

MAIZE VARIETY PERFORMANCE UNDER DIFFERENT MANAGEMENT  
AND ENVIRONMENTAL CONDITIONS

BY

AGNES R. KASARO NGOLWE

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APPROVAL PAGE

This dissertation of Agnes R. Kasaro Ngolwe is approved as fulfilling part of the requirements for the award of the Master of Science in Agronomy by the University of Zambia.

Examiners signature.

Date




16-04-92

Dr. D. Ristanovic.



13/4/92

Dr. D. Mbeve.



10/4/92

Dr. D. Lungu (Supervisor).

## ABSTRACT

The purpose of the study was to compare the performance and relative stability of grain yield among four different maize (*Zea mays* L.) types and also to investigate some agronomic traits and their relationship to overall yield stability. The four types of maize were compared in twelve environments, (3 locations x 4 management levels). Each type, i.e. single cross, double cross, three-way cross and open pollinated, was represented by three entries. A split plot experimental design with three replications was used, the four management levels were the main plots and cultivars as subplots. The parameters measured were grain yield, plant height, shelling percentage and 100 kernel weight. The results showed that hybrids gave an overall higher yield performance compared to open pollinated varieties. Mean yields ranged from 145 kg/ha for MM 752 at Golden valley to 7482 kg/ha for MM 612 at Mansa. Among the hybrids, there were no significant grain yield differences between double crosses and three-way crosses, but there were significant differences  $P \leq 0.05$  between single crosses and double crosses and between single crosses and three-way crosses. In a step wise multiple regression, plant height and shelling percentage had the most contribution to the variation observed in grain yield. The linear regression coefficient (b-value), the deviation from regression ( $Sd^2$ ) and the mean yield were used as stability parameters. All the hybrids

had high linear response compared to the open pollinated varieties but among the hybrids, double cross hybrids were the most stable. They had high average yield, a regression coefficient closer to 1.0 and a low deviation mean square. The highest linear response was obtained by the single cross hybrid MM 601 while MMV 600, an open pollinated variety had the lowest linear response. Double cross variety MME 404 possessed the most desirable combination of stability characteristics. The commercial hybrids MM 601, MM 612, MM 603 which are widely grown in Zambia, exhibited good stability of performance. However, the open pollinated varieties showed low genetic potential for yield. The stability analyses for shelling percentage and 100 kernel weight explained some of the observed differences in yield stability.

DEDICATION

To my late father Lanjesi Kasaro who inspired my enthusiasm for higher education.

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## INTRODUCTION

Maize is a major crop in Zambia. It is the prime source of both food for people and livestock feed in Zambia. At present approximately 1,000,000 hectares of cultivated land are planted to maize giving a maize grain output of 1,300,000 tons annually (McPhillips, 1987). The main maize producing areas of the country have a combination of both climate and soils that are capable of giving yields in excess of 10 tons per hectare. However, on a national average basis, yields are quite low, they average about 1.8 tons per hectare. One of the major factors which contributes to these low yields is the low level of fertilizers applied.

This gap between actual yields and potential yields is of great concern to both agronomists and plant breeders. Agronomists are constantly improving production practices in order to narrow the gap. Any improvement of the agronomic practices such as timely planting, application of adequate amounts of fertilizers, proper crop protection and planting of improved cultivars would definitely narrow this gap. Plant breeders on the other hand are attempting to develop high yielding maize cultivars with stable performance across an array of environments.

The ability of some crop cultivars to perform well over a wide range of environmental conditions has long been appreciated in crop improvement. Development of maize cultivars with a good yield potential and yield stability is important as the crop is grown under varying environmental and management conditions. The wide variation in climatic conditions from season to season, region to region and varying soil fertility levels, mean that no two growing conditions are similar. As a result farmers need varieties (hybrids or open pollinated) that can perform predictably well over a wide range of environmental conditions.

At present, open pollinated varieties of maize are recommended for production by small scale farmers. This recommendation is based on the premise that open pollinated varieties are more stable in performance compared to hybrids under poor management and low input conditions of the small scale farmer. Open pollinated maize varieties are said to derive their stability from the high level of genetic variability that they possess. Hybrids, i.e. single crosses, double crosses, and three-way crosses are currently recommended for production by large scale commercial farmers under high input conditions. The only hybrids that can be recommended for small scale farmers are those with a high level of heterogeneity.

In this case, three-way cross, double cross and variety cross hybrids rather than single-crosses would be recommended for use by the small scale farmers.

The foregoing discussion on the expected comparative stability of open pollinated varieties or hybrids with a high level of heterogeneity such as three-way, double and variety crosses compared to single cross hybrids should not presuppose that single cross hybrids cannot show the same characteristics of stability. Heterosis or hybrid vigour expressed maximally in the F1 of a single cross can be manifested in many other ways. In certain F1 hybrids such as in field beans for example, the number of nodes, leaves and pods is greater than in the parents but the gross size of the plant is not greater. In other hybrids the growth rate is increased but is not accompanied by larger size at maturity. Another manifestation of heterosis is earlier maturity in the F1 than in either parent and sometimes even accompanied by an actual decrease in total plant weight. Other heterotic effects include instances where hybrid organisms have been reported to have greater resistance to diseases and insects, increased tolerance to rigors of climate and various other manifestations of better fitness (Allard, 1960). Blum (1979) supported this observation when he stated that some hybrids will yield relatively well under sub optimal growing

conditions compared to open pollinated varieties because heterosis can be expressed as good adaptation. There is therefore a need to assess the comparative yield stability of various single cross, double cross, three-way cross and open pollinated varieties of maize under varying management conditions in Zambia in order to arrive at an appropriate variety that will combine both high yield and stability instead of simply following the blanket recommendation that small scale farmers plant only open pollinated varieties. It could well be that the country is losing millions of bags of maize through recommending open pollinated varieties for small scale farmers who produce the bulk of the maize crop, when they could have been growing single cross hybrids which have a high yield potential. The basis for recommending single cross hybrids to small scale farmers would be the ability of the hybrid to give a relatively better yield than open pollinated varieties even under sub optimum production conditions.

As mentioned above, Blum (1979) stated that some hybrids will give quite good yields even under sub optimal growing conditions. However, no studies have been made on the comparative performance of single cross, double cross, three-way cross and open pollinated varieties of maize under varying management conditions in Zambia. In view of the paucity of studies on the subject, an experiment was set with the broad

objective of studying the comparative yield stability of single cross, double cross, three-way cross and open pollinated cultivars of maize under varying management conditions. The specific objectives of the study were:

1. To study the comparative yield performance of single cross, three-way cross, double cross hybrids and open pollinated cultivars of maize under different management conditions.

2. To study the performance of these different maize cultivars as expressed by their grain yield stabilities and the stability of some of their agronomic traits in an array of production conditions.

## 2. LITERATURE REVIEW

In this literature section, a review of the phenomenon of the interactions between genotypes and environments and cultivar stability will be done. The review is restricted to the published papers that are relevant to this study.

### 2:1. GENOTYPE BY ENVIRONMENT (GXE) INTERACTION IN CROP IMPROVEMENT.

The performance of crop cultivars may change with environmental fluctuations when there are large differences in environmental factors. An ideal cultivar would produce high yields regardless of environmental conditions. In reality cultivars do not perform equally well in all environments, although the goal in crop improvement could be to develop cultivars that will give good yields under varying environmental conditions. The differential response of different cultivars of the same crop species to environmental fluctuations is known as genotype by environment (GXE) interaction (Comstock and Moll, 1963). It is because of GXE interaction that testing of new lines and cultivars in areas of intended production is a standard procedure in every breeding program. From such multi-location and hence multi-environment trials, a plant breeder can establish areas of

adaptation for particular genotypes and recommend for production those cultivars that prove adapted to an environment (Lungu, 1978). Stable genotypes would have a small GXE interaction.

## 2:2 GENETIC DIVERSITY AND STABILITY.

Dobzhansky and Lavene (1955) gave evidence indicating the average superiority of fitness of heterozygotes over homozygotes when tested in varying environments. These workers found that in Drosophila pseudoobscura individuals homozygous for second chromosome were less well buffered with respect to viability than comparable heterozygotes. They concluded that such homozygotes would do quite well in a restricted range of environments but lack the resilience necessary to maintain their fitness in other environments. In a general summary of his work with animals, Lerner (1954) concluded that adaptedness or the attribute of individuals to be fit in the Darwinian sense to their immediate environment is mediated by the heterozygosity advantage in buffering ability. It is commonly accepted by plant breeders that much the same situation prevails in out breeding plant species.

Allard and Bradshaw (1964) equated stability with the term "well buffered" and defined two types of buffering, i.e.

individual and population buffering. They indicated that the nature of GXE interactions is very complex, but deduced that there are two ways of achieving stability. If a hybrid or a population is composed of a number of different genotypes such as for three-way cross and double cross hybrids and open pollinated varieties, it could possess population buffering. If a hybrid such as a single cross hybrid is composed of members which are alike but each adapted to a wide range of environments, it possesses individual buffering. Thus, a homogenous cultivar must depend largely on individual buffering to achieve stability over a range of environments where as a heterogenous cultivar may use both individual and population buffering for the same purpose. In general, heterozygotes are reported to be more stable in the face of environmental variation than homozygotes. Other workers have made a similar conclusion, Allard (1961) working with lima beans (Phaseolus lunatus L), Jowet (1972) with sorghum (sorghum bicolor L) and Shutz and Brim (1971) with soyabeans (Glycine max L) have all shown population buffering to be the most effective aspect of yield stability.

### 2:3. POPULATION AND INDIVIDUAL BUFFERING IN MAIZE.

In maize research, a number of studies have been carried out to compare the stability of in-bred lines, single cross hybrids, three-way cross hybrids, double cross hybrids and open pollinated varieties.

Shank and Adams (1960) compared in-breds with hybrids of maize with respect to six characters. They found that the coefficients of variability were larger for the in-breds than for the hybrids and at the same time varied markedly between in-breds. The difference among the in-breds showed that buffering is a feature of the genotype while the greater variability shown by in-breds as a group indicated that buffering is also a feature of heterozygosity.

Sprague and Federer (1951) compared the performance of maize single cross and double cross hybrids in a yield trial conducted in several locations over a number of years. They found that both location x cultivar and cultivar x year interactions for yield were smaller for double cross maize hybrids than for single cross hybrids, indicating that the more heterogenous double cross hybrids were as a group more stable than the single crosses.

Weatherspoon (1970) compared single cross, double cross and three-way cross hybrids involving nine unrelated in-bred lines of maize. Results indicated that single crosses were more sensitive to environmental conditions than three-way crosses or double crosses, but observed that single crosses vary in this respect and high performing combinations can be isolated which are relatively stable. Moreover, a high yielding single cross can be poor performing at a given environment but still be superior to the best double cross or open pollinated variety at that environment. Heterosis can also be expressed as greater ability to withstand environmental rigors or greater stability (Allard 1960). This presents a possibility of isolating high yielding stable single cross hybrids of maize.

Eberhart and Russell (1969) reported smaller GXE interactions for double cross than for single cross hybrids of maize. However, they also found two single cross hybrids which were not only as stable as any of the double cross hybrids but were higher yielding and concluded that stability seemed to be mainly a property of the in-bred parents, thus pointing out the importance of individual buffering and suggesting that it is an inherited characteristic in certain genotypes.

It is said that modern high-yield cultivars are by definition

delicate, able to give high yields under optimal growing conditions but liable to catastrophic failures when low fertility, poor climate or severe pest problems are present. It is further suggested that plant breeders need to develop cultivars with a broad genetic base which would have a much greater stability of performance under varying environmental conditions. In order to study the comparative yield potential and stability of maize cultivars released for production over a number of years, Lynch et. al (1973) evaluated all hybrids of maize recommended for commercial production in Ontario Canada from 1968-1972. This study was done after noting that in 1968 there were 43 single crosses and 41 double cross hybrids recommended for commercial production while in 1973 these figures had changed to 80 and 29, respectively. It was feared that if this trend continued, all commercial maize hybrids would be single cross. This situation would be beneficial only if single crosses do significantly out perform double crosses and three-way crosses as suggested by Eberhart and Russell (1969) and Weatherspoon (1970). The results of the study showed that single crosses out yielded three-way crosses and double crosses. Single crosses generally out yielded three way-crosses and double crosses by a greater amount as the potential of the environment increased. There was no indication that single crosses were less stable than three-way crosses or double crosses.

Studies indicate that 60 percent of the improvement in Iowa maize yield could be attributed to genetic improvement but that this improvement is expressed only with modern cultural practices (Duvick, 1977; Russell 1974). Most maize production in the United States is by single cross hybrids, in addition much of the maize breeding effort in the United States is designed to develop hybrids that are able to exploit favourable cultural practices and the normally favourable climatic environments to meet the demand for ever increasing yield levels (Sprague and Eberhart, 1977). As the yield potential of U.S. maize hybrids under favourable conditions is extended to higher levels, questions arise concerning the performance of these hybrids under less favourable environments. Such questions are prompted by potential reductions in available fertilizer supplies due to high energy costs and by the possibility of extended periods of less favourable climatic conditions such as droughts as experienced of late in the maize belt of the United States.

Castleberry et. al (1984) in their study compared the relative yields and apparent rates of yield increase due to genetic improvement in maize cultivars. The cultivars used were representative of those utilised by farmers in the United States in each of the decades since 1930. These cultivars were compared over high and low fertility, irrigated,

deliberately droughted and non irrigated environments. The results indicated that substantially higher yields were obtained with modern hybrids even under yield limiting conditions. The most recent single crosses evaluated in the study provided the best yield response to favourable cultural practices and environments while maintaining better yields under poor conditions than other older hybrids or varieties. They concluded that the transition of farmers in the United States from open pollinated varieties to double cross to high yielding and management responsive single cross maize hybrids has not increased vulnerability in unfavourable production situations. In a similar study, Carlone and Russell (1987) evaluated maize response to plant densities and nitrogen levels. Cultivars representing 10-year periods beginning with open pollinated varieties (1930-1940) and subsequent 10 year periods of single cross hybrids from 1940-1980 were included. The open pollinated varieties released in the initial decade, i.e. 1930-1940 and the early hybrids released from 1940 to 1960 had the lowest response to nitrogen while all subsequent hybrids released in the 1970 and 1980 eras had positive linear responses.

Ristanovic and Mungoma (1989) compared yield and yield stability among experimental single crosses, double crosses, three-way crosses and open pollinated varieties. Also included

in the study were commercially grown hybrids which were used as standards. Of a total of 25 cultivars 19 were locally developed Zambian cultivars. Their results showed that open pollinated cultivars had significantly the lowest linear response in a stability analysis. Single cross and three-way cross hybrids had the highest linear response while double cross and standard hybrids did not differ in their response. Three-way crosses had the lowest deviation from linear regression while standard hybrids and experimental single crosses had the highest deviation from linear regression curve.

#### 2:4 METHODS OF EVALUATING VARIETY STABILITY.

GXE interactions occur when two or more genotypes are compared in different environments and found to differ in their responses. The existence of such an interaction is shown by significant two or three factor interactions such as genotype (or cultivar) x site x years in the analysis of variance. One of the most commonly used methods of characterising behaviour of cultivars or lines in varying environments is the use of replicated performance trials over a series of environments. These tests are analyzed as follows:

Table 1. Form of the analysis of variance for a repeated trial.

Source of Variation	Degrees of Freedom	Mean Square	Expectation of Mean Square
Environments	$e - 1$		
Genotypes	$g - 1$	$MS_1$	$\sigma^2 + r\sigma^2ge + re\sigma^2g$
GXE	$(g - 1)(e - 1)$	$MS_2$	$\sigma^2 + r\sigma^2ge$
Error	$ge(r - 1)$	$MS_3$	$\sigma^2$

Source: Moll and Stuber (1974).

The above analysis provides the mean squares for a simple F test ( $MS_2/MS_3$ ) for evaluating the overall significance of GXE interactions.

Another measure of GXE interactions involves the correlation of performances of an array of genotypes in one environment with their performances in other environments, (Stuber et al, 1973). Large positive values indicate little GXE interactions where as the converse is true.

GXE environment interactions and their estimates have been reported by many researchers (Allard and Bradshaw, 1964; Comstock and Moll, 1963; Baker, 1968).

Moll and Stuber (1974) had observed that a number of authors including Yates and Cochran (1938) had proposed that the regression of yield on the environmental index, as measured by the mean yield of all cultivars in a particular environment would provide a parameter for characterisation of the stability of hybrids.

Finlay and Wilkinson, (1963), Eberhart and Russell (1966), Perkins and Jinks (1968), Bucio (1966), have observed that the relationship between the performance of different genotypes in

various environments is often linear or nearly so. Freeman and Perkins (1971) concluded that there is strong evidence that there is a genuine underlying linear relationship between performance of particular genotypes and environmental conditions, even though it does not always account for all the observed interactions. Due to this linear relationship, attention has been paid to the measurement of cultivar response to different environmental conditions under which the cultivar is growing and also to the determination of the difference between the responses for different genotypes. In particular, regression analyses have been used to provide measures of phenotypic stability. Many of the regression analyses used for this purpose do not entirely satisfy rigorous statistical requirements (Freeman and Perkins, 1971). Even so, the regressions computed have been shown to be useful predictors of stability, and would appear to be particularly meaningful in plant improvement, (Moll and Stuber 1974).

In a study of 277 barley cultivars, Finlay and Wilkinson (1963) regressed cultivar mean yield on site mean yield using a logarithmic scale. The mean yield of all cultivars at each site and for each season provided a numerical grading of the environment over sites and seasons. Regression coefficients and cultivar mean yields over environment were used to

classify cultivars specifically adapted to high or low yielding environments and for general stability. They indicated that a regression coefficient of unity ( $\beta_i=1.0$ ) indicates average stability. A cultivar with  $\beta_i>1$  indicates below average stability and  $\beta_i<1$  indicates above average stability. Absolute phenotypic stability would be expressed by  $\beta_i=0.0$ . The ideal cultivar was described by Finlay and Wilkinson (1963) as possessing genetic potential in the highest environment and maximum phenotypic stability.

Finlay (1963) using the above procedure studied the comparative adaptation of hybrid barley populations with homogenous cultivars grown in an array of environments. He noted that much of the increased phenotypic stability of the F2 can be attributed to heterosis in genotypes specifically adapted to low yielding environments in which the heterotic effects would be maximal.

Eberhart and Russell (1966) improved the regression technique for evaluating stability by considering two empirical parameters, the slope of the regression line and the deviations from the regression line. These parameters are defined with the following model:-

$$Y_{ij} = \mu_i + \beta_i I_j + \sigma_{ij},$$

where  $Y_{ij}$  is the  $i^{\text{th}}$  cultivar mean at the  $j^{\text{th}}$  environment,  $\mu_i$  is

the  $i^{\text{th}}$  mean of the cultivar over all environments,  $\beta_i$  is the regression coefficient that measures the response of the  $i^{\text{th}}$  cultivar to varying environments,  $\sigma_{ij}$  is the deviation from regression of the  $i^{\text{th}}$  cultivar at the  $j^{\text{th}}$  environment, and  $I_j$  is the environmental index obtained as the mean of all cultivars at the  $j^{\text{th}}$  environment minus the grand mean, as expressed by the following equation.

$$[I_j = (\sum_i Y_{ij}/v) - (\sum_i \sum_j Y_{ij}/vn)], \sum_j I_j = 0.$$

An index independent of the experimental variances and obtained from environmental factors such as rainfall, temperature and soil fertility would be desirable. However, present knowledge of the relationship of these factors and yield does not permit computation of such an index (Eberhart and Russell, 1966).

Moll and Stuber (1974) in their review analyzed the use of the mean of all genotypes grown in a specific environment as a value assigned to the environment and reported that it does not provide an independent measure of the environmental effects and therefore, does not satisfy the requirements of a regression analysis as rigorously as one would like. However, it appears to provide sufficiently reliable estimates to be useful.

Moll and Stuber (1974) reported that Perkins and Jinks (1973) had compared the use of the usual dependent assessment of environments with three independent measures in a study of 82 lines of Nicotiana rustica L. They found that it made little difference whether they used dependent or independent environment assessment. The independent measures used were, division of the replicates of each genotype into two groups, using one group to measure environment and the other to evaluate interactions and the use of one or more genotypes as standards to assess the environment.

Eberhart and Russell (1966) defined a stable cultivar as one with a regression coefficient of unity ( $\beta_i = 1.0$ ), and a minimum deviation from the regression line  $Sd_i^2 = 0$ .

The basic difference between this model and the Finlay and Wilkinson (1963) model, is the use of an environmental index instead of actual mean yields, and the application of an additional parameter, the deviation mean square value in the Eberhart-Russell (1966) model. They also suggested that the deviation mean square may be a more important parameter for evaluating maize cultivars in the United States. Data on maize in-breds and hybrids presented by Eberhart and Russell (1966) showed considerable variation for stability parameters; however, the results suggested that both parameters, i.e. the

regression coefficient and the parameter measuring deviation from regressions are of prime importance for varietal evaluations.

The Eberhart and Russell (1966) model was used by Stroiike and Johnson (1972) for identification of superior winter wheat cultivars for use in breeding programs. They used the three evaluation parameters, cultivar mean performance, regression coefficient and regression deviation mean square. They found the parameters to be useful for describing and predicting cultivar performance. Together, the three parameters provided useful interpretive information on the general adaptation and performance stability.

Gama and Hallauer (1980), Prior and Russell (1975), also used the model and reported prolific maize hybrids to be more stable in yield than the single eared hybrids.

A number of workers working with various crops, Eberhart and Russell (1969) with maize, Jowet (1972) with sorghum, Norden et. al. (1986) with peanut and Stroiike and Johnson (1972) with wheat, have defined a stable cultivar as one with a b-value near or equal to 1.0, with a small deviation mean square or small standard error of b, and above average mean performance.

Other methods have been suggested in stability studies, Baker (1969), Freeman and Perkins (1971) Tai (1971).

Stability studies continue to be very important in other crops, for example, Beaver et. al. (1985) with dry bean, Funnah and Mak (1980) with soyabeans, Moeljopawiro (1989) with rice and Patanothai and Atkins (1974) with sorghum.

### 3. MATERIALS AND METHODS

#### 3.1. MATERIALS AND LOCATION.

##### 3.1.1. MATERIALS.

Twelve varieties of maize representing four different types, single cross, double cross, three-way cross hybrids and open pollinated varieties, were grown at three locations for one year in the 1989/90 rain season. The cultivars included both commercial and experimental cultivars from the maize improvement programme of the Research Department of the Ministry of Agriculture of the Republic of Zambia. Table 2 presents the list of genotypes involved in the study.

##### 3.1.2. LOCATION.

The three sites used for the study were the National Irrigation Research station (N.I.R.S.) in Mazabuka representing zone 1 for the low rainfall areas, Golden Valley farm in Chisamba in zone II which is a medium rainfall area and Mansa for the high rainfall areas, in zone III (see Table 3). The three test sites were chosen to provide an array of environmental conditions with various patterns of rainfall distribution, soil types, disease and pest incidence.

Table 2. Cultivars used in the study.

Variety	Type	Days to harvest
MM 752	SC	155-160
MM 502	SC	135-140
MM 601	SC	140-145
MM 612	DC	150-155
MME 402	DC	145-150
MME 403	DC	145-150
MME 305	TC	145-150
MM 604	TC	145-150
MM 603	TC	135-140
Acr 7844	OP	145-150
Pop 10	OP	140-145
MMV 600	OP	145-150

Legend:

SC. Single cross

DC- Double cross

TC- Three way cross

OP- Open pollinated

Source: Maize Research Team.

Table 3. A general description of sites used in the study.

Site	Zone	Soil Type	PH	Rainfall mm/year	Growing Season (Days)
N.I.R.S	I	Black clay loam	5.6	< 800	120-150
Golden Valley	II	Brown clay loam	5.0	800-1000	120-160
Mansa	III	Sandy loam	4.0	1000-1500	150-180

Note: Zone I. Hot, drought prone.  
 Zone II. High potential areas.  
 Zone III. Acid soils, cob rot, maize streak virus.

Source: Maize Research Team.

### 3.2 METHODS.

The twelve cultivars of maize involved in this study, apart from being tested in the three different locations, were also tested under four management levels at each experimental site. The four management levels were adopted to represent four possible sub environments under which these cultivars would be produced in Zambia with regard to fertilizer application. The four management levels were; no fertilizer, half Lima recommendation, Lima recommendation and Commercial fertilizer recommendation. The quantities of fertilizer applied under each management level are presented in Table 4.

All other agronomic practices were the same for all cultivars. A recommended spacing of 75 X 30 cm to give a plant population of 44000 plants per hectare was used. D compound fertilizer was applied at planting as basal dressing while Ammonium Nitrate was applied as top dressing at six weeks after planting at the rates shown in Table 4. A judicious weed control program using hand hoes was observed in order to eliminate any stress to the maize plant arising from competition with weeds.

A split plot experimental design with three replications was used. The four management levels were the main plots and

cultivars as sub plots. This experiment was repeated at the three test sites shown in Table 3.

Data were obtained on the two middle rows of four row plots of 5 meters length. The cultivar performance information collected was as indicated in Table 5.

Table 4. Fertilizer applied to the maize crop under different management levels.

Recommendation	Fertilizer Rate (Kg/ha)	
	D compound	Ammonium Nitrate
Commercial	400	300
Lima	200	200
Half Lima	100	100
Unfertilised	0	0

Source: Eklund (1985).

Table 5. Characters measured at harvest on the cultivars involved in the study.

Character	Unit of measure
Grain yield: Weight of clean grain from each plot converted to yield per ha. basis at 12% moisture.	kg
100 Kernel weight: Determined as the weight of 100 kernels taken at random.	g
Cob weight: Determined as weight of all cobs from each harvest area converted to weight per hectare.	kg
Cob weight shelling: Sub sample weight of 8 representative cobs from each plot before shelling.	g
Weight shelled grain: Sub sample weight of shelled grain from 10 cobs from each plot.	g
Percent moisture: Obtained using a moisture meter.	%
Plant height: Average height of plants measured from ground to flag leaf collar.	cm
Ear height: Average ear height in the plot measured from the ground to the node where top ear is attached.	cm
Shelling percentage: Determined as percent of shelled grain weight over weight of grain + cob, from a sub sample of each plot.	%

### 3.3. STATISTICAL ANALYSIS.

The data was analyzed as a split plot design with varieties and sites considered random and management levels fixed. Appropriate analyses of variance were conducted for each trait at each location. Furthermore, data from all the three locations were combined for a combined analysis of variance, (Steel and Torrie, 1980) across the three locations. In this combined analysis of variance the interest was to establish whether there was a cultivar by location interaction which would give preliminary information on the differential stabilities or absence of it in the cultivars involved in the study.

Stability parameters for yield data, shelling percentage and 100 kernel weight were computed using the method proposed by (Eberhart and Russell, 1966). The management-location combinations were considered as environments and this arrangement gave 12 environments for testing the genetic stability. In testing for stability of cultivar performance, the mean performance of each cultivar across three replications in each management-location combination was regressed on the environmental indices.

Environmental indices were computed for all management-location combinations shown in Table 6.

Table 6. Management-Location combinations representing twelve environments for which indices were computed.

Location	Management level			
	0	1/2 Lima	Full Lima	Commercial
Mansa	x	x	x	x
Golden Valley	x	x	x	x
N.I.R.S.	x	x	x	x

Note: The x designates the management-location combinations considered as different environments, since all twelve cultivars were tested under each of these environments.

The environmental index (I) for each management-location combination was computed as follows:

$$[I_j = (\sum_i Y_{ij}/v) - (\sum_i \sum_j Y_{ij}/vn)], \sum_j I_j = 0.$$

$I_j$  = Total performance of all cultivars at the  $j$ th environment divided by the number of cultivars grown there, minus the performance of all cultivars in all locations and management levels (grand total) divided by the total number of observations.

Or the mean of all cultivars at the  $j$ th environment minus the grand mean.

It was on these environmental indices that the mean performance of each cultivar across three replications for each management level was regressed.

## 4. RESULTS

### 4.1 ANALYSIS OF DATA.

The three experiments at Mansa, Golden Valley and N.I.R.S. were analyzed as repeated split-plot experiments with locations included as sources of variation. Yield data for this combined analysis of variance was transformed using the logarithmic transformation as an error control measure (Steel and Torrie, 1980). Table 7 presents the results of the combined analysis of variance for yield. Results of the analysis of variance show that there were significant differences among locations, management levels and cultivars. There were also significant management x location and location x cultivars interactions. However, the management x cultivars interaction was not significant. The significant cultivars x locations interactions show that the cultivars performed differently in the three locations which warrants the need to assess the performance stabilities of the twelve maize cultivars used in the study. The significant cultivars x location interaction showed that the cultivars have differing yield stabilities.

Tables 8, 9, and 10 present the mean separation analysis using the Duncan's Multiple Range Test for test sites, management levels and cultivars. These results indicate that the highest average yields were obtained at Mansa and the lowest at Golden Valley. As expected the commercial fertilizer recommendation gave the highest yields while the zero gave the lowest yields. Hybrid MM 601 had the highest average yield while population 10 gave the lowest. Generally, all hybrids except MM 752 had higher yields compared to open pollinated varieties. This is further shown in Table 11 which presents results of orthogonal comparison.

In order to study the behaviour of other yield related attributes, combined analyses of variance for plant height, shelling percentage, 100 kernel weight and cob placement were conducted. The results of these analyses are presented in Table 12.

Table 7. A combined analysis of variance for yield with yield data transformed using the log<sub>10</sub> transformation.

Source of variance	D.F.	Mean square	F.
Locations	2	5.420	**
Replications (Locations)	6	1.658	**
Management	3	3.550	**
Location x Management	6	1.218	**
Error	18	0.383	
Cultivars	11	0.571	**
Location x cultivars	22	0.163	**
Management x cultivars	33	0.060	ns
Location x Management x cultivars	66	0.074	ns
<i>Error</i>	<i>264</i>	<i>0.074</i>	

CV 8.83%

\*\* Significant at  $P \leq 0.01$

ns Not significant

Table 8. A Duncan's multiple range test comparing the productivity of the three test sites.

Site	Mean yield (kg/ha)	
Mansa	1820	A
Golden Valley	759	B
N.I.R.S.	1349	A

CV 8.83%

Lsd = 0.0516 (calculated using transformed data).

Alpha = 0.01

Means followed by the same letter are not significantly different according to Duncan's multiple range test.

Table 9. A Duncan's multiple range test comparing the yields under four management levels.

Fertilizer level	Mean yield (kg/ha)	
Zero	759	C
1/2 Lima	1096	BC
Lima	1380	AB
Commercial	2042	A

CV 8.83%

Lsd = 0.2424 (calculated using transformed data)

alpha = 0.01

Means followed by the same letter are not significantly different according to Duncan's multiple range test.

Table 10. A Duncan's multiple range test comparing the mean yielding performance of the twelve cultivars over the three location and management levels.

Variety	Type <sup>†</sup>	Mean Yield (kg/ha)	
MM 752	SC	676	C
MM 502	SC	1288	AB
MM 601	SC	1738	A
MM 612	DC	1479	A
MME 402	DC	1660	A
MME 404	DC	1445	A
MME 305	TC	1230	AB
MM 604	TC	1514	A
MM 603	TC	1479	A
Across 7844	OP	933	BC
Pop 10	OP	933	BC
MMV 600	OP	955	BC

CV 8.83%

Lsd = 0.1663 (calculated using transformed yield data)

Alpha = 0.01

Means followed by the same letter are not significantly different according to Duncan's multiple range test.

+ SC, DC, TC and OP refer to single cross, double cross, three-way cross and open pollinated, respectively.

Table 11. Combined analysis of variance for yield plus orthogonal comparisons.

Source of variation	D.F.	Mean square	F
Locations	2	5.420	**
Replications (Locations)	6	1.658	**
Management	3	3.550	**
Locations x Management	6	1.218	**
Error	18	0.383	
Cultivars	11	0.571	**
SC vs OPs	1	0.403	*
SC vs DC	1	0.839	**
SC vs TC	1	0.403	*
DC vs OPs	1	2.225	**
DC vs TC	1	0.079	ns
TC vs OPs	1	1.465	**
Location x Cultivar	22	0.163	**
Management x Cultivar	33	0.060	ns
Locations x Management x Cultivar	66	0.074	ns
Error	264	0.074	

CV 8.83%

\*\* Significant at  $P \leq 0.01$

\* Significant at  $P \leq 0.05$

ns Not significant

Table 12. Combined analysis of variance for plant height, cob placement, shelling percentage, and 100 kernel weight.

Source of Variation	Degrees of Freedom	Plant Height (cm)		Cob Placement (cm)		Shelling %		100 Kernel Weight (g)	
		Mean square	F	Mean square	F	Mean square	F	Mean square	F
Locations (l)	2	28216.694 **		15096.636 **		11393.343 **		48.377 ns	
Replications (r)	6	9641.887 *		3461.028 ns		51.373 **		85.219 **	
Management levels (m)	3	36339.494 **		17667.737 **		160.056 **		239.900 **	
l x m	6	4916.096 ns		1114.229 ns		38.130 *		41.799 ns	
Error	18	3544.467		1374.309		13.950		23.075	
Cultivars (c)	11	3214.768 **		1664.103 **		93.113 **		530.205 **	
l x c	22	984.735 ns		271.019 ns		67.757 **		24.663 **	
m x c	33	787.948 ns		331.466 ns		14.315 ns		22.721 **	
l x m x c	66	660.319 ns		294.013 ns		33.308 **		11.800 ns	
Error	264	607.332		319.103		18.283		12.616	

Note: \*, \*\* indicates significance at the 0.05 and 0.01 levels of probability, respectively, while ns indicates non significance.

4

The results showed that for all the traits, there were significant differences ( $P \leq 0.01$ ) in performance among the cultivars. Only shelling percentage and 100 kernel weight showed cultivar x location interaction. The tremendous sensitivity of shelling percentage and 100 kernel weight to environmental changes as indicated by the significant cultivar x location interaction show that these traits which are also yield components would also affect the yield performance of maize cultivars. A step wise multiple regression was done to determine the contribution of plant height, cob placement, shelling percentage and 100 kernel weight to the variation observed in yield. Plant height had the highest contribution followed by shelling percentage and then 100 kernel weight. Cob placement did not contribute to variations observed in grain yield. The results of this analysis are presented in Table 13.

Table 13. Stepwise Regression of maize yield on plant height, shelling percentage and 100 kernel weight.

<u>Yield component combination</u>	<u>R2(%)</u>
Plant height	31.617
Plant height + shelling %	58.405
<u>Plant height + shelling % + 100 kernel wt.</u>	<u>58.843</u>

#### 4.2. YIELD STABILITY ANALYSIS.

The environmental indices for each of the twelve environments are presented in Table 14. The best environment was achieved at Mansa with commercial fertilizer recommendation and the worst environment was at Mansa again at zero fertilizer application rate. Overall, Mansa provided better environments while Golden Valley provided the least favourable environments. Generally, the season and sites provided predominantly low yielding environments.

Table 14. Environmental indices calculated for each location-management combination.

<u>Location-Management</u>	<u>Index</u>
MANSA	
0 Fertilizer	-998
1/2 Lima	347
Lima	824
Commercial	3401
GOLDEN VALLEY	
0 Fertilizer	-897
1/2 Lima	-897
Lima	-755
Commercial	-303
N.I.R.S.	
0 Fertilizer	-374
1/2 Lima	-472
Lima	-28
Commercial	152

Mean yields ranged from as low as 145 kg/ha for MM 752 at Golden Valley to 7482 kg/ha for MM 612 at Mansa. Means for yield data averaged over replications are presented in Table 15. The data showed an overall increasing trend from zero fertilizer rate to commercial fertilizer recommendation. Mansa recorded the highest yields while the yields at Golden Valley and N.I.R.S. were very low due to drought. Hybrids had higher mean yields as compared to the open pollinated types (see Table 15).

Stability parameters for the twelve cultivars grown under four management levels in the three locations are presented in Table 16. Mean yields ranged from 1114 kg/ha for Pop 10 to 2288 kg/ha for MM 601.

Regression coefficients for cultivar mean yields on environmental indices ranged from 0.3979 for MMV 600 to 1.4941 for MM 601. The hybrids had higher regression coefficients except for MME 402 and MME 305 which had regression coefficients below 1.0. All the open pollinated varieties had low regression coefficients compared to the hybrids.

Deviation mean square values for yield differed greatly among the maize cultivars ranging from 50536.4 for MME 404 to

564055.6 for MM 604. All single crosses had relatively low and similar deviation mean squares. Among the double crosses, MME 404 exhibited exceptionally low deviation mean squares. The three-way crosses showed relatively low deviation mean squares but MM 604 had the highest value of all the cultivars. Two of the open pollinated varieties gave low deviation mean squares but Across 7844 gave high values.

Regression of yields for MM 601, MM 752 and MM 502 (single crosses) on the environmental index is shown in Figure 1. MM 601 with high mean yield and a high regression coefficient is compared to MM 752 with a very low mean yield of 1222 kg/ha and a low regression coefficient and to MM 502 with a higher mean yield than MM 752 but a low regression coefficient. These three single cross hybrids did not differ much in their deviation mean squares. MM 601 with a higher deviation mean square of 222842 and the lowest 190218 for MM 502. However, they all exhibited b values which were above 1.0 with hybrid MM 601 having the highest b value of 1.49. This shows that the single cross hybrids were generally more responsive to environmental improvement.

Results of regression of yields of MM 612, MME 402 and MME 404 (double crosses) regressed on the environmental indices are illustrated in Figure 2. The three cultivars had similar mean

yields which were high, but they had different regression coefficients; i.e. 1.4835, 1.0119 and 0.8789 for MM 612 MME 404 and MME 402, respectively. The larger regression coefficient of MM 612 indicates that its potential yield is higher than that of MME 404 or MME 402 in favourable environments. MM 612 and MME 402 had large deviation mean squares but MME 404 had a very small deviation mean square.

Figure 3 graphically illustrates the regression of yield on environmental indices of three-way cross varieties MM 604, MM 603 and MME 305. MM 604 and MM 603 with high mean yields and large regression coefficients contrasts with the low mean yield and smaller regression coefficient of MME 305. The deviation mean square was very large for MM 604 while that of MM 305 was small.

The open pollinated varieties Across 7844, Pop 10 and MMV 600 had very low mean yields and small regression coefficients. Among the open pollinated varieties, Across 7844 had the highest mean yield of 1209 Kg/ha and also the highest regression coefficient of 0.5685 which was similar to that of Pop 10. MMV 600 had the lowest regression coefficient of 0.3979 and a large mean square deviation (see Figure 4).

The mean yields for the four cultivar types in twelve environments is presented in Table 17. The stability parameters are presented in Table 18. The hybrids had high mean yields, the highest being that of the double crosses at 1852 kg ha. They also had high regression coefficient, but a relatively large mean square deviation. The single crosses and double crosses had smaller deviation mean squares while the three-way crosses had the largest value.

Table 15. Mean yield (kg/ha) for 12 maize cultivars in 12 environments.

	CULTIVARS												
	MM 752	MM 502	MM 501	MM 612	MM 402	MM 404	MM 305	MM 504	MM 603	ACF 744	POP 10	MMV 600	Average
M1	524	324	327	831	1426	600	933	437	557	353	692	345	620
M2	1545	3083	3133	1959	2123	1991	1156	1824	2179	2023	1363	1139	1965
M3	3037	2661	4325	2415	2895	2415	1734	1104	2723	1483	1496	3055	2443
M4	5559	5000	7025	7482	4775	5212	4183	7145	6233	2831	3006	1807	5019
G1	413	743	822	1030	334	807	381	1365	723	614	634	733	722
G2	239	770	845	817	1528	1054	609	448	833	207	361	442	721
G3	145	847	1479	1902	993	1211	703	1972	1483	718	407	395	863
G4	203	1148	2606	1130	1611	1352	1071	1991	1483	2317	516	548	1216
N1	331	813	1390	1007	2028	902	1469	1563	1321	807	1452	1445	1244
N2	851	1503	1156	1135	973	1191	1623	1419	769	1393	605	839	1147
N3	785	1139	2178	2153	2259	1578	1697	1517	1247	1321	1403	1739	1530
N4	966	1807	2133	1630	2376	2234	1377	1945	1927	2234	1159	1189	1770
Average	1222	1667	2268	1892	1951	1712	1464	1835	1853	1209	1114	1161	1618

††, Note that M, G, and N refer to Hansa, Golden Valley, N.I.R.S. locations respectively.

The numerical scripts, 1, 2, 3, and 4 refer to management levels ie. O, 1/2 Lima, Lima and Commercial, respectively.

Table 16. Stability parameters for yield of 12 maize cultivars grown under four management levels in three locations.

Cultivar	Type +	Mean yield (kg/ha)	b value	Dev. MS
MM 752	SC	1222	1.2681	216244.6
MM 502	SC	1667	1.0470	190218.2
MM 601	SC	2288	1.4941	222842.0
MM 612	DC	1892	1.4835	202888.0
MME 402	DC	1951	0.8789	189202.8
MME 404	DC	1712	1.0119	50536.4
MME 305	TC	1454	0.7535	136947.8
MM 604	TC	1895	1.2963	564055.6
MM 603	TC	1858	1.2319	168360.6
Across 7844	OP	1209	0.5685	225852.9
POP 10	OP	1114	0.5673	74846.9
MMV 600	OP	1161	0.3979	424980.9

+ SC, DC, TC, OP refer to single cross, double cross, three-way cross open pollinated, respectively.

Table 17. Mean yield (kg/ha) for 4 maize types in 12 environments

Environments	Cultivar Types				MEAN
	SC	DC	TC	OP	
M1	407	969	642	463	620
M2	2587	2026	1719	1530	1966
M3	3361	2545	1854	2011	2443
M4	5858	5823	5847	2548	5019
G1	659	744	825	660	722
G2	621	1133	795	337	722
G3	824	1040	1086	503	863
G4	1319	1364	1993	584	1315
N1	845	1312	1586	1235	1244
N2	1203	1100	1272	1012	1147
N3	1387	1997	1457	1520	1590
N4	1637	2167	1750	1527	1770
MEAN	1726	1852	1736	1161	1618

Note that each cultivar type was represented by three cultivars hence these are averaged over three cultivars. M, G, and N refer to Mansa, Golden valley, and N.I.R.S. locations, respectively. The numerical scrips, 1, 2, 3, and 4 refer to management levels, i.e. 0, 1/2 Lima, Lima and Commercial, respectively.

Table 18. Stability parameters for yield of SC, DC, TC, and OP grown under four management levels in three locations

Cultivar type+	Cultivar NO	Mean yield kg/ha	b value	Dev MS
SC	3	1726	1.2697	91315.6
DC	3	1852	1.1248	41197.2
TC	3	1736	1.0939	146207.2
OP	3	1161	0.5112	106579.4

+. SC, DC, TC, OP refer to single cross, double cross, three-way cross and open pollinated, respectively.

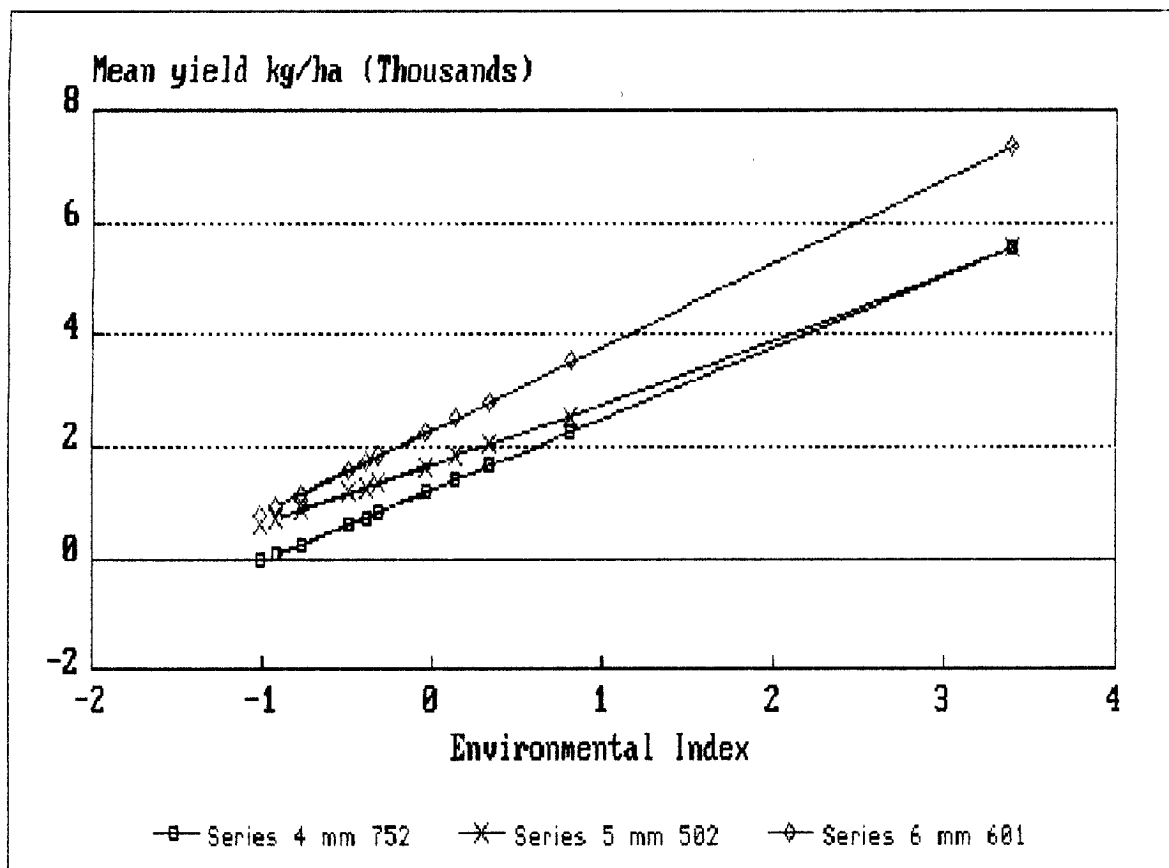


Figure 1. Regression of yield of MM 752, MM 502 and MM 601 (Single crosses) on environmental indices.

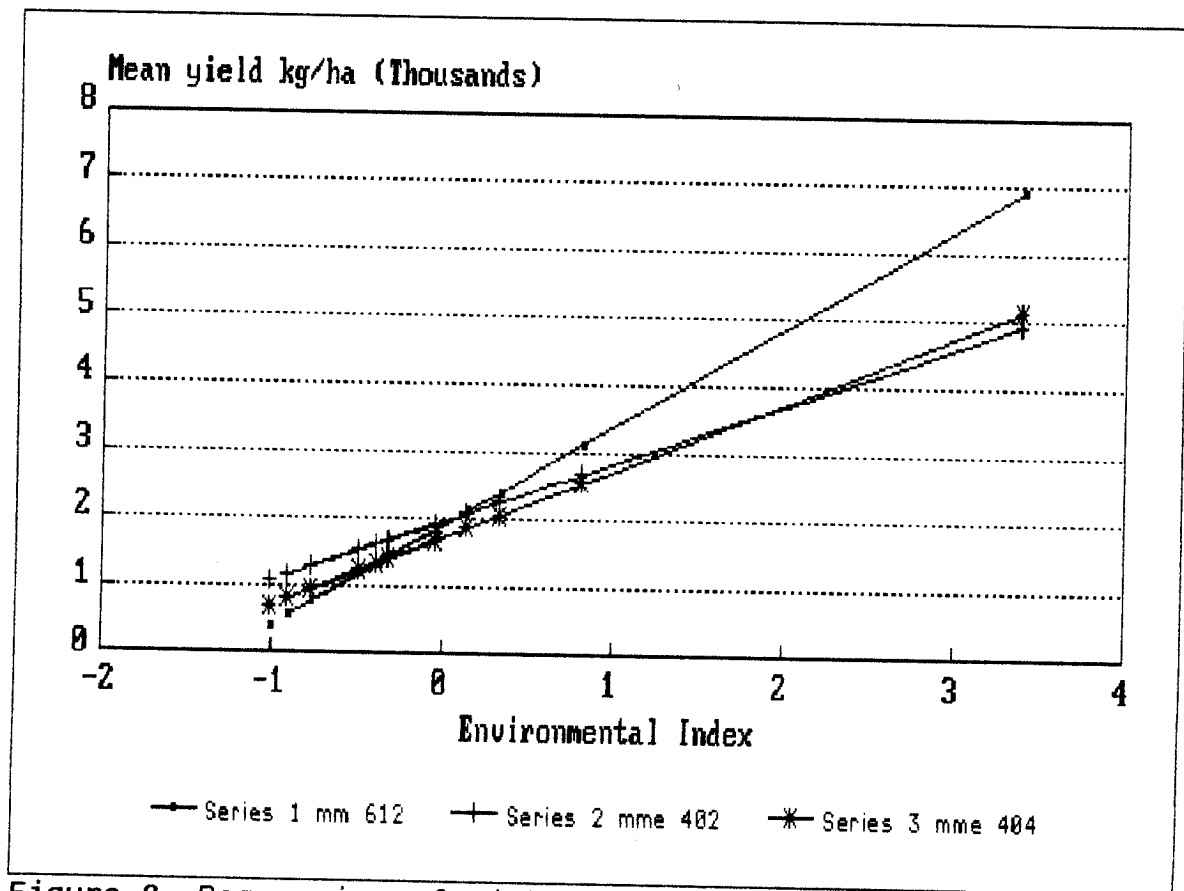


Figure 2. Regression of yield of MM 612, MME 404 and MME 402 (double crosses) on the environmental indices.

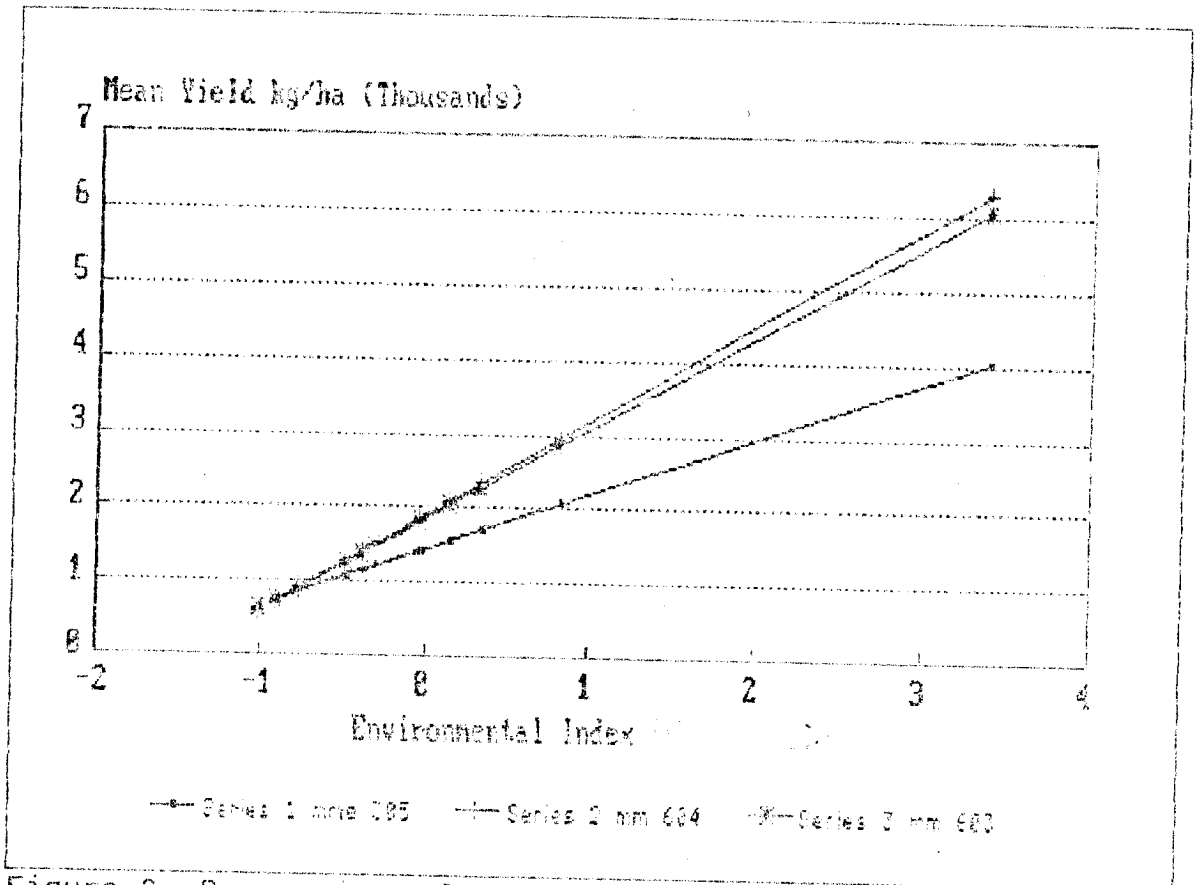


Figure 3. Regression of yield of MM 305, MM 604 and MM 603 (Three way crosses) on the environmental indices.

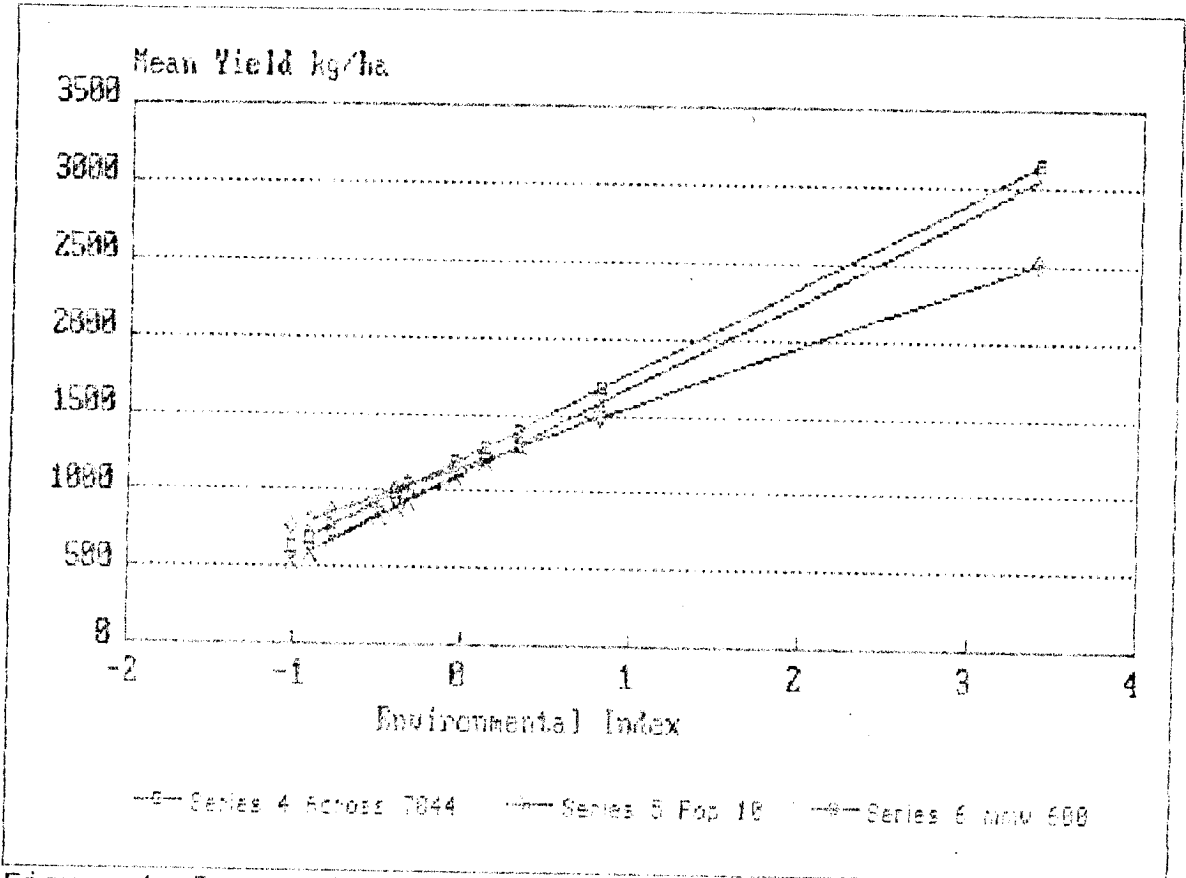


Figure 4. Regression of yield of Across 7844, Pop 10 and MMV 600 (Open pollinated varieties) on environmental indices.

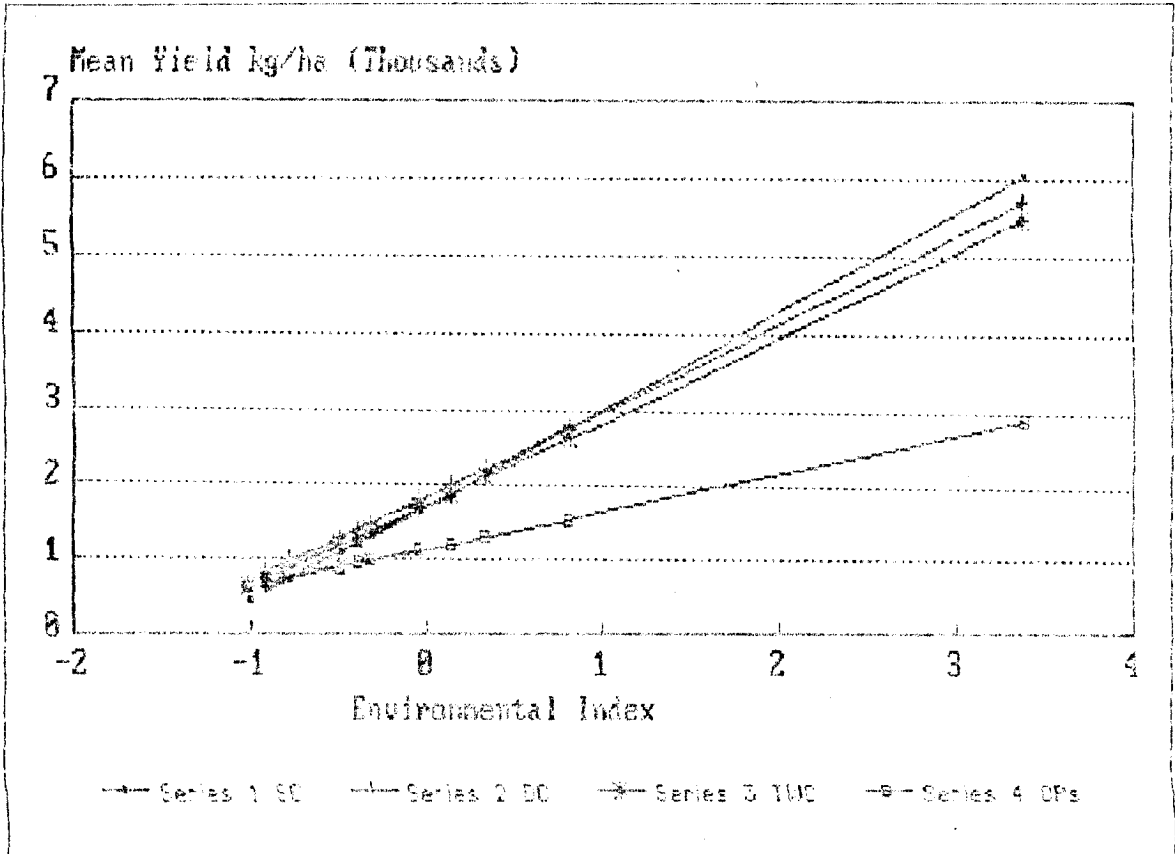


Figure 5. Regression of yield of SC, DC, TC, and OP on environmental indices.

#### 4.3. STABILITY PARAMETERS FOR OTHER TRAITS.

##### 4.3.1 Shelling percentage.

Data for mean shelling percentage for the twelve maize cultivars in twelve environments is presented in Table 19. Mansa had high shelling percentage followed by N.I.R.S., while Golden valley had very low shelling percentages due mainly to poor yields caused by drought stress.

Stability parameters for shelling percentage are presented in Table 20. Overall mean shelling percentage ranged from 74.305 percent for MM 752 to 79.750 percent for MME 404. Regression coefficients ranged from 0.6878 for MME 404 to 1.5769 for MM 752. Deviation mean squares varied between 2.02667 for MM 601 to 32.06556 for MM 752. Except for the high deviation mean square for MM 752, the rest had deviation mean squares of between 2.02667 to 10.71080.

Table 19. Mean shelling percentages for 12 maize cultivars in 12 environments.

ENVIRONMENTS	CULTIVARS												
	MM 752	MM 502	MM 601	MM 612	MHE 402	MHE 404	MHE 305	MM 604	MM 603	AGT 7844	POP 10	MHV 600	Average
M1	64.667	81.333	85.000	84.667	84.000	80.000	83.667	82.333	87.000	79.333	82.333	75.667	80.833
M2	85.000	85.333	86.333	85.000	82.667	79.667	88.333	82.000	85.667	91.667	78.000	85.333	83.833
M3	83.000	83.333	85.333	85.000	85.667	83.000	84.333	82.667	83.667	80.667	81.333	82.667	83.899
MA	90.000	82.333	86.667	85.000	82.667	89.333	87.333	85.667	85.333	83.000	84.333	84.333	85.511
G1	64.000	79.333	69.333	67.667	65.667	70.333	63.000	67.000	55.333	85.000	65.000	72.000	66.500
G2	54.000	56.667	67.000	69.333	74.000	74.333	65.333	67.667	82.000	82.000	85.667	82.667	65.806
G3	60.000	67.000	69.000	64.667	70.667	73.667	71.000	75.333	67.667	68.000	69.333	63.000	68.195
G4	56.667	71.333	68.333	66.667	73.333	72.667	66.333	71.667	66.667	65.667	70.667	71.333	68.811
N1	80.333	79.000	85.333	82.667	82.000	82.000	82.667	80.333	79.667	78.333	80.333	80.000	81.806
N2	83.333	80.000	83.333	79.667	85.333	94.000	83.333	82.000	80.667	79.000	80.000	81.333	81.806
N3	81.667	76.667	82.333	81.667	80.333	84.333	83.333	77.667	81.000	81.333	80.000	83.000	81.111
NA	84.000	80.333	84.333	81.333	82.333	83.667	84.667	84.000	83.000	83.000	79.333	81.667	82.639
Average	74.306	76.972	79.333	77.861	79.056	79.750	78.811	78.195	75.806	75.722	76.361	76.917	77.491

††, See table 15..

Table 20. Stability parameters for shelling percentage of 12 maize cultivars grown under four management levels in three locations

Cultivar Name	Cultivar Type +	mean shelling %	b-value	Dev. MS
MM 752	SC	74.305	1.5769	32.06556
MM 502	SC	76.972	0.8046	4.22719
MM 601	SC	79.333	1.0717	2.02667
MM 612	DC	77.861	1.0557	5.02729
MME 402	DC	79.056	0.7750	7.11247
MME 404	DC	79.750	0.6878	5.88267
MME 305	TC	78.611	1.1899	3.23904
MM 604	TC	78.195	0.7823	4.85646
MM 603	TC	76.806	1.2898	10.31008
ACR 7844	OP	75.722	1.0055	2.24551
POP 10	OP	76.361	0.8062	3.13359
MMV 600	OP	76.917	0.9546	10.71080

+. SC, DC, TC, OP refer to single cross, double cross, three-way cross and open pollinated, respectively.

Table 21. Mean 100 kernel weight for 12 maize cultivars in twelve environments.

	ENVIRONMENTS						CULTIVARS						
	MM 752	MM 502	MM 601	MM 612	HME 402	HME 404	HME 305	MM 604	MM 603	ACT 7844	POP 10	MMV 600	Average
M1	26.800	22.433	28.033	30.100	27.600	29.200	36.333	31.767	25.533	20.100	23.567	25.133	26.717
M2	32.833	30.367	33.333	31.300	24.667	25.333	35.800	28.067	27.533	28.600	22.867	24.867	28.822
M3	38.233	26.500	32.667	29.633	24.967	28.433	32.167	29.833	30.100	24.200	21.133	31.167	31.167
M4	39.333	28.667	36.500	35.467	26.267	31.833	37.633	33.367	35.567	26.367	28.060	28.100	32.075
G1	32.600	22.200	28.500	28.400	23.233	23.900	34.333	34.330	29.667	20.300	21.500	23.500	26.897
G2	32.667	26.433	31.400	31.667	25.700	23.800	29.867	31.400	28.367	22.900	21.133	26.000	27.611
G3	41.100	29.900	34.767	34.667	29.267	27.233	33.700	29.367	30.767	20.633	20.633	27.633	38.931
G4	47.200	29.667	32.033	30.333	28.867	26.500	36.700	34.400	34.567	24.433	22.700	26.800	30.933
M1	30.433	29.500	29.833	28.633	26.367	27.600	31.333	31.933	30.567	20.767	24.967	28.233	27.914
M2	31.700	28.600	28.700	28.400	26.400	27.300	32.533	27.300	26.267	23.433	22.267	26.167	27.272
M3	31.933	27.633	31.600	32.260	23.533	27.300	30.833	32.433	27.200	22.667	22.333	26.967	28.053
M4	29.200	26.500	33.133	28.667	29.200	27.667	32.833	33.233	30.600	24.533	24.333	26.100	28.988
Average	34.544	28.398	31.706	30.706	26.339	26.392	33.672	31.453	29.719	23.503	22.769	26.222	28.666

++, See table 15.

#### 4.3.2 100 KERNEL WEIGHT.

Mean 100 kernel weight data for the twelve cultivar is presented in Table 21. Stability parameters for 100 kernel weight are presented in Table 22. The weights varied from 22.769 g for Pop 10 to 34.544 g for MM 752. The regression coefficients varied widely from 0.1827 for Pop 10 to 2.8523 for MM 752. Deviation mean squares ranged from 1.85416 for MM 601 to 13.42594 for MM 752. There was little difference among the cultivars except for MM 752 which had a very high deviation mean square.

Table 22. Stability parameters for 100 kernel weight of 12 cultivars grown under four management levels and in three locations

Cultivar Name	Cultivar Type +	Mean 100 Kernel wt	b-value	Dev. MS
MM 752	SC	34.544	2.8523	13.42594
MM 502	SC	26.358	0.8616	3.49278
MM 601	SC	31.708	1.3741	1.85416
MM 612	DC	30.706	0.9510	3.77630
MME 402	DC	26.339	0.4958	4.00726
MME 404	DC	26.392	1.0321	2.79713
MME 305	TC	33.672	0.7793	5.11827
MM 604	TC	31.453	0.3025	5.80671
MM 603	TC	29.719	1.6128	2.57922
ACR 7844	OP	23.603	1.0295	3.75106
POP 10	OP	22.769	0.1827	2.33554
MMV 600	OP	26.722	0.5270	3.41731

+, SC, DC, TC, OP, refer to single cross, double cross, three-way cross and double cross, respectively

## 5. DISCUSSION

### 5.1. SEASONAL EFFECT.

Mean yield performance of cultivars will depend on the particular sample of sites and seasons used for the estimation. In the present study, the season and sites presented predominantly low-yielding environments.

Rainfall and thus soil moisture was the most important factor varying from location to location, Table 23 presents rainfall amounts and distribution records for the three test sites during the 1989/90 season. The data show that at Mansa, the rainfall total of 1425 mm was well above the annual mean, but Golden valley and N.I.R.S. had deficits of 140 mm and 90 mm, respectively.

The quantity and distribution of rainfall is illustrated in appendix I and II, indicating the length of the growing season, the water balances and estimated evapotranspiration for two of the test sites. Generally, the rainfall distribution was not favourable for good plant growth at all the three sites though Mansa was a more favourable site and this was the major factor contributing to variation in yield between the sites.

Data for potential evapotranspiration is derived from (Muchinda, 1985). Golden valley does not have records for potential evapotranspiration.

Table 23. Rainfall distribution for the three test sites (1989-90 season).

PERIOD		RAINFALL (MM)		
		MANSA	GOLDEN VALLEY	N.I.R.S.
OCT	1-10	000	000	000
	11-20	001	000	000
	21-31	012	004	001
NOV	1-10	000	000	000
	11-20	111	023	022
	21-30	020	012	002
DEC	1-10	020	016	000
	11-20	246	034	003
	21-31	079	004	106
JAN	1-10	022	108	125
	11-20	048	043	104
	21-31	231	066	153
FEB	1-10	025	045	064
	11-20	197	066	028
	21-28	102	015	015
MAR	1-10	019	000	004
	11-20	034	000	004
	21-31	059	024	016
APR	1-10	030	050	025
	11-20	023	000	000
	21-30	011	025	023
MAY	1-10	016	000	000
	11-20	000	000	000
	21-31	000	000	000
Seasonal total		1425	694	709
Deviation from mean		+291	-140	-90

Source: Maize Research Team

## 5.2. GENERAL PERFORMANCE.

The experiment provided an opportunity to study the performance of the twelve maize cultivar under different management levels and varying environmental conditions.

The results of the analysis of variance showed that there was significant genotype x location interaction for yield and some yield components among the various maize cultivars. However, this only detected GE effects among all cultivars. Since the experiment provided data from an array of environments, it was possible to do stability analyses to study the relative responses of these cultivars to environmental changes.

Orthogonal comparisons presented in the combined analysis of variance provided a general picture of the performance of the different maize cultivars and types. The results showed an overall hybrid superiority over the open pollinated varieties. This is an indication of heterosis in the hybrid maize cultivars. The hybrids are not only intrinsically high yielding but are also specifically adapted to the rising fertility levels compared to open pollinated varieties.

Among the hybrids, there were no significant differences between double crosses and three-way crosses, but there were significant differences  $P \leq 0.05$  between single crosses and double crosses and between single crosses and three-way crosses. The results are in agreement with findings of Sprague and Federer (1951), Eberhart and Russel (1969) and Weatherspoon (1970) that single crosses were more sensitive to environmental conditions than double crosses or three-way crosses. However, despite their sensitivity, they tend to outperform the open pollinated varieties even when grown in suboptimal conditions.

### 5.3. STABILITY PERFORMANCE FOR YIELD

The regression parameters derived from the Eberhart-Russel model were used to evaluate the different maize cultivars. The mean yield over the different environments was indicative of the average performance level that a cultivar can be expected to maintain if grown again in a similar range of environment. The regression coefficient predicts the sensitivity of a cultivar to changing environments. The deviation mean square provides evidence of the consistency or repeatability of performance. In this definition high performance and stability of performance under fluctuating environmental conditions are an indication of a desirable

cultivar.

Biologically a stable cultivar is one with maximum yield potential in the most favourable environment combined with high phenotypic stability (Finlay and Wilkinson, 1963). Such a cultivar will show low genotype-environment interaction through consistent high performance. In reality cultivars with high phenotypic stability have low mean yields.

Eberhart and Russell (1966) defined a stable cultivar as one with a regression coefficient of ( $b=1.0$ ), with a minimum deviation from regression line and a high mean yield. Double cross hybrid MME 404 was closest to satisfying the definition of a stable cultivar in all three parameters. MME 404 had above average yield, a linear regression coefficient of 1.0119 and a relatively small deviation mean square of 50536.4. A stable cultivar by the above description will yield well under good conditions and still yield better than other cultivars under poor conditions as shown in Figure 2. when compared to other double crosses and in Figure 6. when compared to MM 752 which would be described as an unstable hybrid. MM 752 with a low mean yield and a high regression coefficient could be described as sensitive to environmental changes and unproductive in low yielding environments. It would be expected to be more productive in favourable environments and

less productive in unfavourable environments.

Many different combinations of the stability parameters are possible and each has a different interpretation. In Figure 1, the performance of the three single crosses were compared; MM 601 had a high mean yield, and a high regression coefficient. This hybrid could be described as productive, strongly responsive to changes in the environment and particularly suited to favourable environments. Its performance in favourable environments would be good in relation to the other cultivars, but as the environment becomes poorer, the superiority of the cultivar relative to other cultivars would decrease. While MM 752 with low overall mean yield and a high regression coefficient would be expected to be more productive in favourable environments. MM 502 with average mean performance and a regression coefficient of 1.0470 can be described as a relatively stable cultivar; it will yield well under favourable environments and still yield better than other cultivars under poor conditions. The three cultivars did not differ greatly in their deviation mean squares which were generally not too high.

The performance of the three double crosses is illustrated in Figure 2. These cultivars had similar high mean yields but differed in the magnitude of their regression coefficients.

MM 612 had a higher regression coefficient indicating its strong response to changes in the environment compared to the other two. The large regression coefficient of MM 612 is associated with higher potential yield in more favourable environments. MME 404 has been described as a stable cultivar. MME 402 had a high mean performance but low regression coefficient which indicates that this cultivar will tend to respond weakly to changes in the environment, compared to MM 612, it is a better cultivar in the poorer environments. This relationship is clearly illustrated in Figure 2.

Figure 3 illustrates the performance of three-way cross hybrids, MM 604, MM 603 and MME 305. MM 604 and MM 603 had equal mean yield and regression coefficients. Both hybrids are productive and their potential yield is higher in the more favourable environments. The two hybrids differ in the degree of predictability of performance in specified environments. MM 604 with a very high deviation mean square would not be grown with the same confidence as MM 603. MME 305 has a low mean performance and a small regression coefficient indicating that it is non productive and responds weakly to changes in the environment.

The open pollinated varieties generally showed low genetic potential for yield. They had very low mean yields and small

regression coefficients. These varieties can be described as unproductive and unresponsive to changes in the environment. The three varieties differed in the magnitude of their deviation mean square, Pop 10 had a low deviation mean square indicating a high degree of predictability of its performance compared to MMV 600 with high deviation mean square (Figure 4).

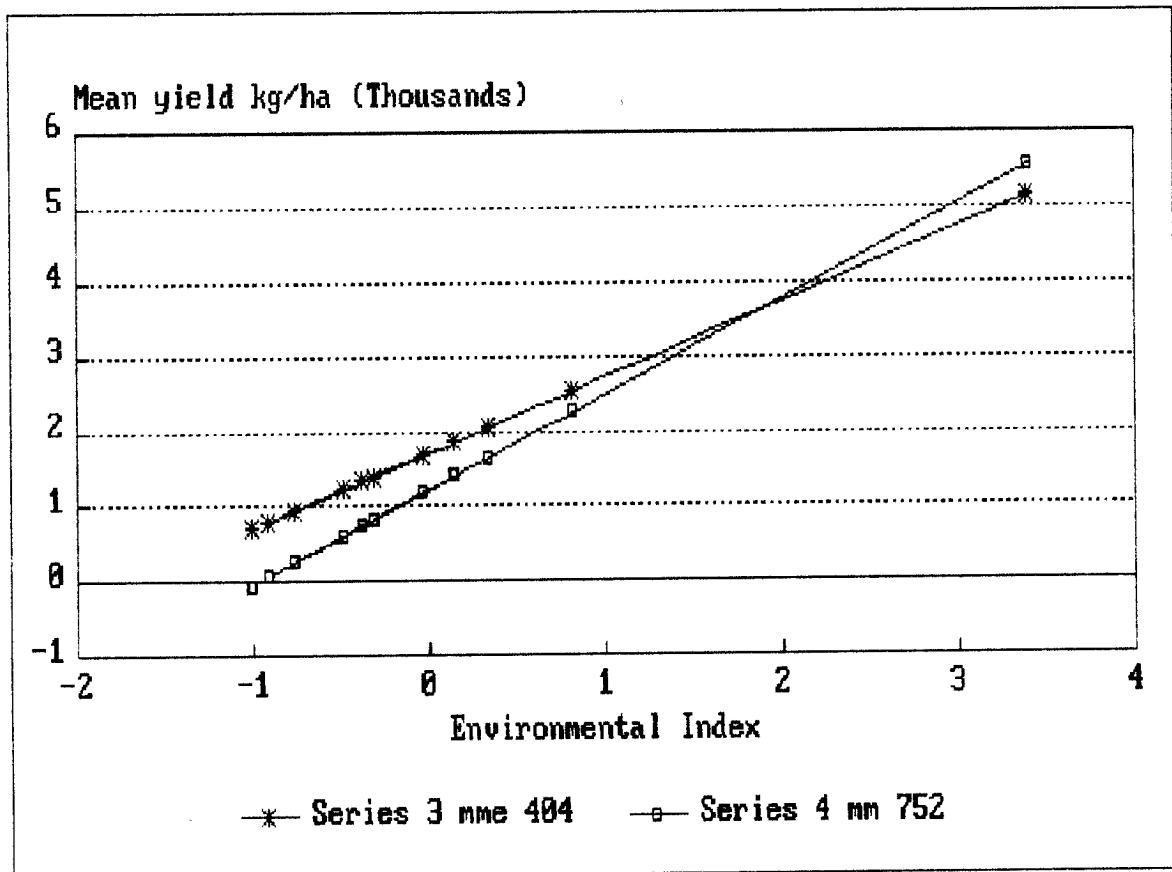


Figure 6. Regression of yield of MM 752 and MME 404 on the environmental indices

#### 5.4 STABILITY ANALYSIS OF FOUR TYPES OF MAIZE CULTIVARS.

The overall mean yields for the three hybrid types (Figure 5) were high, indicating above average performance compared to the open pollinated types. The high regression coefficients could be described as indicating high responsiveness to changes in the environment. Double crosses would be classified as stable, they had a high mean yield, a regression coefficient closer to 1.0 and a low deviation mean square. The three-way crosses had very high deviation mean square in comparison to the other two hybrid types. Open pollinated types had very low mean yield, a very low regression coefficient indicating low productivity and insensitive to environmental changes. Open pollinated varieties can be expected to exceed the performance of the hybrids under very unfavourable conditions. In this experiment these conditions were zero fertilizer application and severe drought at flowering and grain filling stage. This is illustrated in the Appendix I and II (Figs 8 and 9) by the rainfall distribution pattern at two of the test sites.

Figure 7 illustrates a sample of some of cultivars selected from each type. These are compared to the stable double cross hybrid MME 404. Hybrid MM 612, MM 601 and MM 603 had high

regression coefficients indicating better performance in good environments, while MME 404 will yield better in the poorer environments and still perform better than the best open pollinated variety Across 7844.

The results of this study confirm the findings of Ristanovic and Mungoma (1989) that the three widely commercially grown standard hybrids MM 601, MM 612 and MM 603 possess good stability of performance when grown in different environments.

Data from this experiment confirms the study of Eberhart and Russell (1969), Weatherspoon (1970) that single crosses were more sensitive to environmental conditions than three-way or double cross hybrids, but that single crosses vary in this respect and that some high yielding single crosses can be poor performing at a given environment and still be superior to some double crosses; MM 601 is a good example of such a hybrid in this case.

The open pollinated varieties had low regression coefficient, indicating lower sensitivity to environmental change. This type is specifically adapted to low-yielding environments. But some hybrids would still have higher yields than the open pollinated varieties even under very poor environmental conditions (Host and Watts, 1982).

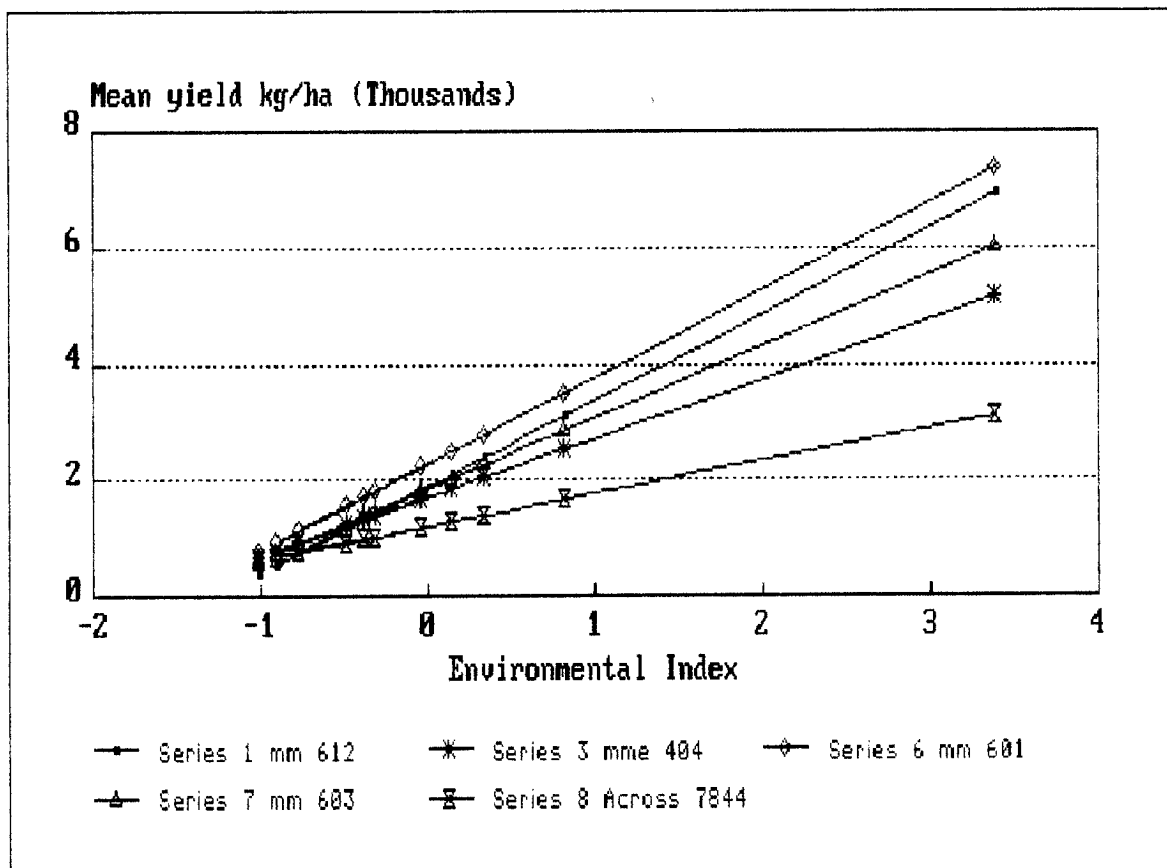


Figure 7. Regression of yield of MM 612, MME 404, MM 601, MM 603 and Across 7844 on the environmental indices.

#### 5.5. STABILITY ANALYSIS OF OTHER TRAITS.

The Eberhart and Russell (1966) method was also applied for some yield components. As already shown, the combined analysis of variance for yield components, plant height, shelling percentage, and 100 kernel weight shows that there were highly significant cultivar x location interactions for shelling percentage and 100 kernel weight but not for plant height. The stability analysis was only done for shelling percentage and 100 kernel weight which had showed a significant cultivar x location interaction.

The stability parameters for shelling percentage varied between cultivars (Table 20). Of interest is hybrid MM 752 which had low mean shelling percentage (74%) and high regression coefficient of 1.5769 and high deviation mean square 32.06556, (Table 20), indicating that its shelling percentage would be higher in favourable environments and low in unfavourable environments. This is typical of MM 752, as, under stress conditions including drought and low fertility, the gap between tasselling and silking becomes larger until a point is reached when pollination and seed set is reduced (Harrison, 1986). Contrastingly, hybrid MME 404 had a high mean shelling percentage (79.750), a low deviation mean square

(5.88267) and a low regression coefficient (0.6878) indicating that MME 404 was very stable but unresponsive to changes in the environment. Shelling percentage was one of the main yield components which contributed to variations in yield as observed in the stepwise regression (Table 11).

Wide significant differences ( $p \leq 0.01$ ) among cultivars were measured for 100 kernel weight. MM 604, MM 402, MMV 600 and Pop 10 were very insensitive to environmental changes as regards 100 kernel weight, as seen from their low regression coefficients of 0.3025, 0.4958, 0.5270, 0.1827, respectively. MM 752 had a very high regression coefficient of 2.8523 and a high mean 100 kernel weight of 34.544, indicating that its kernel weight was highly responsive to changes in the environment.

These stability parameters do explain some of the differences in yield stability. For example, the stable hybrid MME 404 had a very high mean shelling percentage and was stable for both shelling percentage and 100 kernel weight, while hybrid MM 752 was unstable for both shelling percentage and 100 kernel weight but very responsive to favourable environments.

## 6. CONCLUSION

The performance of twelve maize cultivars grown in three locations and under four management levels was studied. Stability parameters were computed using the Eberhart and Russell (1966) statistical model.

Wide differences were detected among the twelve cultivars in response to the changing environment and predictability of performance. Stability parameters for agronomic traits such as plant height, shelling percentage and 100 kernel weight were also analyzed.

Double cross hybrid MME 404 possessed the most desirable combination of stability characteristics, having greater than average mean yield, a regression coefficient = 1.0 and a minimum deviation mean square. Hybrids MM 601, MM 612 and MM 603 were identified as possessing good performance stability. On the contrary, open pollinated varieties had the lowest linear response.

Results from this research provide valuable information to the agronomist in determining which cultivars to recommend for production by the different categories of farmers in Zambia. The Open pollinated varieties are a poor choice for commercial production because of their low yield potential. Generally,

the hybrids performed well compared to the open pollinated types. Among the hybrids, the double crosses had the best satisfying definition of a stable type.

In each cultivar type, it was observed that stable crosses could be identified which could be recommended for production by the small scale farmers. Taking into consideration the management level of Lima and half Lima fertilizer recommendation, most of the hybrids would still out perform the Open pollinated types at these levels.

The hybrid recommendation for small scale farmers which restricts them to growing three-way and variety crosses could be improved. The recommendation should be based on the performance stability of individual hybrids since even among double crosses and single crosses, high yielding and stable hybrids can be identified.

This study was conducted in one season and cannot be regarded as conclusive. Multiple locations and years of testing with various rainfall patterns and fertility levels is required for proper evaluation of the cultivars to enable researchers come up with desired recommendations for the farmers.

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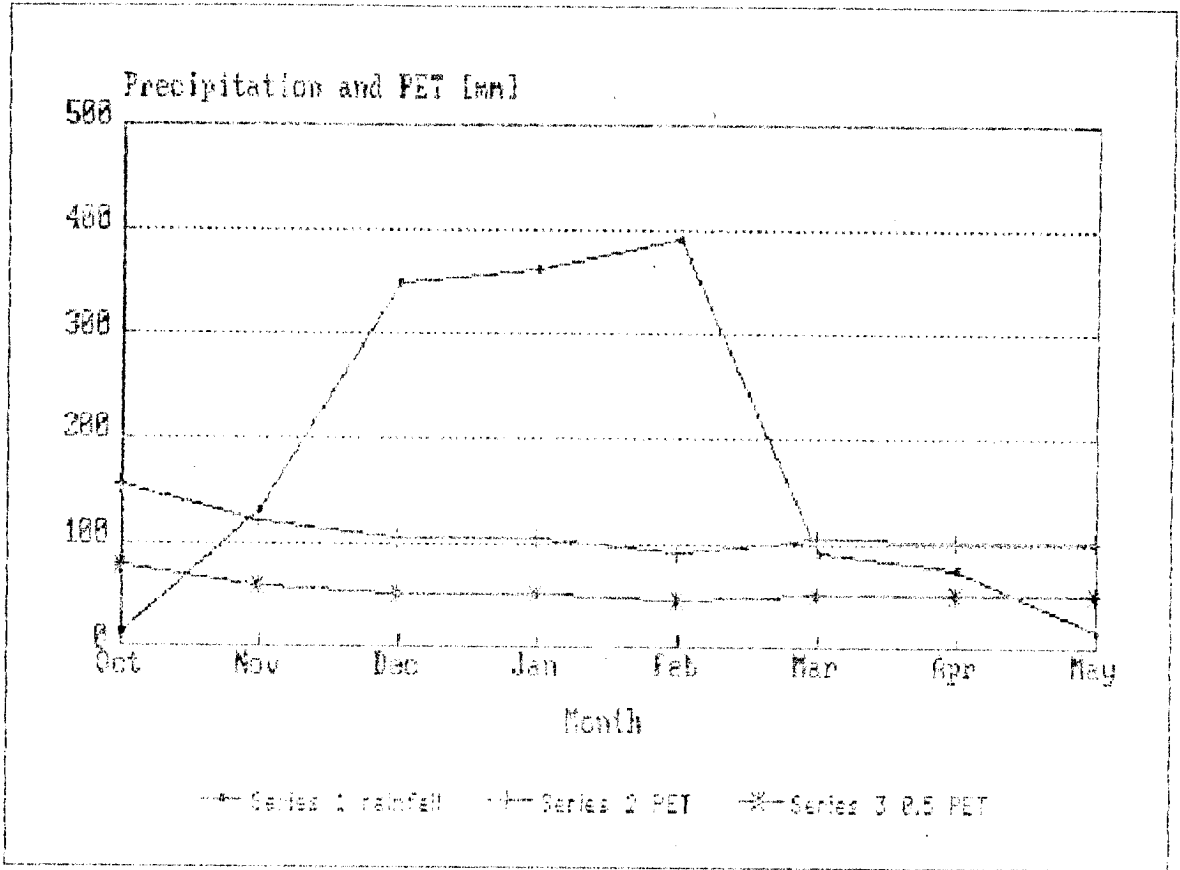


Figure 8. Water Balances Station MANSA.

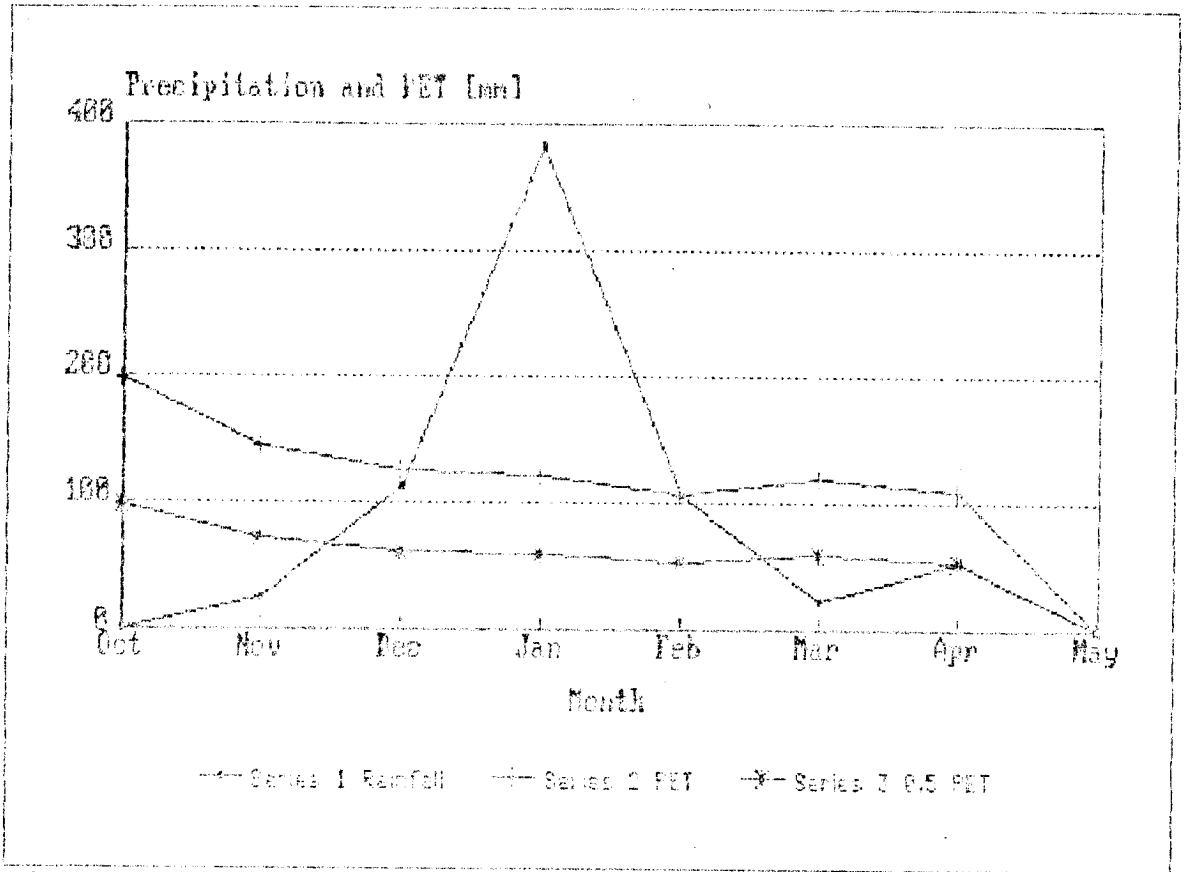


Figure 9. Water Balances Station N.I.R.S.

Figure 8. Water Balances Station MANSA.

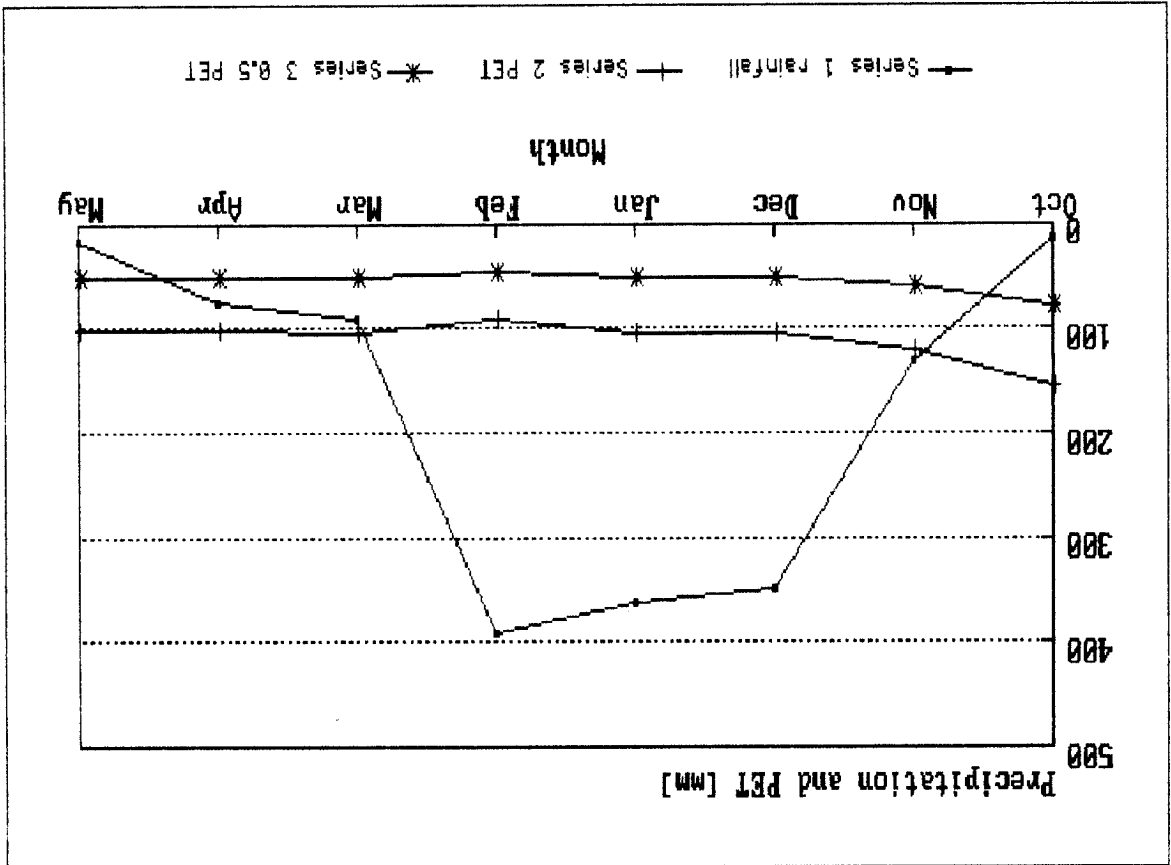


Figure 9. Water Balances  
Station Golden Valley.

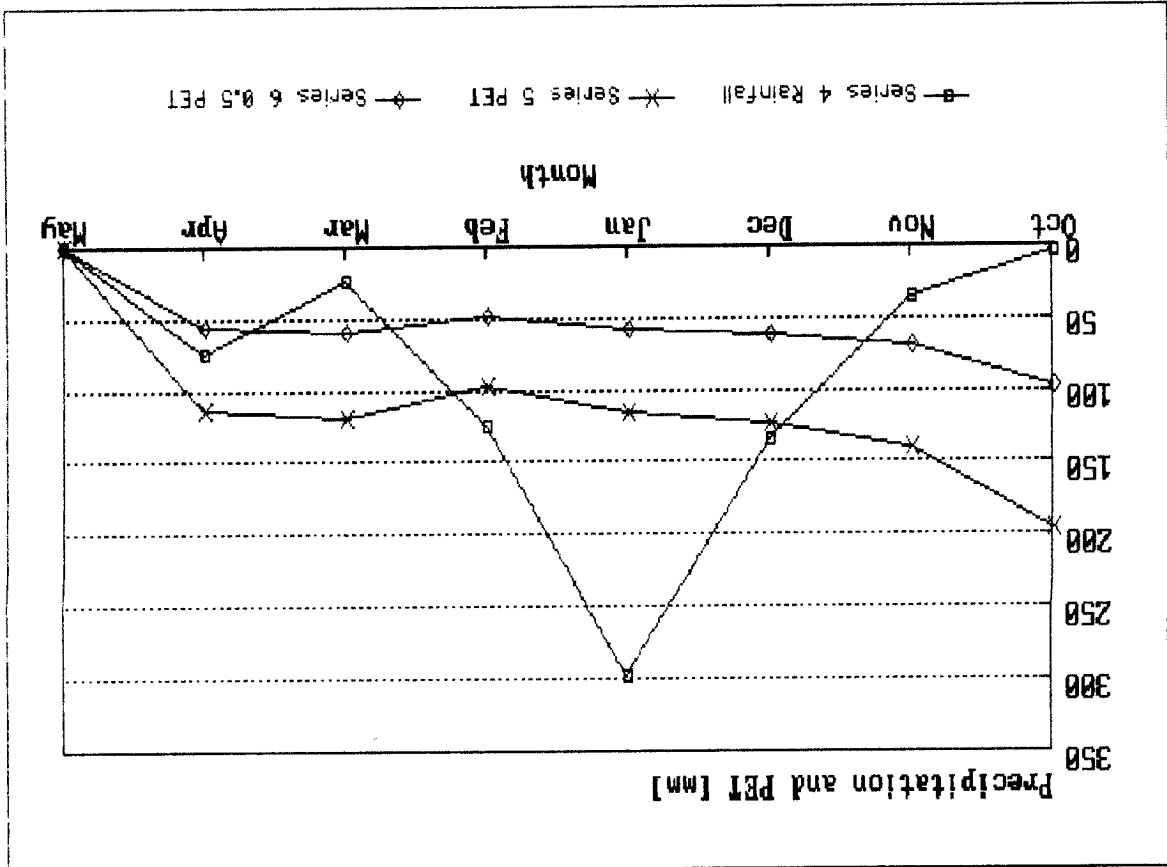
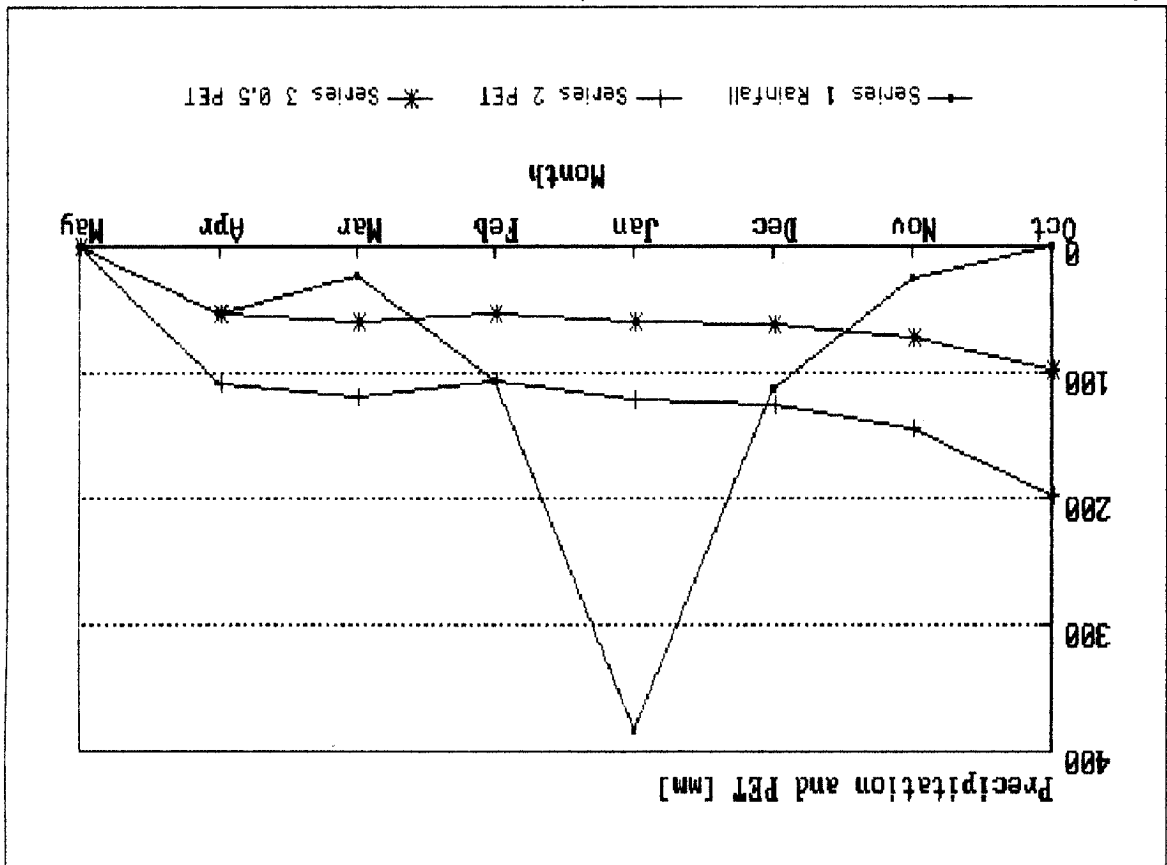


Figure 10. Water Balances Station N.I.R.S.



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