showed good stability and yield. PAN 7355 had a good yield and stability. The least stable hybrid was SNK 77 (0.7811) with the poorest yield.

The multilocation analysis for 1998, 1999 and 2000 showed HYSUN345 to be the most stable with average yield. PAN 7355 had the best yield with less stability. HV3037 had a average yield with less stability and SNK77 was the least stable with low yield and was thus sensitive to environment interactions.

4.3.4 Shukla's method of stability variance

Shukla's stability variance parameters (1972) depend on stability variance across environments for discrimination of stability. According to Lin and Binns (1986), Shukla's stability variance is a relative measure depending on the cultivars in the test and thus the results must be restricted to only those genotypes in the test and should not be generalized. A genotype is therefore only considered to be stable in relation to other genotypes if it is compared to other sets of genotypes. Shukla's stability variance using no covariate (σ^2_i) and environment as a covariate (s_i^2) is shown in Table 4.9 to Table 4.15. Shukla (1972) described the use of environment as a covariate, as a stability-variance statistic calculated following the removal of heterogeneity attributable to a known covariate.

4.3.4.1 Analysis across locations

Shukla's stability method had very similar results to Wricke's analysis method as well as the deviation from regression. The ranking followed almost exactly the same pattern of ranking. Some differences occurred when environment was used as a covariate.

The hybrids HYSUN 345, CRN 1435 and ADV 1003 were the most stable for the 1998 season in Table 4.9, but did not good have yield. These hybrids were thus predictable in the test environments but due to stable low yields and the inability to react to environmental changes, should not be selected. The hybrid PAN7392 was also stable but had a better yield and would thus be the preferred hybrid for selection. Taking the analysis with environment as a covariate into consideration, it is PAN 7392 that would still be the most stable hybrid with good yield.

In Table 4.10 for the 1999 season LG 5630 had the best stability and therefore had the least reaction to environmental conditions, although it had the lowest yield. The better hybrid was HV3037 with intermediate yield and CRN 1414 with both good yield and stability. With the environment as a covariate a similar result for CRN 1414 as well as LG 5630 was seen.

In Table 4.11 of the 2000 season the hybrid SNK 74 had the best stability combined with good yield. The other hybrids AGSUN 5551, PHB 6488 and Hysun 338 had good stability and yield with all yielding above 2.38 t/ha. The hybrid SNK 79 was stable but had a weak yield that proves inability to react to environmental changes. CRN1414 and PHB 65A02 had the lowest stability as well as average yield. A similar pattern existed when environment was used as a covariate.

4.3.4.2 Analysis across locations and years

Of the three best hybrids in the analysis for the 1998 and 1999 seasons in Table 4.12 PAN 7355 and PAN 7351 was stable and gave high yield. This could be due to similar genetic background of the hybrids. The hybrid HV3037 had the best stability but had a intermediate yield level. AGSUN8751 and SNK 77 had average yield with poor stability. With the environment as a covariate no difference was found. This was possibly due to the combination of years with similar environmental conditions.

In Table 4.13 the hybrid PAN 7355 proved to be the most stable in the high yield range with HV 3037 in the low yield range. The hybrid SNK 77 was the least stable with high yield. The most stable was HYSUN345 and PAN7371 with relatively poor yield.

For the 1998 and 2000 seasons in Table 4.14 PAN 7371 was the most stable hybrid with a relatively good yield followed by PAN 7355 with the highest yield level. SNK 77 had the least stability followed by HYSUN333 in the poor yield range. Noticeable differences occurred when environment was used as a covariate, possibly due to a big difference between the 1998 and 2000 seasons.

For the years 1998,1999 and 2000 (Table 4.15) hybrids rated similarly by both Shukla's parameters of stability. Hybrids PAN 7355 and PAN 7371 were most stable in the high yield range. HYSUN 345 was the most stable in the low yield range. The hybrids HYSUN 333 and SNK 77 were the least stable hybrids in the study.

4.3.5 AMMI analysis

The IPCA scores of a genotype in the AMMI analysis are an indication of the stability of a genotype over environments. The greater the IPCA scores, either negative or positive (as it is a relative value), the more specifically adapted a genotype is to certain environments. The more the IPCA scores approximate zero (0), the more stable the genotype is over all the environments sampled. If the IPCA scores of a genotype are interpreted in conjunction with the IPCA 1 scores of the individual environments, the adaptability of the genotype can largely be determined by characterization of the environments, for example whether they are low potential environments.

4.3.5.1 AMMI analysis over years

The AMMI analysis of variance (ANOVA) of the cultivar evaluation trials for the 1998 season is presented in Table 4.16. For the 1998 season the IPCA 1 score explained 38% and IPCA 2 another 34% of the variability, while the remaining 27.22% would be residual. For the 1999 season the IPCA 1 score explained 47% and IPCA 2 24% of the variability for yield, with the IPCA 3 at 12%. For the 2000 season's model the IPCA 1 explained 36%, the IPCA 2 27% and IPCA3 17% of the variability. This would mean that the IPCA3 with the relatively small contribution would be ignored during interpretation.

Figure 4 indicates the AMMI bi-plot for the1998 season. Distinct patterns are identifiable around genotypes as well as environments. For genotypes, the PAN hybrids were very close in relation to each other indicating similar germplasm. The SNK hybrids were also in close proximity to each other. Although the hybrids HYSUN 345 and PAN 7392 are widely adapted and very stable, they formed a group around the Bloemfontein environment indicating their adaptation to that environment. Warmbaths, Potchefstroom early and Potchefstroom late are the outliers and show their tendency to differ substantially from the other sites. The two Potchefstroom trials are outliers on the IPCA score and would thus show their instability within the trial. The best stability would be HYSUN345, SUNSTRIPE350 and PAN7392. An indication of specific stability relating to environments is SNK 80, SNK 77 and SNK 50 that are adapted specifically to Lichtenburg. The Koster site related to ADV1003 and the PAN hybrids seemed to relate more to the Bloemfontein environment. Taking the ASV (AMMI stability value, Purchase, 1997) into consideration with the second principal in Table 4.17 component it appears that ADV1003 would also be acceptably stable. The hybrids CRN1470 and SNK80 appeared to be the most unstable and correlated in the bi-plot with IPCA1.

According to Figure 5 of the 1999 season the Potchefstroom early and Warmbaths had good conditions creating high yield potential environments. They are on the outlier areas of the Bi–plot and would thus have high instability within the environments. The Lichtenburg and Potchefstroom late environments had the best stability. The genotypes PHB6500, CRN1435, SNK50 and PHB6488 although lower in yield than the trial mean, had good stability. The better yielding hybrids were CRN 1414 and PAN 7355 with good stability, PAN 7351, PAN 7392, HYSUN333, HYSUN345 and HYSUN350 were all better adapted to certain favorable environments, while CRN 1424, AGSUN 5551, AGSUN 8751 and SNK 77 were adapted to unfavorable conditions in general, but also to specific and certain higher potential environments. Taking the AMMI stability value of the second principal component into consideration it is noticeable that PHB6488 appears very stable in the IPCA1 bi-plot, but using ASV (Table 4.18), it had the second lowest score making it very unstable. The other hybrids followed the same pattern as in the IPCA1 bi-plot graph.

The graph for the 2000 season (Figure 6) showed that hybrids AGSUN 8751 and HV3037 were the most stable with HYSUN hybrids and CRN 1414 better adapted to favorable areas relating to the Lichtenburg environment and PHB 65A02 to unfavorable conditions with SNK77, SNK74 and PAN7351 adapted to specific high potential areas relating to Warmbaths and Potchefstroom late environments. Potchefstroom early and Koster had low potentials but were stable, while Lichtenburg had a high potential but was an unstable environment.

According to the ASV table (Table 4.19) using the second principal component, HYSUN 350,that had good stability in the bi-plot lost its placing completely and AGSUN8751 became unstable as well. The hybrid PHB 65A02 correlates well with the bi-plot analysis as the least stable or rather stable in unfavorable environments.

Table 4.16 ANOVA's of the AMMI for yield for all three seasons

Source	1998			1999			2000		
	df	SS	MS	df	SS	MS	df	SS	MS
Total	377	465.397		341	94.895		323	161.754	
Env. (E)	5	403.137	80.627**	5	45.125	9.025**	5	103.927	20.785**
Reps in env.	12	9.184	0.765	12	4.968	0.414	12	4.630	0.386
Genotype (G)	20	16.667	0.833**	18	8.603	0.478**	17	2.770	0.163
G x E	100	18.249	0.182**	90	21.187	0.235**	85	25.335	0.298**
IPCA 1	24	6.982	0.291**	22	10.098	0.459**	21	9.336	0.445**
IPCA 2	22	6.300	0.286**	20	5.113	0.256**	19	6.886	0.362**
IPCA 3	20	2.502	0.125*	18	2.572	0.143**	17	4.432	0.261**
IPCA 4	18	1.741	0.097	16	1.996	0.125*	15	2.812	0.187
Residual	240	18.160	0.076	216	15.012	0.070	204	25.092	0.123

* p= 0.05 ** p= 0.01

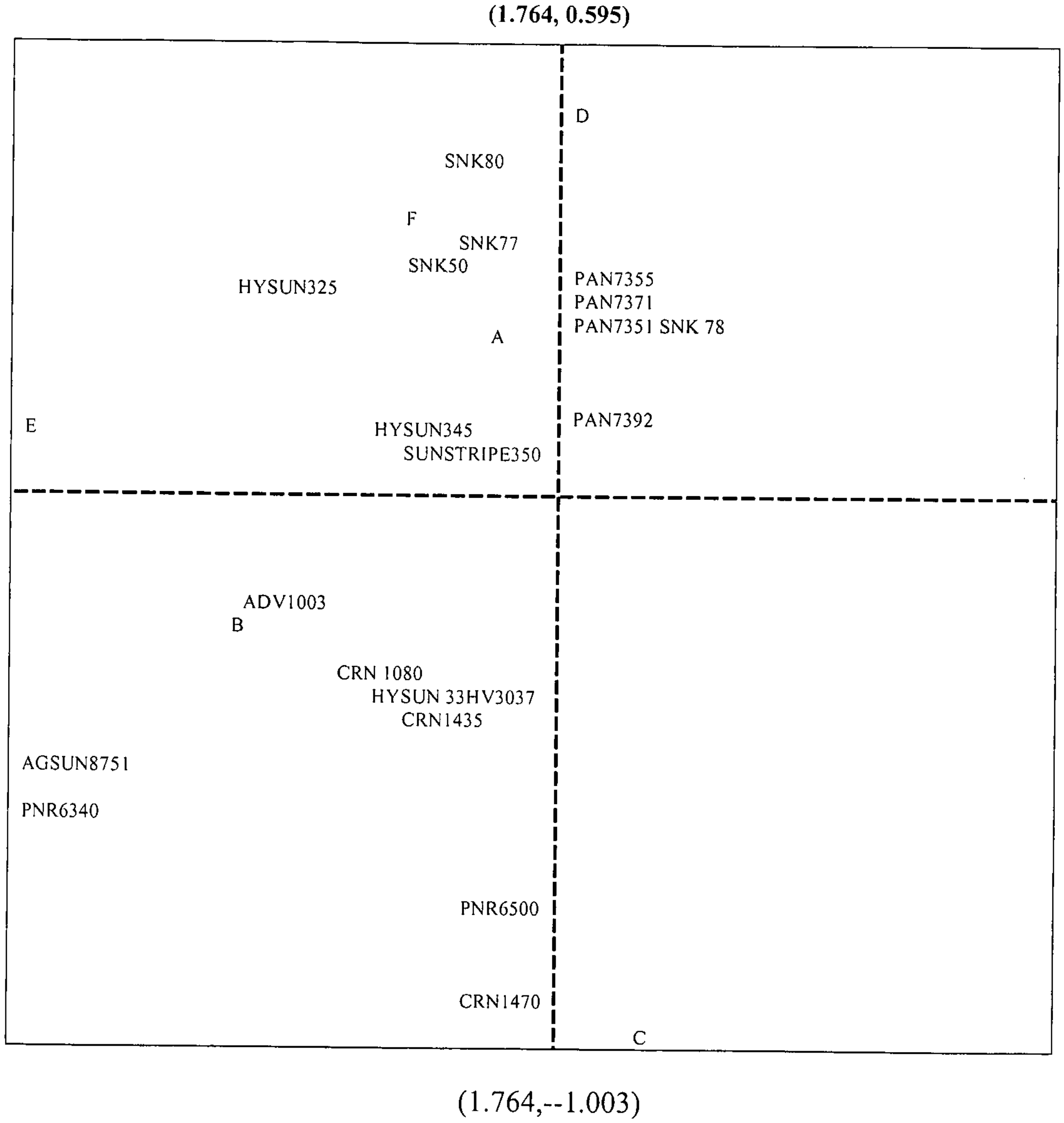

Figure 4 AMMI-1 model for the 1998 season for seed yield (kg/ha) showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1). The environments; A=Bloemfontein, B=Koster, C=Potchefstroom early, D=Potchefstroom late, E= Warmbaths and F=Lichtenburg.

Table 4.17 Mean yield rank, IPCA1, IPCA2 and ASV and it's ranking for 1999 season

Hybrid	Yield Rank	IPCA 1	IPCA 2	ASV	ASV Rank
HYSUN345	13	0.0614	-0.0260	0.0046	1
ADV1003	10	-0.0909	-0.0487	0.011	2
PAN7392	4	0.1010	0.0363	0.0120	3
SUNSTRIPE	8	0.0086	0.1331	0.0177	4
HYSUN333	16	-0.1920	0.0678	0.0434	5
SNK78	5	0.1816	-0.1052	0.0457	6
CRN1435	14	-0.2118	0.0074	0.0472	7
CRN1080	19	-0.1681	-0.1352	0.0480	8
PAN7351	2	0.1993	0.0881	0.0495	9
PAN7371	1	0.2209	-0.0456	0.0534	10
HYSUN325	20	0.2040	-0.1940	0.0814	11
HV3037	7	-0.1948	0.3363	0.1530	12
SNK50	18	0.2168	-0.3392	0.1645	13
AGSUN8751	12	-0.2718	0.3298	0.1865	14
PNR6500	11	-0.3944	-0.1940	0.2013	15
PNR6338	9	-0.2710	0.4300	0.2626	16
PAN7355	3	0.2963	0.4208	0.2694	17
SNK77	17	0.3184	0.1260	0.3604	18
SNK80	15	0.4366	0.1296	0.4794	19
PNR6340	21	0.1999	-0.6806	0.5052	20
CRN1470	6	-0.6501	-0.3365	0.5581	21

Stability of ASV = 0

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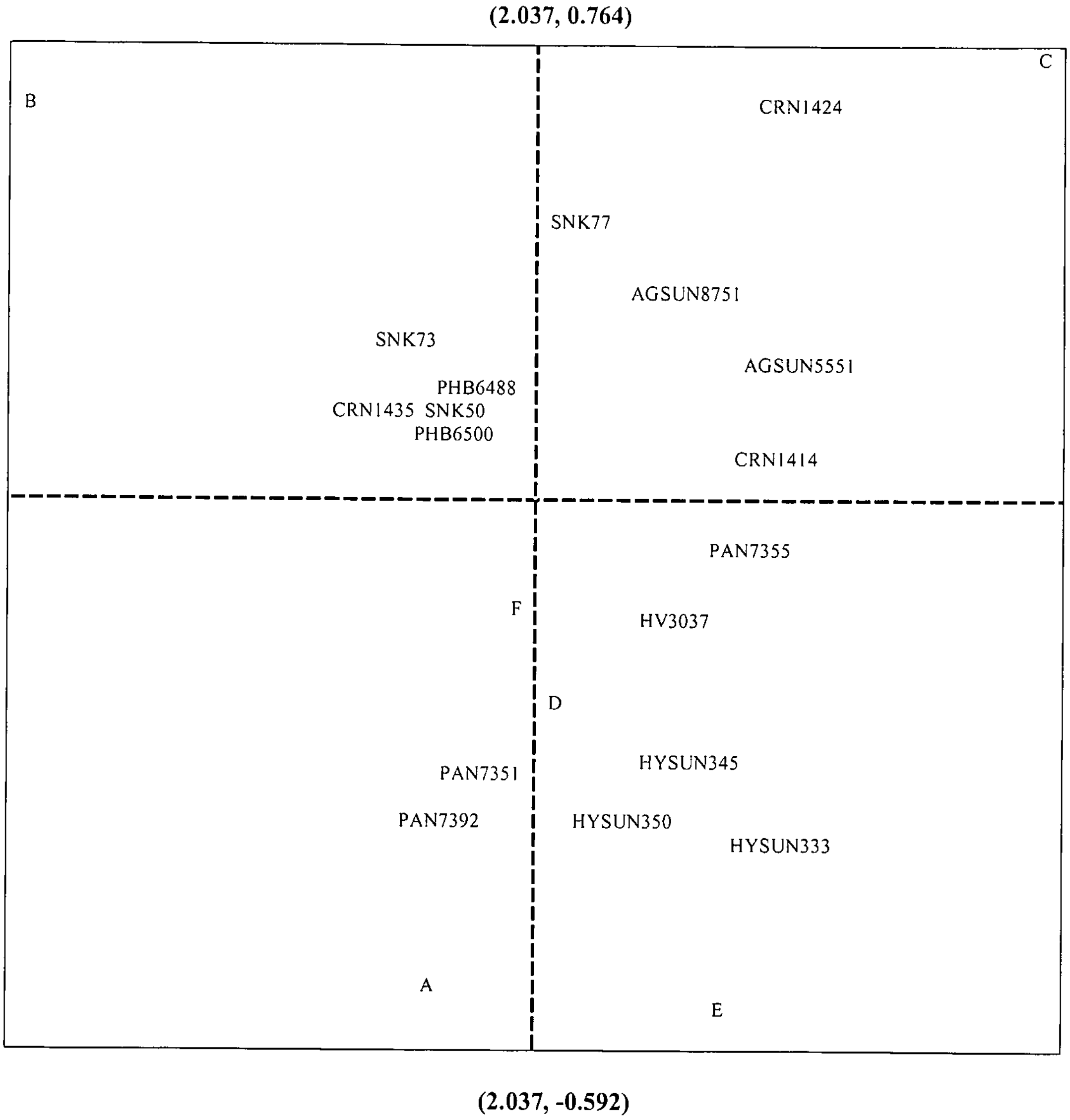

Figure 5 AMMI-1 model for seed yield (kg/ha) in 1999 showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1) The environments; A=Bloemfontein, B=Koster, C=Potchefstroom early, D=Potchefstroom late, E= Warmbaths and F=Lichtenburg.

Table 4.18 Mean yield rank, IPCA1, IPCA2 and ASV and it's ranking for 1999 season

Hybrid	Yield Rank	IPCA-1	IPCA-2	ASV	ASV Rank
CRN1414	3	0.0452	-0.0158	0.0031	1
LG5630	19	0.0350	-0.1107	0.0139	2
HV3037	7	-0.1477	0.0133	0.0308	3
CRN1435	15	0.0992	0.1328	0.0314	4
AGSUN5551	1	0.1828	-0.0605	0.0506	5
SNK73	17	0.1105	-0.1834	0.1105	6
AGSUN8751	6	0.3197	-0.0229	0.1441	7
SNK50	13	0.1031	0.3683	0.1505	8
HYSUN345	8	-0.3085	-0.1361	0.1522	9
PAN7351	12	-0.3286	-0.0470	0.1539	10
PHB6500	18	0.0617	0.4778	0.2336	11
PAN7355	5	-0.0767	-0.4796	0.2382	12
PAN7371	11	-0.3754	-0.2274	0.2497	13
PAN7392	16	-0.3745	-0.2302	0.2500	14
HYSUN333	4	-0.1477	0.0390	0.2520	15
HYSUN350	9	-0.3864	0.2886	0.2931	16
SNK77	10	0.4692	-0.2324	0.3633	17
PHB6488	14	0.0617	0.5927	0.3774	18
CRN1424	2	0.7337	-0.1667	0.7842	19

Stability of ASV = 0

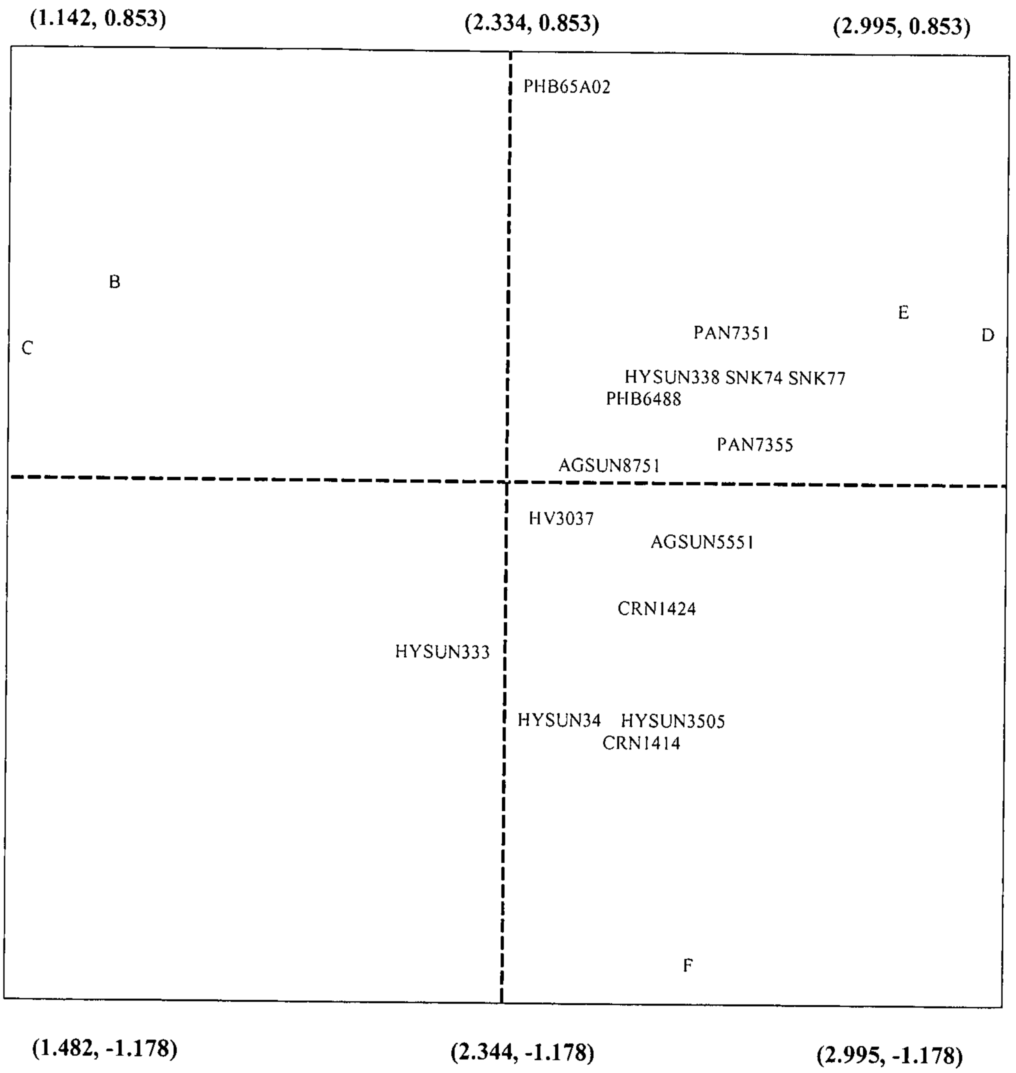

Figure 6 AMMI-1 model for seed yield (kg/ha) in 2000 showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1) The environments; A=Bloemfontein, B=Koster, C=Potchefstroom early, D=Potchefstroom late, E= Warmbaths and F=Lichtenburg.

Table 4.19 Mean yield rank, IPCA1, IPCA2 and ASV and it's ranking for 2000 season

Hybrid	Yield Rank	IPCA1	IPCA2	ASV	ASV Rank
PHB6488	6	0.0982	0.0912	0.0234	1
PAN7001	17	0.0589	0.1549	0.0294	2
AGSUN5551	8	-0.1494	0.1884	0.0704	3
SNK74	5	0.1422	-0.1993	0.0713	4
AGSUN8751	11	-0.0109	0.3225	0.1041	5
SNK79	16	0.0554	-.3285	0.1127	6
HYSUN338	4	0.1775	0.2625	0.1182	7
PAN7371	15	0.2780	-0.1347	0.1341	8
PAN7351	3	0.2626	0.2639	0.1775	9
SNK77	7	0.1740	-0.3754	0.1883	10
PAN7355	1	0.0494	-0.4380	0.1956	11
CRN1414	10	-0.4041	0.0495	0.2580	12
CRN1424	9	-0.2720	0.3986	0.2732	13
HYSUN345	14	-0.4202	-0.1077	0.2879	14
HYSUN333	18	-0.3899	-0.2907	0.3224	15
HV3037	13	-0.0585	0.5731	0.3338	16
HYSUN350	2	-0.4444	-0.3367	0.4224	17
PHB65A02	12	0.8532	-0.0917	1.1478	18

4.3.5.2 Analysis across locations and years

Where the seasons 1998 and 1999 in Figure 7 were combined in a Bi-plot only eight hybrids could be utilized over the seasons. The hybrid HV3037 and PAN 7355 had the best stability. The environments Bloemfontein and Potchefstroom late were in close proximity. SNK77 and AGSUN8751 were best adapted to unfavorable environments in general but specific to higher potential areas. The other hybrids HYSUN333 and HUSUN345 as well as PAN 7351 and PAN 7371 (in proximity of Lichtenburg Bloemfontein and Warmbaths environments) were best adapted to favorable environments although Lichtenburg and Bloemfontein had lower than mean potential. There was a strong relation between Bloemfontein and PAN 7351 and PAN 7371.

The ASV in Table 4.20 changed the ranking with HYSUN345 being the most stable and PAN7355 second best. The rest of the ranking seem similar to the bi-plot.

As displayed in Figure 8 of the AMMI bi-plot for the 1999 and 2000 seasons it is obvious that AGSUN 8751, PAN 7351, PAN 7371 and HV3037 were the most stable hybrids. PAN 7351, AGSUN 8751 and PAN 7355 were adapted to Potchefstroom early. HYSUN 345 and HYSUN 333 would be more adapted to favorable environments such as Bloemfontein and Warmbaths. SNK77 was generally stable for unfavorable conditions or specific high potential conditions. The environments Koster, Bloemfontein 1999 and Warmbaths were in the low yield range with instability.

In Figure 9 for the 1998 and 2000 seasons the AMMI 1 model showed the hybrids Sunstripe, HYSUN 345 and PAN 7392 to be the most stable with PAN 7392 with the better yield. The hybrids ADV 1003, CRN 1080, HYSUN 333, HV3037 and CRN 1435 had good specific adaptability to the Koster site. For the Bloemfontein site the hybrids most suitable were PAN 7355, PAN 7371, PAN 7351 and SNK 78 and SNK 80, SNK 77 and SNK 50 were most suitable for Lichtenburg. The least stable hybrids were SNK 80 and CRN 1470.

Figure 10 combines the AMMI analysis for the three seasons. Accordingly the hybrids with the best stability were PAN 7351 and PAN 7371 as well as AGSUN 8751. The hybrid HV 3037 would also be considered stable in the high potential quadrant. Koster remained at the same quadrant for all three seasons, giving lower potential with good stability but having more unfavorable conditions. Potchefstroom late had good potential and stability. Other environments experienced good potential for single seasons and no pattern of stability was seen. The hybrids SNK 77 and PAN 7355 had the best general stability for unfavorable conditions. The HYSUN hybrids 333 and 345 had specific stability in favorable environments and were well adapted to the Bloemfontein site during 1999.

Taking the second principal component into account in Table 4.22 using the average stability value or ASV, AGSUN 8751 and HV 3037 showed better stability in comparison to the IPCA1 value. PAN 7355 and PAN 7351 was the most stable using the IPCA1, but lost stability when the ASV was applied. HYSUN 333 and SNK 77 had poor values using both IPCA1 and ASV.

Table 4.20 Mean yield rank; IPCA1, IPCA2 and ASV and it's rank for 1998 and 1999 seasons

Hybrid	Rank	IPCA1	IPCA2	ASV	Rank
HYSUN345	7	-0.2537	-0.1970	0.1298	1
PAN7355	1	0.1216	0.4176	0.1953	2
HV3037	4	-0.0244	-0.2171	0.2841	3
PAN7351	2	-0.4093	0.3356	0.3497	4
PAN7371	3	-0.4435	0.3781	0.4212	5
HYSUN333	8	-0.3074	-0.6576	0.5561	6
AGSUN8751	5	0.5931	-0.3086	0.5927	7
SNK77	6	0.7236	0.2487	0.8026	8

Table 4.21 Mean yield rank, IPCA1, IPCA2 and ASV and it's rank for the 1998 and 2000 seasons

Hybrid	Rank	IPCA1	IPCA2	ASV	Rank
AGSUN8751	5	0.1292	0.1028	0.0295	1
HV3037	4	-0.2111	-0.2223	0.1000	2
PAN7355	1	0.3971	0.0161	0.1792	3
PAN7371	3	-0.1313	-0.4358	0.2094	4
HYSUN345	7	-0.4675	0.3144	0.3469	5
PAN7351	2	0.0087	-0.7489	0.5595	6
HYSUN333	8	-0.6007	0.5574	0.7203	7
SNK77	6	0.8757	0.4163	1.0439	8

Table 4.22 Mean yield rank, IPCA1, IPCA2 and ASV and it's ranking for 1998, 1999 and 2000

Hybrid	Rank	IPCA1	IPCA2	ASV	Rank
PAN7371	3	0.1522	0.1399	0.0462	1
PAN7355	1	0.4692	0.1163	0.2669	2
AGSUN8751	5	-0.5064	0.0882	0.3028	3
PAN7351	2	-0.1719	0.4923	0.3028	4
HYSUN345	7	-0.0162	-0.5955	0.3549	5
HYSUN333	8	0.0426	-0.6670	0.4469	6
HV3037	4	-0.6268	0.1617	0.4782	7
SNK77	6	0.6574	0.2640	0.5669	8

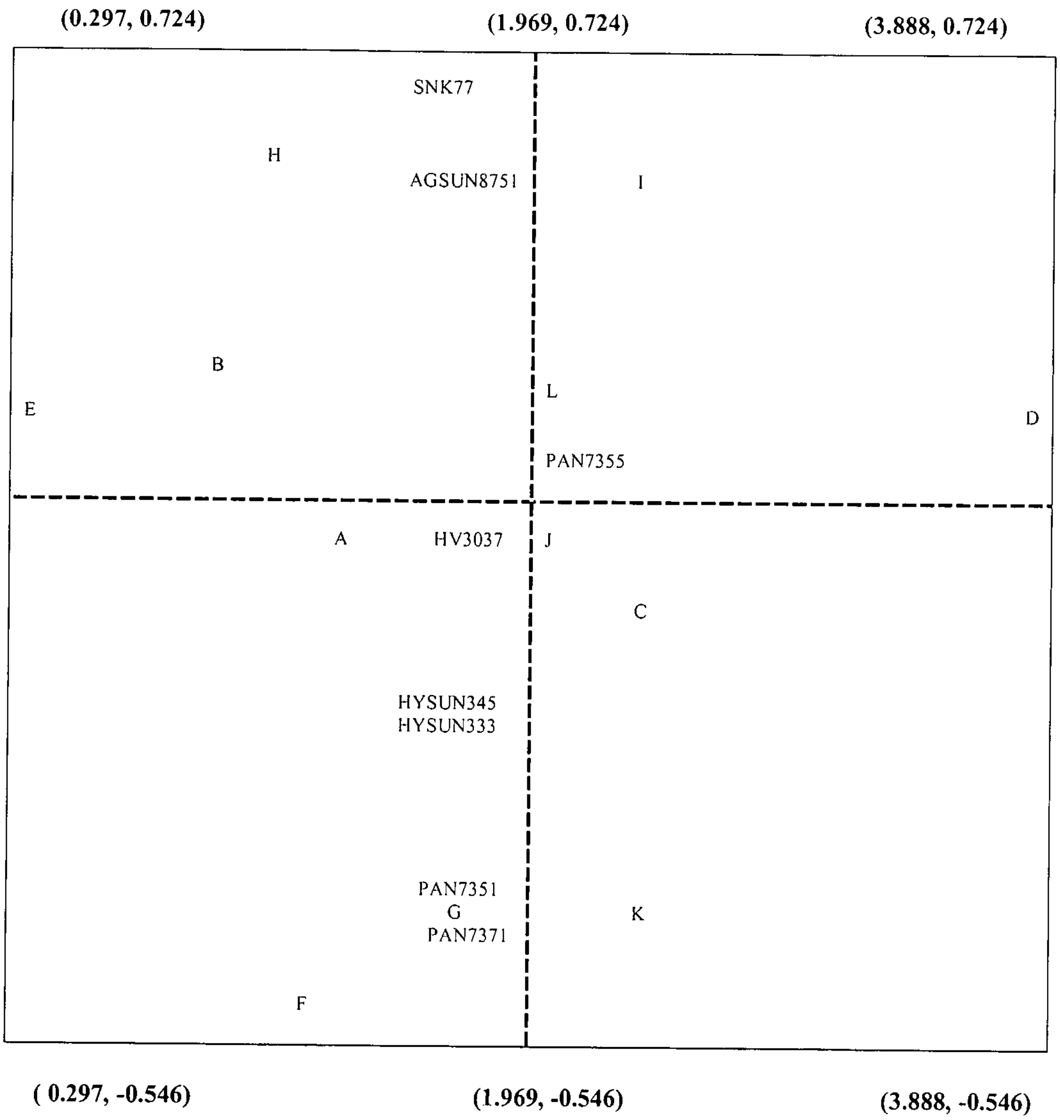

Figure 7 AMMI-1 model for seed yield (kg/ha) in the combined seasons 1998 and 1999 showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1) The environments; A and G =Bloemfontein, B and H =Koster, C and I =Potchefstroom early, D and J =Potchefstroom late, E and K = Warmbaths and F and L=Lichtenburg.

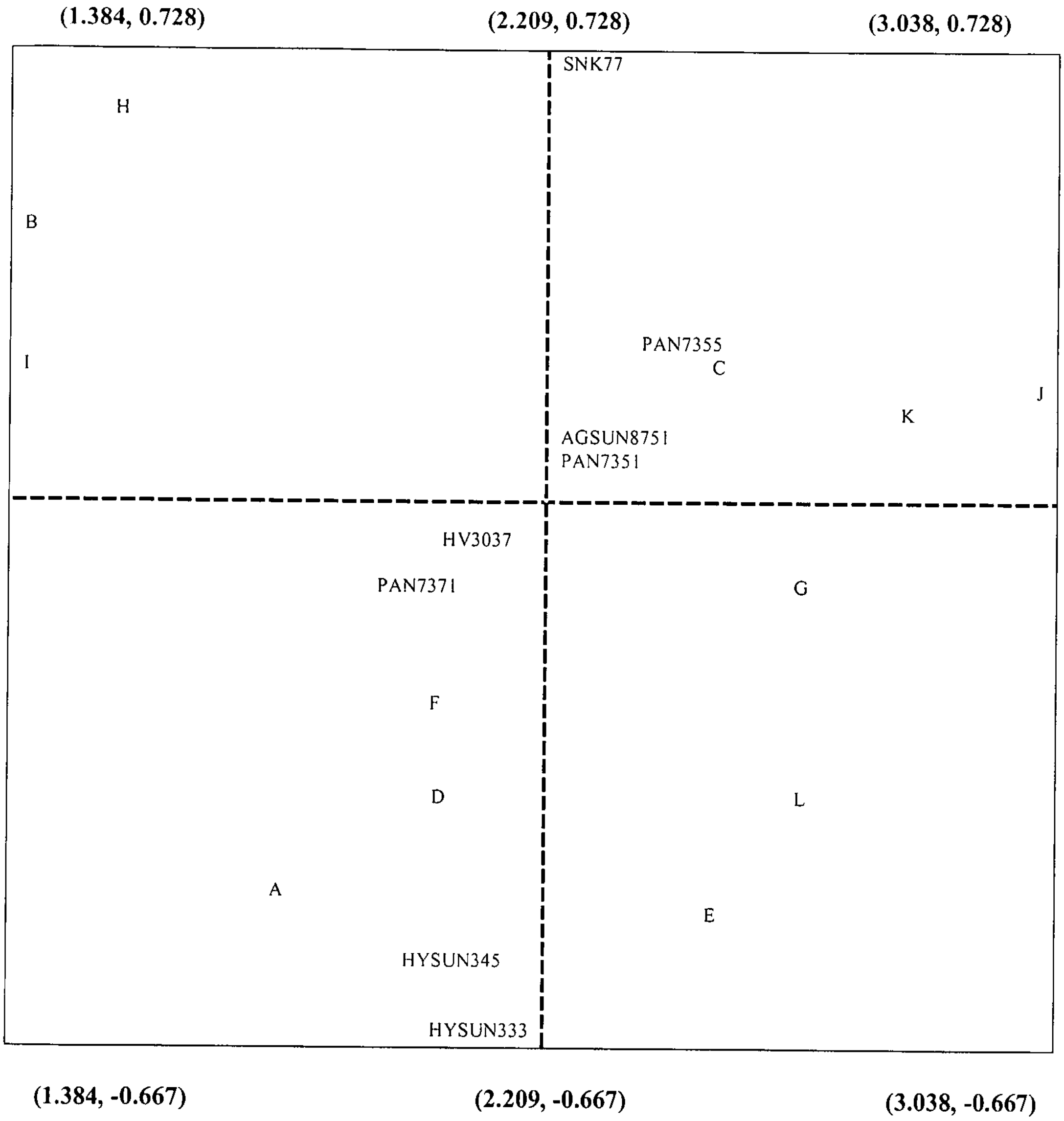

Figure 8 AMMI-1 model for seed yield (kg/ha) for 1999 and 2000 seasons showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1) The environments; A and G =Bloemfontein, B and H =Koster, C and I =Potchefstroom early, D and J =Potchefstroom late, E and K = Warmbaths and F and L=Lichtenburg.

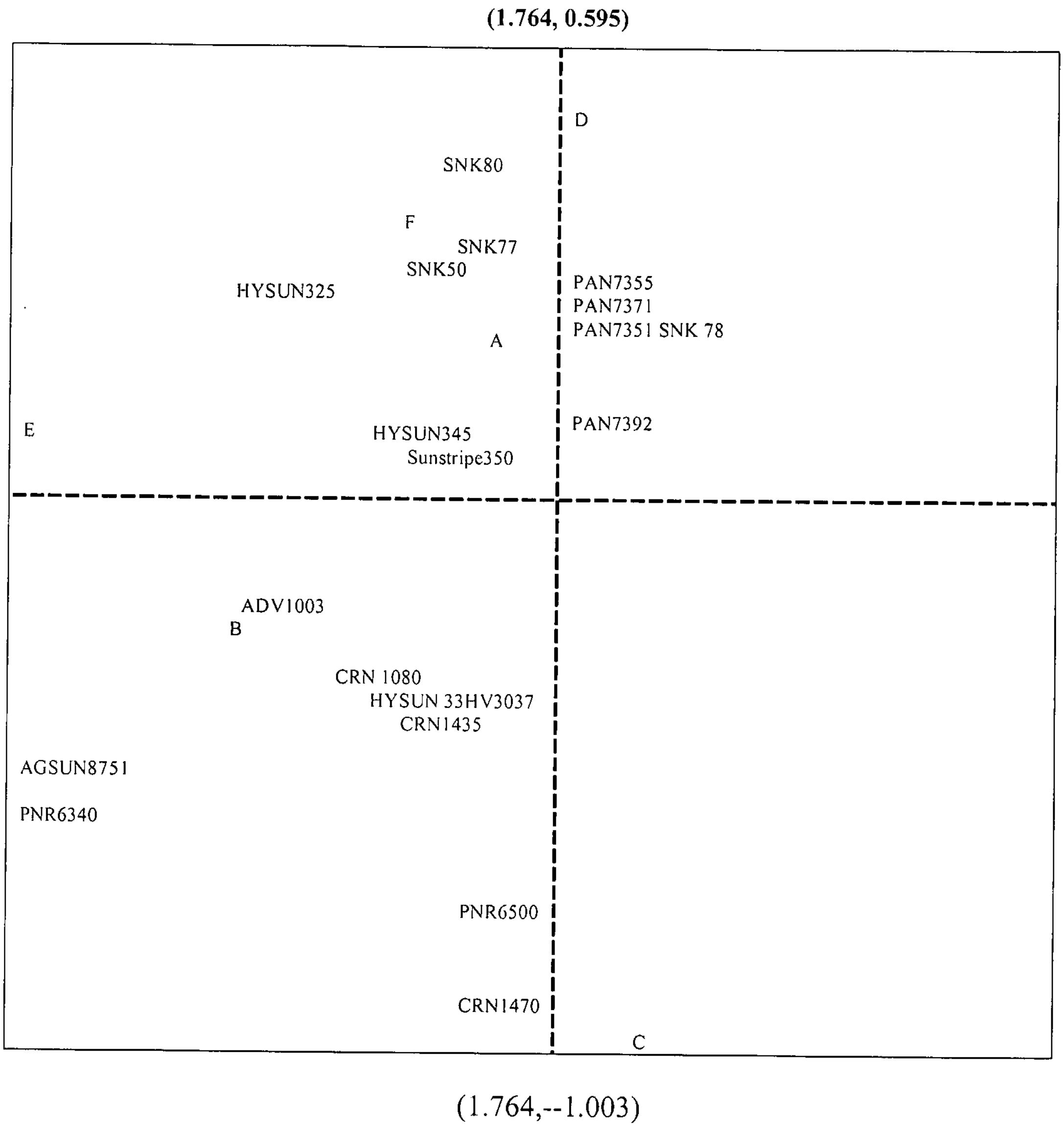

Figure 9 AMMI-1 model for seed yield (kg/ha) for 1998 and 2000 seasons showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1) The environments; A and G =Bloemfontein, B and H =Koster, C and I =Potchefstroom early, D and J =Potchefstroom late, E and K = Warmbaths and F and L=Lichtenburg.

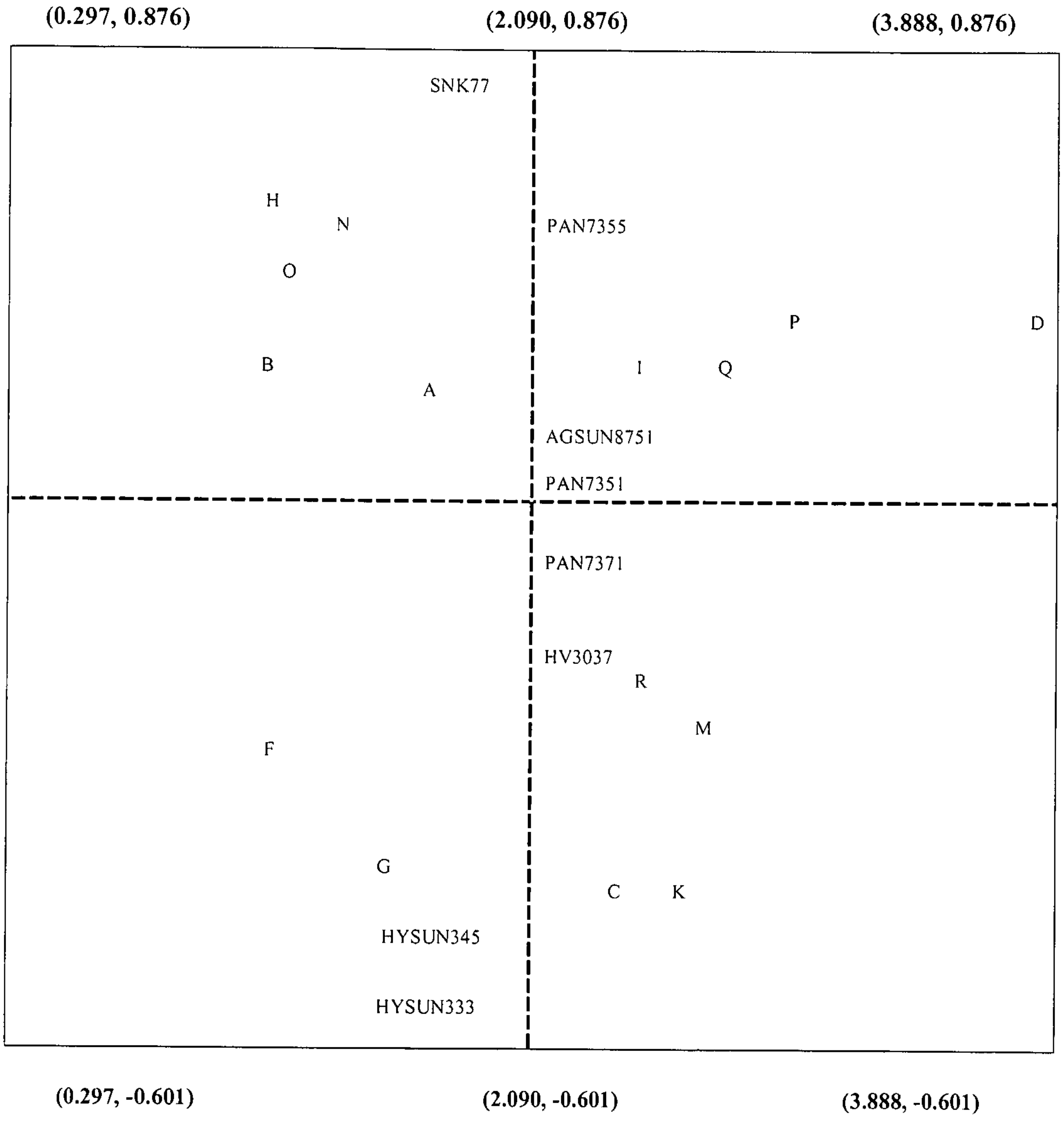

Figure 10 AMMI-1 model for sunflower yield (kg/ha) for 1998, 1999 and 2000 seasons showing means of genotypes and environments plotted against their respective scores of the first interaction principal component (IPCA-1). The environments; A, G and M =Bloemfontein, B, H and N =Koster, C, O and I =Potchefstroom early, D, J and P =Potchefstroom late, E, K and Q = Warmbaths and F, L and R =Lichtenburg.

4.4 Comparison of stability analysis

According to Freeman (1972) one of the main reasons for growing genotypes in a wide range of environments is to estimate their stability. The use of two stability parameters may be valuable for some purposes. Table 4.23 where PAN 7355 is the most stable on average, but had a poor rating when using the regression coefficient of Finlay and Wilkinson (1963) proves this observation. Lin et al. (1986) defined four groups of stability statistics. Group A is based on deviation from the average genotype effect (DG), group B on G x E interaction term (GEI) and groups C and D on either DG or GEI. Furthermore, formulae of groups A and B represent sums of squares and those of groups C and D represent regression coefficients or deviation mean squares from regression. Statistics within a group are either the same or rank equivalently and the rank correlations among the statistics within a group are expected to be high, while statistics of different groups would likely to be uncorrelated. The Eberhart and Russell (1966) and Shukla (1972) regression models are structurally similar (Lin et al., 1986).

The resulting ANOVA'S for the individual seasons show heterogeneity in 1998 and 1999 that could result in incorrect deductions when taking only one season's statistics into consideration. This instability is also shown in Table 4.2 for ranking of yield for 1998. PNR 6338, with days to 50% flowering of 65 gives an indication of an early hybrid that has a positive reaction to moisture stress conditions. Although PNR 6338 is a weak hybrid, it yielded second best at Warmbad in 1998. The total rainfall for the growing period at the Warmbad site for the 1998 season was 131 mm (Table 3.2). Epinat-Le Signor et al. (2001) reported a similar reaction on early maturity corn. A possible reason for this is the smaller leaf size of earlier maturity plants that have a limiting effect on the evapotranspiration and is therefore favorable for a restricted water supply.

When the combined analysis of 1998 and 1999 was done over locations and years the stability analysis of Eberhart and Russell (1966) of regression differed substantially from the deviation from the regression, but was similar to the cultivar superiority measurements. Reports by Purchase (1997), Adugna et al. (2003) indicated that most of the stability analyses were closely related in sorting out relative stability, but cultivar superiority measure showed some deviations. Although Wescott (1987) indicated that hybrids with a regression coefficient (b_i) less than 1.0 usually have mean yields below the grand mean, the same deduction could not be made in Table 4.23 for all the hybrids. PAN 7351 had the best value of 0.9982 with a yield rank above the mean. The other stability analysis of ecovalence and Shukla's no covariate and environment as covariate differed little in ranking. Similar deductions could be made in the years 1999/00, 1998/00 and 1998/99/00.

The parameter of Shukla's (1972) stability variance (σ^2_i) and Eberhardt and Russell's (1966) deviation parameter (s^2d_i) ranked similar with Wricke's (1962) ecovalence (w_i) with most of the hybrids being similar. The above-mentioned parameters ranked PAN 7355 as the most stable. This was also the hybrid with the highest yield and the parameter of Lin and Binns (1988) cultivar superiority (Pi) ranked it first. Using ASV it was placed third. Shukla's method of using environment as a covariate (s_i^2) did not correlate exactly with the other stability analyses, although similarity does exist with deviation from regression (S^2d_i) and stability variance (σ^2_i).

The second best hybrid was PAN 7371 ranking first with Shukla's (1972) stability variance and with that of Eberhardt and Russell. It ranked fourth with Wricke's ecovalence and Lin and Binns cultivar superiority with a fifth rank in ASV. The mean yield was 0.21 t/ha less than PAN 7355. All the other hybrids analyzed were within 0.06 t/ha difference from each other. In a study performed by Pham and Kang (1998) they confirmed the statements made by Lin, et al. (1986) of correlations with the statistics of deviation from regression (S^2d_i), stability variance (σ^2_i) and environment as a covariate (s_i^2).

The AMMI analysis proved the effectiveness of the other stability analyses but showed PAN 7351 and PAN 7371 to be more stable with good yield. The hybrid PAN 7355 had good yield, but the AMMI showed its stability in unfavorable conditions. The hybrid might therefore never ensure yields of three tons that could be harvested in favorable conditions.

Spearman's coefficient of rank correlation was then determined for stability variance- no covariate, stability variance with environment as covariate, ecovalence, AMMI as well as deviation from the regression. The stability variance with environment as a covariante showed significant positive rank correlation with stability variance with no covariance as well as with Wi. There is a non-significant correlation with AMMI and $S^2d_{i.}$ There is also a significant correlation with stability variance with no covariate and Wricke's ecovalence.

Table 4.23 Ranks of all stability parameters for sunflower hybrids 1998, 1999 and 2000

Hybrid	Yield	R	CV	R	σ^2_i	R	s_i^2	R	b_i	R	S^2d_i	R	Wi	R	Pi	R	Mean	ASV	R	Mean
PAN7355	2.24	1	41	5	0.1558	2	0.2035	5	1.0795	7	0.0137	2	0.8055	2	0.0453	1	1	0.1792	3	1
PAN7351	2.03	2	40	3	0.1906	5	0.2211	6	**0.9982**	1	0.0273	5	0.9534	5	0.0793	2	3	0.5595	6	3
SNK77	2.09	3	39	1	0.1780	4	0.1735	3	0.9692	8	0.0233	4	1.6167	8	0.1313	6	4	0.2094	4	8
AGSUN8751	2.09	4	45	8	0.1632	3	0.1875	4	0.9828	6	0.0198	3	1.0391	6	0.1122	5	5	0.1000	2	4
HYSUN345	2.08	5	42	6	0.2108	6	0.3405	8	1.0374	4	0.0317	6	0.7013	1	0.1339	7	7	0.0295	1	5
HV3037	2.09	6	40	4	0.3467	8	0.2570	7	0.8981	3	0.0616	8	0.8367	3	0.1066	3	6	1.0439	8	6
PAN7371	2.03	7	40	2	0.1313	1	0.1490	2	1.0303	5	0.0110	1	0.8995	4	0.1112	4	2	0.3469	5	2
HYSUN333	2.03	8	43	7	0.2410	7	0.1380	1	**1.0045**	2	0.0407	7	1.1674	7	0.1489	8	8	0.7203	7	7

R=Ranks; CV=Coefficient of variability; σ^2_i = Shukla's (1972) stability variance; s_i^2 = Shukla's environment as covariate b_i=Finlay and Wilkenson ((1963) regression coefficient; S^2d_i= Eberhardt and Russel (1966) deviation parameter ;Wi = Wricke's ecovalence; P_i= Lin and Binn's (1988) cultivar superiority performance; ASV=AMMI Stability value

Table 4.24 Spearman's ranking order correlation coefficient matrix for five G x E stability analysis procedures on eight sunflower hybrids evaluated over 18 sites.

	σ^2_i	s_i^2	Wi	AMMI
σ^2_i				
s_i^2	0.9345**			
Wi	0.9999**	0.9338**		
AMMI	0.1736	0.1787	0.1710	
S^2d_i	-1.1721	-0.1603	-0.1720	-0.1582

σ^2_i= Shukla's stability variance, s_i^2 = Shukla's environment as a covariate, Wi= Wricke's ecovalence, AMMI= Additive main effects and multiplicative interaction , S^2d_i = deviation from the regression

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

Data from multilocation trials help researchers estimate yields more accurately, select better production alternatives, and understand the interaction of yield with environments. In breeding programs it is of interest to decide whether observed stability differences are due to chance or statistically significant. Significance testing is strongly advisable to determine the quality of stability estimates (Piepho and Lotito, 1992).

Several methods have been presented for efficient statistical analysis of such data. For geneticists, plant breeders, and agronomists, parametric stability statistics, obtained by linear regression analysis, are mathematically simple and biologically interpretable. According to Crossa (1990), this method has major disadvantages: (a) it is uninformative when linearity fails; (b) it is highly dependent on the set of genotypes and environments included in the analysis; and (c) it tends to oversimplify the different response patterns by explaining the interaction variation in one dimension (regression coefficient), when in reality it may be highly complex.

A broad range of multivariate methods can be used to analyze multilocation yield trial data to asses yield stability. Although some of them overcome the limitations of linear regression, the results are often difficult to interpret in relation to genotype X environment interaction. The integration of certain ordination methods into "pattern" analysis and the bi-plot method are valuable tools for grouping environments or genotypes showing similar response patterns.

The combination of analysis of variance and principal component analysis in the AMMI model, along with the prediction assessment, is a valuable approach for understanding genotype x environment interaction and obtaining better yield estimates. Agronomic predictive assessment with AMMI can be used to analyze the results of trials.

The use of stability analysis other than the ANOVA and yield ranking would enhance prediction of cultivar choice. The ecovalence and Shukla's analysis would give an independent analysis of stability, and reacts in contrast to rank on yield, cultivar superiority and deviation from the regression. Thus, hybrids with good yield and high ratings in ecovalence would prove to be more stable since all stability parameters would then be satisfied. The result of the abovementioned stability analysis in combination with AMMI analysis would further add stability in the choice of the best hybrid. Not only would the most stable hybrid be chosen but the AMMI also adds the advantage of grouping hybrids with a location where they have good specific adaptability. Adaptation to unsuitable conditions would also be shown. Thus the AMMI model proved to be a useful tool in diagnosing the G x E interaction patterns and improving the accuracy of the response estimates in these trials. It provided more precise estimates of the true yield potential of both cultivars and specific environments where individual tests were evaluated. Increased accuracy in selection could help researchers identify specific cultivars with competitive yields across diverse environments.

Of the environments used, the Potchefstroom late site had the best yield potential and a good stability. Since only a few hybrids could be analyzed, the patterns formed by the G x E interaction is wide. It was noticeable that the seasons of 1998 and 2000 did not have any hybrids associated with this site. A possibility does exist that more hybrids would have had a better pattern and hybrids associated with it.

HV 3037 had the best association with the Bloemfontein and Lichtenburg site and was thus the best hybrid for the 2000 season. Unfortunately the 1998 and 1999 seasons were most unstable for Bloemfontein. On average, this is a very unstable site.

The Lichtenburg site had a reasonable stable 1998 and 2000 season and a very stable 1999 season with PAN 7351 and PAN 7371 associated with it, thus it would be an acceptable site. The Koster site had similar stability over the three seasons but had no hybrids associated with that site.

Potchefstroom early had good stability for 1999 and 2000 but was unstable in 1998. The possibility of the supplement irrigation adding to instability is a factor worth considering. Little rain fell on the site before and during the first month of planting.

The Warmbad site has been known for very unstable climate patterns. It does represent an area where sunflower is planted as an alternative to cotton. The 1998 season had good stability, but this was due to exceptionally low moisture, 131 mm of rain, and therefore very small differences in yield. The 1999 season had poor stability; 905 mm of rain and the 2000 season had good stability with 417 mm of rain during the growing season. This site would therefore not be recommended for data analysis.

To make any more deductions from the AMMI analysis, more environments as well as more hybrids are needed.

In this study it was obvious that the AMMI analysis does give the best performance as a stability analysis tool. Using the AMMI analysis it is also obvious that the Warmbad and Bloemfontein sites are not worth planting with their history of instability. This would mean that the ARC would have to plan the plantings with this in mind. Sites in high potential areas like Koster give more uniform stability.

The hybrids with low stability or associated with one or two sites would have a disadvantage of not adapting to other sites. It is therefore important for farmers to select hybrids of good general stability that would also not only adapt, but also be productive in unstable environments.

CHAPTER 6

SUMMARY

- Sunflower (*Helianthus annuus)* is the most important oilseed crop in South Africa with a current demand of around 600 000 ton of seed per year. The average national yield is from 1 to 1.3 t/ha. Because sunflower is planted in the marginal maize areas, the climate and interaction varies considerably. It is this variation that present selection problems for breeders and scientists. The aim of this study was to evaluate and recommend methods of stability analyses better than the normal yield ranking and ANOVA that is mostly the tools used in selection.

- For this study the trials performed by the Agricultural Research Council and its cooperators were used. Entries in the trials are commercial hybrids or registered hybrids and the results would be used to ensure quality hybrids entering the market and recommending hybrids based on yield stability and oil content.

- The literature review highlighted all the studies performed recently on different traits of sunflowers. Although G x E interaction has been used in India to prove the suitability of some hybrids, no comparative studies of the stability analysis could be found that would assist a breeder or scientist.

- Since the rate of success of these trials was not consistent from season to season, some locations could not be used. The hybrids were not all evaluated in successive years. Since only four entries are allowed per company in one year, the hybrids are usually rotated. Thus only six locations were used in the analysis and for the across year analysis eight hybrids were common.

- Using the stability analysis of Eberhardt and Russell, Wricke's ecovalence, Shukla and Lin and Binns superiority measure, the most stable hybrids were PAN 7351 for the 1998 /99 seasons, HV3037 for the 1999 / 00 seasons, PAN 7351 for 1998/00 and PAN7355 for 1998/99/00.

- According to the AMMI analysis the hybrids PAN 7355 and HV3037 were most stable for the 1998/99 seasons, PAN 7351, HV3037, PAN 7371 and AGSUN8751 were most stable for the 1999/00 seasons, SUNSTRIPE350, HYSUN 345 and PAN 7392 for 1998/00 seasons and PAN 7351, PAN 7371 and AGSUN 8751 for the combined 1998/99/00 seasons. The implementation of ASV does have an influence on the use of the AMMI analysis. The ASV showed AGSUN 8751 to be more stable than PAN 7355.

- Combining all the analysis measures to make a selection, PAN 7355 and PAN 7371 were the most stable. Using the advantage of the information provided by the AMMI analysis of hybrids and their adaptation to certain locations, a high yielding stable hybrid could be selected.

OPSOMMING

- Sonneblomme (*Helianthus annuus*), met 'n aanvraag van omtrent 600 000 ton saad per jaar, is die belangrikste oliesaad gewas in Suid Afrika. Huidiglik is die nasionale gemiddelde opbrengs tussen 1 en 1.3 t/ha en 'n bydraende faktor is die onvoorspelbare klimaat en die variasie van interaksie wat 'n kenmerk is van die marginale areas waar sonneblom geproduseer word. Dit is hierdie interaksie wat probleme met seleksie vir telers en wetenskaplikes veroorsaak. Die doelwit van die studie was om stabiliteits analises te evalueer en aan te beveel wat gebruik kan word bo en behalwe die huidige opbrengs en ANOVA wat gebruik word.

- Die proewe wat deur die Landbou Navorsings Raad en die medewerkers geplant word, is gebruik. Die inskrywings in die proewe is almal kommersiële basters of reeds geregistreer en die data van die proewe word gewoonlik gebruik om nuwe basters wat die mark betree se kwaliteit te verseker gebaseer op die opbrengs en olie opbrengs.

- In die literatuur oorsig word al die studies wat onlangs gedoen is op die veskillende kenmerke van sonneblomme uitgelig. Alhoewel die G x E interaksie gebruik is in Indië om basters se aanpasbaarheid te bewys, is daar geen vergelykbare studies gedoen om telers of wetenskaplikes te help nie.

- Omdat die sukses syfer nie konsekwent was tussen seisoene nie , kon sommige lokaliteite nie gebruik word nie. Al die basters het ook nie oor al die jare voorgekom nie. Die rede hiervoor is dat slegs vier inskrywings toegelaat word per maatskappy in 'n jaar wat aanleiding gee tot baster rotasie. Daar is dus net na ses lokaliteite gekyk en vir meerjarige analise is net agt basters gebruik.

- Deur gebruik te maak van Eberhardt and Russell se regressie analise, Wricke se ekovalensie en Shukla en Linn en Binn se superioriteits meting, was die mees stabiele basters PAN 7351 gedurende die 1998/99 seisoene, HV3037 gedurende

die 1999/00 seisoene, PAN 7351 gedurende 1998/00 en PAN7355 gedurende 1998/99/00.

- Na aanleiding van die AMMI analise was PAN 7355 en HV3037 die mees stabiele basters vir die 1998/99 seisoen, PAN 7351, HV3037, PAN 7371 en AGSUN8751 was meer stabiel vir die 1999/00 seisoene, Sunstripe, Hysun 345 en PAN 7392 vir die 1998/00 seisoene en PAN 7351, PAN 7371 en AGSUN 8751 vir die gekombineerde 1998/99/00 seisoene. Deur die ASV te gebruik is gevind dat dit wel 'n invloed het op die AMMI analise. Die ASV het AGSUN 8751 as 'n meer stabiele baster getoon as PAN 7355.

- Na aanleiding van 'n kombinasie van al die stabiliteits analises om 'n seleksie te maak, is bevind dat PAN 7355 en PAN 7351 die mees stabiele basters was. Deur van die AMMI analise se voordeel rondom inligting betreffende basters en hul aanpasbaarheid by sekere lokaliteite wat verskaf word, gebruik te maak, kan basters met hoë opbrengs en stabiliteit geselekteer word.

CHAPTER 7

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