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Induced water stress effects on grain yield and yield components of twelve maize (*Zea mays* L.) genotypes

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The University of Arizona, 1991

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INDUCED WATER STRESS EFFECTS ON GRAIN YIELD AND YIELD COMPONENTS OF TWELVE MAIZE (Zea mays L.) GENOTYPES

by

Sidi Fall

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APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

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April 18, 1991
Date

DEDICATION

I dedicate this work to my mother and father for their loving care, to my wife Fatimetou and daughter Asta, and to my brothers and sisters. God bless you all.

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ABSTRACT

Three maize populations developed for their ability to withstand drought and salinity, and their reciprocal F_1 crosses were tested under induced water stress and normal moisture conditions. Two commercial hybrids and one open-pollinated variety were also included in the study. The objective was to investigate yield and its components under induced drought.

Significant differences in yield were observed in both irrigation treatments. DeKalb 689, one of the commercial hybrids, outyielded all the other entries under wet conditions, whereas under dry conditions the open-pollinated variety, Page Ranch, had the highest yield. Significant differences between populations and their hybrids were also observed. Significant correlations were noted in grain yield as observed in wet and dry conditions and the reduction in the number of ears per plant was positively correlated with the reduction in grain yield resulting from drought.

INTRODUCTION

The greatest challenge facing the world at the end of this century is to provide enough food for a growing population that has been estimated at 4.9 billion (Ehrlich, 1985). With an increase rate of 1.7 percent the world population will double in 41 years (Ehrlich, 1985). Fisher (1985) has projected a world population of 6.1 billion by year 2026.

While population pressures on resources have become visible in rich nations, they have reached tragic proportions in many poor countries. Ehrlich (1985) estimated that worldwide perhaps three-quarters of a billion people, mostly in developing countries, are significantly undernourished. As a consequence of this situation 15 million children die each year of malnutrition and other poverty-related causes (UNICEF, 1982).

It is obvious that world population growth must be paralleled by increases in agricultural production in order to improve the nutritional status of the poorest nations (FAO, 1972). This can be achieved by increasing the production per unit land area and by expanding land under cultivation (Christianson, 1969). However, land for food production is becoming increasingly scarce owing to erosion and desertification that are taking tremendous tolls on arable lands (Secretariat, U. N. Conference, 1977). In addition, water shortage is limiting crop growth in many areas of the world (Meigs, 1953). Therefore any lasting solution for increasing world food supplies hinges on ways of maximizing water use since water is the major limiting factor to plant productivity (Meigs, 1953). Under conditions of water scarcity the alternative that seems achievable is to boost world food production through the adaptation, selection, and use of new strains that are productive and that have been tailored to meet specific local environments (Kahn and Simon, 1983).

Maize is the world's third most important cereal crop. It represents 21 percent of the world's harvest, whereas wheat and rice represent respectively 30 and 27% (FAO, 1983). Although maize is grown for direct consumption as a staple food in 18 countries in Africa and Latin America, these two continents produce only 20% of the world's maize (FAO, 1983).

The majority of the world's maize harvest, 54.5%, is produced in developed countries whereas in countries located in arid and semiarid zones, particularly the Sahel, maize production is low compared to the rest of the world. Africa produced only 6.5% of the world's maize production in 1983 (FAO, 1983).

Drought stress of short or long period of duration is common during the life cycle of maize particularly in rainfed production areas. Substantial reductions in grain yield have been ascribed to unsuitable environments, of which water stress is a major limiting factor (Boyer, 1982). In maize, where the grain represents the harvested part, the magnitude of yield reduction from water deficit is dependent upon the severity and duration of the deficiency (Boyer and McPherson, 1975).

The growth and development of silk and pollen on which yield depends is only possible if plant water potential is adequate to allow these physiological processes to occur properly (Westgate and Boyer, 1986). These authors demonstrated that pollination was successful at pollen water potential as low as -12.5 MPa. In contrast slight decreases in silk water potential caused large losses in grain production. At silk water potential of -1.2 MPa no grain developed at all. This was attributed to failure of pollen to germinate on desiccated silks. Therefore failure in fertilization that leads to seedless ears is chiefly due to silk impairment and not to pollen which is capable to remain viable at very low water potentials.

Herrero and Johnson (1981) and Moss and Downey (1971) agree that water deficit delays silking emergence, so the interval between pollen anthesis and silking is increased, and these authors pointed out that this will result in a large number of barren or poorly filled ears leading to a sharp reduction in the number of grain per cob and as a consequence the total grain weight is also reduced. A positive linear relationship has been found between grain yield and water supply (Gurovich and Ramos, 1985). Denmead and Shaw (1960) showed that a yield loss of up to 50% may occur in water-stressed maize plants.

Genetic studies, conducted under optimum water conditions on maize yield components including ear length, ear circumference, row number and kernels per row, revealed that grain yield was negatively correlated with most of its components. However a positive correlation was found between kernels per row and grain yield but the magnitude of this correlation was not sufficient to be useful in prediction (Leng, 1963). Nevertheless this author suggested that certain environmental conditions or genetic modifications can alter the phenotypic level of one or several yield components and this could be determinant for the expression of total grain yield. Environmental changes brought about by water deficit can markedly affect maize growth and development through some important components such as ear number, kernel weight, kernel number and ear length (Harold, 1986). Leng (1954) reported that total grain yield per plant is the product of the following major components: number of ears per plant, weight of grain per ear, kernel weight, number of kernels per ear, row number and number of kernels per row. Grant et al. (1989) observed a yield loss up to 65% resulting from water stress. This was chiefly ascribed to a reduction in kernel weight and kernel number, 47% and 21% respectively.

Another consequence of water stress during silking and ear development stages, reported by Claassen and Shaw (1970), is a sharp reduction in yield accompanied by a reduced ear size, row number and total number of kernels. According to Harold (1986) the potential size of the ear and the number of ovules formed are determined during the vegetative period and hence one would expect kernel numbers to be reduced by water stress. Therefore it appears that these components, which are potential contributors to yield, need to be investigated in studies where yield is the main focus, particularly in arid environments where plant productivity tends to be low due to water shortages.

Epstein et al. (1980) suggested that selection and breeding for resistance to any environmental stress ultimately depends on two factors: genetic variability with respect to resistance to stress and exposure of genetically variable populations to the stress. Both phenotypic and genotypic selection have been applied to maize in order to develop strains with the ability to thrive under limited soil moisture. Arboleda-Riverra and Compton (1974) reported results from selection for yield in three environments in the tropics--selection in either rainy or dry season was more effective than selection in both seasonal conditions. These authors suggested that selection for prolificacy in maize under severe drought conditions may result in increases under good conditions, whereas selection for prolificacy under good conditions may not carry through when the material is placed under drought stress. Moreover selection or yield testing carried out simultaneously under optimum water conditions and under water stress may provide useful information on how yield is affected and allow one to screen for genotypes that are more tolerant than others to water stress. Johnson and Geadelmann (1989) pointed out that given the importance of both drought tolerance and responsiveness to favorable conditions, selection for both may require some form of genotypic selection using multiple-environment testing.

Blum (1979) showed that there are two distinct avenues for approaching the problem of breeding for drought resistance. The first is governed by the need to improve crop yields by developing superior yielding varieties under optimal conditions that will also yield relatively well under suboptimal conditions. The second states that high potential is irrelevant and that what is important is to breed for adaptation to a specific environment such as the semiarid zone. Thus, the genetic variability that exists among and between maize species can be exploited by breeders and agronomists to develop new strains with specific traits for drought tolerance (Hunter et al., 1936). Investigations of yield which reflects the integrated effects of the many factors, has been suggested as a useful approach to select plants for their yielding ability under drought conditions (Boyer and McPherson, 1975). Selection based on a single characteristic that contributes to yield may not be satisfactory, when some other important factors are limiting.

In this study, three maize populations, developed for their ability to withstand drought and salinity, and their reciprocal crosses, were tested under induced water stress and normal moisture conditions at Marana. The primary objective of this study is to investigate grain yield and some yield components of the twelve entries and to get additional information on the intercrosses between genotypes.

MATERIALS AND METHODS

This study was conducted at the Marana Agricultural Center during the summer of 1988 on black soils classified by Post et al. (1978) as entisols. These are mineral soils with a minimum of natural genetic horizon development; they are characterized by unconsolidated materials such as recent alluviums.

Three maize populations, their six reciprocal hybrids, two commercial hybrids and one open-pollinated variety were evaluated under normal moisture conditions and induced water stress in the field. A total of 12 entries were used in the study (Table 1). The six reciprocal hybrids were single crosses made by crossing each population to the others as male, then as female. The 'Day Salt' population was a germplasm known as Arizona 8601 adapted to saline environments. Arizona 8601 has a broad genetic base and contains a number of different plant types. Genetic recombination and selection under saline conditions was performed at the Safford Agricultural Center by Dr. A. A. Day over a 20-year period. The 'Day Arid' population was released as Arizona germplasm G-P 147 adapted to arid environments (Day et al., 1986). 'Arizona/Mexico' population is a bulk of surviving entries of a CIMMYT maize drought-tolerance grain-yield test grown under rainfed

Table 1. Descriptions and symbols assigned to 12 maize entries grown under wet and dry conditions

Entry	Description	Symbol
Ariz/Mexico x Day Arid	Population cross	P_1xP_2
Day Arid x Ariz/Mexico	Population cross	P_2xP_1
Ariz/Mexico x Day Salt	Population cross	P_1xP_3
Day Salt x Ariz/Mexico	Population cross	P_3xP_1
Day Arid x Day Salt	Population cross	P_2xP_3
Day Salt x Day Arid	Population cross	P_3xP_2
Ariz/Mexico	Population parent	P_1
Day Arid	Population parent	P_2
Day Salt	Population parent	P_3
Page Ranch	Open-pollinated variety	Page
DeKalb 689	F_1 Hybrid	DK 689
DeKalb XL 72 AA	F_1 Hybrid	DK 72

conditions in an Avra Valley, Arizona desert area. 'Page Ranch' is an improved population from Arizona/Mexico but had undergone addition improvements. DeKalb 689 and DeKalb XL 72 AA are both commercial hybrids.

The experiment was machine planted on 14 June 1988, using randomized complete blocks arranged in a split-plot design. The two main-plot treatments consisted of normal moisture and restricted irrigation. Restricted irrigation was meant to create moisture stress conditions throughout the growing season. The main treatments will be referred to as "wet" and "dry". Wet plots received 818 mm of water in seven irrigations and dry plots received 503 mm in five irrigations. Each main plot treatment was replicated twice and divided into four randomized complete blocks to which 12 genotypes were randomly assigned. Each plot was 6.1 m long with 1.02 m between rows. Four rows were planted, the two outer rows served as borders and the two inner rows were sampled. Thinning produced a stand of 48 plants per row with a plant density of 77138 plants ha^{-1}.

Prior to maturity, lodging was scored for each entry across irrigation treatments. A score ranging from 1 to 5 was assigned to entries, with 1 indicating no lodging and 5 indicating severe lodging. Data were collected on grain yield, number of ears per plant, kernel number per ear, five-hundred-seed weights and lodging. Five hundred seeds were counted with an electronic seed counter and weighed with a precision balance. Also data were recorded for some plant characteristics: ear number per plot, ear weight, kernel weight per ear, ear length, test weight and percent shelling.

Analysis of variance was carried out within each irrigation level, and mean separation was performed using Duncan's Multiple Range Test for ranking the different entries for grain yield, yield components, and lodging. Regressions were performed between percent yield reduction as the dependent variable and percent yield component reduction as the independent variable. Regressions between mid-parent heterosis for yield from the wet treatment and the relative yield were computed for the six hybrid populations. The same procedure was applied using mid-parent heterosis for yield from the dry treatment as dependent variable. Correlations were calculated between mid-parent heterosis for yield as observed in dry conditions and mid-parent heterosis for yield as observed in wet conditions.

Percent yield reduction and yield component reduction were computed using the formula: (Yield from wet treatment)-(Yield from dry treatment) x 100 / (Yield from wet treatment) (Aguilar and Villareal, 1989). The same procedure was applied to compute percent yield component reduction. Relative yield was determined as yield from the dry treatment divided by yield from the wet treatment multiplied by 100, and this was used as a criterion of drought tolerance (Williams et al., 1967; Mederski and Jeffers, 1973). Mid-parent heterosis, a measure of the genetic divergence between the three populations was computed as $(F_1 - MP) \times 100 / MP$, where F_1 is the hybrid and MP the mid-parent mean (Zanoni and Dudley, 1989). Values for mid-parent heterosis were obtained for each replication and analysis of variance was preformed to calculate the least significant difference (LSD).

RESULTS AND DISCUSSION

Grain Yield

a) Wet conditions

The commercial hybrid DK 689 was the highest yielding cultivar under wet conditions. Its grain yield was significantly different from all the other entries. This hybrid outyielded the other commercial hybrid (DK 72) by 38.4% in wet conditions. Among the three populations in the study, P_1 was the highest yielding. Its yield under wet conditions was significantly different from the two other populations, P_2 and P_3. The lowest yielding population was P_3 with 4759 kg/ha (Table 2). The hybrid P_1xP_3, which is the progeny of the highest yielding (P_1) and the lowest yielding populations (P_3), is the most promising hybrid population with a yield of 7132 kg/ha. This hybrid outyielded P_3xP_2, P_2xP_3, DK 72, P_2 and P_3. The genotypes P_1xP_3 and P_1xP_2, which have one female parent in common showed a good yielding ability. P_1 combined well as the female parent with the two other populations.

Table 2. Grain yields (kg/ha), yield rankings, and percentages of yield reduction of twelve maize entries grown under wet and dry conditions.

Genotype	Wet Yield		Rank	Dry Yield		Rank	% Yield Reduction
DK 689	8321.5	a	1	4775.0	ab	2	43
P_1xP_3	7131.6	b	2	4400.3	abc	3	38
P_1xP_2	6982.0	b	3	4063.4	abcd	4	42
P_1	6798.5	bc	4	3971.5	bcd	6	42
Page	6721.8	bcd	5	4823.3	a	1	28
P_3xP_1	6613.3	bcd	6	3707.4	cd	8	44
P_2xP_1	6553.0	bcd	7	3722.6	cd	7	43
P_3xP_2	6191.5	cd	8	4056.3	abcd	5	34
P_2xP_3	6061.0	cd	9	3615.9	cd	9	40
DK 72	6009.4	de	10	2605.8	e	12	57
P_2	5421.8	ef	11	3357.6	ed	10	38
P_3	4759.1	f	12	2742.0	e	11	42
Mean	6464.0			3820.1			41

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

b) Dry conditions

The Page variety, which ranked fifth under wet conditions, was the highest yielding entry under dry conditions, whereas the commercial hybrid DK 689 ranked second. P_1xP_3 and P_1xP_2 hybrids displayed relatively good yielding ability in wet conditions as well as in dry conditions. No significant differences were detected at the 0.05 level between experimental population hybrids (Table 2). Hybrid P_3xP_2 improved its relative performance under dry conditions and outyielded its male parent (P_3). DK 72 was the lowest yielding entry under dry , whereas P_2 and P_3 slightly improved their ranks relative to wet.

Figure 1 shows a significant correlation ($p < 0.05$) between grain yield under wet and dry conditions indicating that the screening of the present material could have been carried out either in wet or dry conditions. Therefore the suggestion, made by Blum (1979) to breed under optimal conditions for genotypes with high yield potential so that there would be a carry over when the material is placed under suboptimal conditions, is substantiated by this study. Moreover Mederski and Jeffers (1973) suggested that the non-stress environment would allow the greatest genetic expression for the yield and maximize the differences in genetic potential. However Epstein (1980) advocated the approach consisting of exposing genetically variable

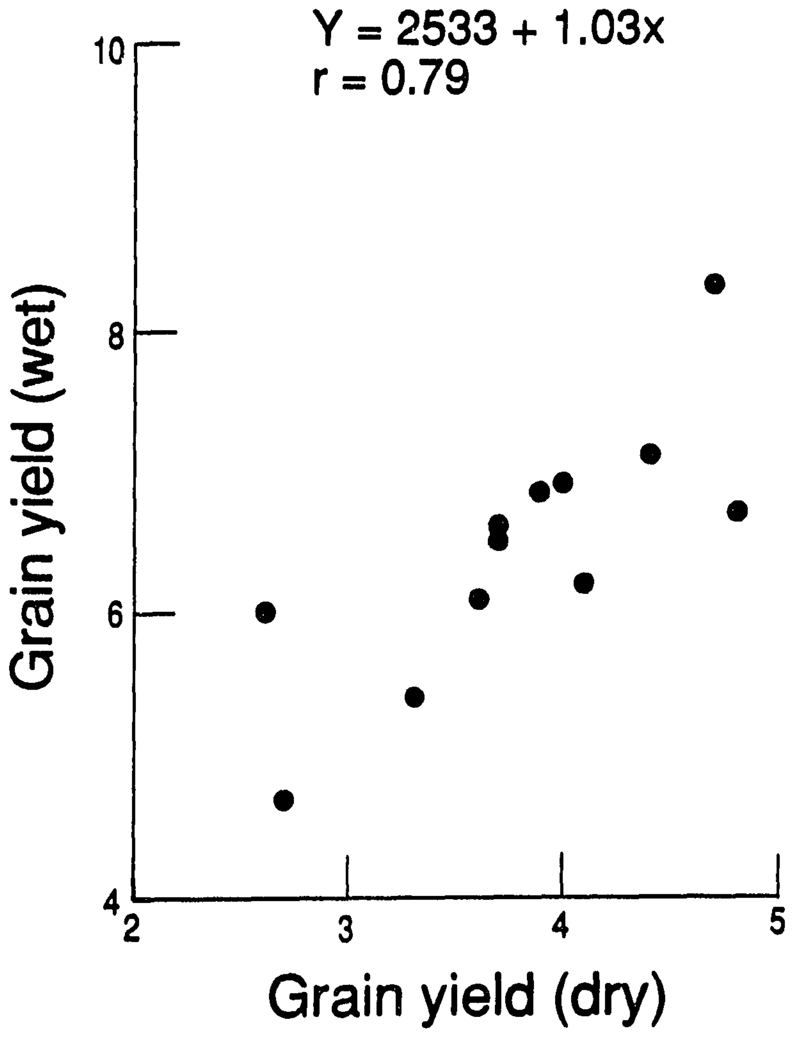

Fig. 1 Relationship between grain yield (t/ha) of 12 entries grown under wet and dry conditions.

populations to the stress so that individuals possessing the desired phenotype could be identified and selected. Arboleda-Rivera and Compton (1974) think that selection under optimal conditions may not carry through when the material is placed under suboptimal conditions.

Yield components

1. Number of ears per plant

Under wet conditions the genotype DK 689 had a number of ears per plant significantly greater than the other entries excluding P_1xP_2 (Table 3). Among the three populations P_1 had a significant greater number of ears per plant than P_2 and P_3, whereas P_2 was better than P_3. Among the hybrid populations P_1xP_2, which showed no reciprocal differences with its reciprocal, had a significant greater number of ears per plants than the other hybrid populations. No statistically significant reciprocal differences were observed.

Under dry conditions there were no significant differences between DK 689 and P_1xP_2. The genotype P_3xP_2, which had a significant lower number of ears per plant than DK 689 and P_1xP_2 under wet conditions , was as good as these two genotypes under dry conditions. Among the three populations P_1 had the greatest number of ears per plant.

Table 3. **Number of ears per plant and percentages of ear number reduction of twelve maize entries grown under wet and dry conditions**

Genotype	Wet Ears plant^{-1}	Dry Ears plant^{-1}	% ear number reduction
DK 689	0.92 a	0.72 ab	21.73
P_1xP_2	0.87 ab	0.77 a	11.49
P_1	0.84 bc	0.67 b	20.23
P_2xP_1	0.80 bcd	0.67 b	16.25
P_3xP_2	0.79 cde	0.72 ab	8.86
P_1xP_3	0.77 de	0.69 b	10.38
P_3xP_1	0.76 de	0.69 b	9.21
Page	0.74 def	0.68 b	8.10
P_2	0.72 ef	0.68 b	5.55
P_2xP_3	0.72 ef	0.67 b	6.94
DK 72	0.67 fg	0.38 d	43.28
P_3	0.63 g	0.56 c	11.11
Mean	0.76	0.65	14.47

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Significant differences were observed between P_1xP_2 and its reciprocal.

A significant correlation was found between the number of ears per plant and grain yield in wet and dry conditions, respectively (r = 0.84) and (r = 0.74). These findings suggest that prolificacy as mentioned by Arboleda-Rivera and Compton (1974) might be useful in identifying genotypes with increased grain yield under limited soil moisture.

2. Kernel number per ear

Under wet conditions the genotype DK 689 had a number of kernels per ear significantly greater than any of the other entries (Table 4). Among the three populations P_3 had a number of kernels per ear significantly greater than P_1, whereas P_3 and P_2 had no significant differences. The hybrid populations P_1xP_3, P_3xP_1, P_3xP_2, and P_2xP_3 showed no significant differences. The hybrid P_1xP_3 had a number of kernels per ear significantly greater than P_2xP_1 and P_1xP_2 whereas hybrid P_3xP_1 outyielded P_1xP_2. The study revealed no significant reciprocal differences between hybrid populations.

Under dry conditions there were no significant differences in number of kernels per ear between genotypes DK 689, P_1xP_3, P_3 and P_3xP_2. No significant differences were noted between populations P_3, P_2 and P_1 whereas under wet

Table 4. Kernel number ear^{-1} ad percentages of kernel number reduction of twelve maize entries grown under wet and dry conditions

Genotype	Wet Kernels ear^{-1}	Dry Kernels/ear^{-1}	% kernel number reduction
DK 68	488 a	333 a	32
P_1xP_3	428 b	317 ab	26
P_3xP_1	411 bc	306 abcde	26
P_3	407 bc	304 abcde	25
P_3xP_2	406 bcd	311 abcd	23
P_2xP_3	405 bcd	298 bcde	26
P_2	401 cd	281 cde	30
P_2xP_1	400 cd	272 cde	32
Page	385 d	315 abc	18
P_1xP_2	381 de	279 de	27
P_1	360 ef	282 cde	22
DK 72	350 f	277 de	21
Mean	402	280	26

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

conditions P_3 topped P_1. The hybrid population P_1xP_3 had a greater number of kernels per ear than P_2xP_1 and P_1xP_2. No significant reciprocal differences were observed for this trait.

From wet to dry conditions a decrease up to 32% was observed in genotypes DK 689 and P_2xP_1. This loss in kernels per ear may be explained by what Westgate and Boyer (1986) observed. These two authors suggested that decreased grain production due to low water potential around anthesis may be associated with disruption in megasporogenesis prior to anthesis, failure in tassel emergence, or embryo collapse preventing seed development.

3. **Seed weight**

The genotype DK 72 which showed the lowest kernels per ear had a seed weight significantly greater than all the other entries under both irrigation treatments (Table 5). P_1 and Page genotypes followed the same pattern whereas the genotype DK 689, which had the greatest number of kernels per ear, showed the lowest seed weight under wet conditions. Among the three populations P_1 had a seed weight significantly greater than P_2 and P_3 under both irrigation treatments. Among the hybrid populations P_1xP_3, P_1xP_2 and P_3xP_1 showed a significant greater seed weight than P_3xP_2 under wet conditions. However under dry conditions P_3xP_2

Table 5. 500 seed weights (g) and percentages of seed weight reduction of twelve maize entries grown under wet and dry conditions

Genotype	Wet Seed weight	Dry Seed weight	% seed weight reduction
DK 72	131.0 a	126.5 a	3
Page	119.7 b	114.2 b	5
P_1	116.2 b	107.6 bc	7
P_1xP_3	109.1 c	104.0 cd	5
P_1xP_2	108.8 c	97.1 de	11
P_3xP_1	108.5 c	90.3 e	17
P_2xP_3	107.0 cd	93.1 e	13
P_2xP_1	105.6 cd	104.8 cd	1
P_3xP_2	101.0 de	92.6 e	8
P_2	97.0 e	89.6 e	7
P_3	97.0 e	81.5 f	15
DK 689	95.0 e	101.0 cd	6
Mean	107.9	100.2	8

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

showed almost no decrease in seed weight and exceeded, for this trait, the hybrid populations P_3xP_1 and P_2xP_3. Only P_1xP_3 hybrid showed a seed weight significantly greater than its reciprocal P_3xP_1 under dry conditions. The genotypes DK 72 and P_1 which had a relative small number of kernels per ear were among the genotypes which showed the greatest seed weight under both irrigation treatments. Kiniry et al (1990) reported that a reduction in seed number in maize due to restricted pollination may bring about an increase in seed weight. In the present study the increased seed weight in relation to the number of kernels was observed in both irrigation treatments.

The decrease of yield that resulted from drought was not correlated with most of the yield components that were measured (Table 6). Only the correlations between the decrease in the number of ears per plant and the reduction in grain yield were significant ($r = 0.81$). The approach used in this study is similar to that used by Blum in sorghum (1973). This author regressed each component in the two environments (stress and non-stress) with differences in yield and he found only one significant correlation--between differences in the number of panicles m^{-2} and differences in yield.

The decrease observed in the number of ears per plant may have resulted from failure of the reproductive parts

Table 6. Yield components and coefficients of determination (R^2) from regressions between % yield reduction and % yield component reduction in 12 maize entries grown under wet and dry conditions

Yield Components	R^2 (Components vs yield reduction)
Ears plant^{-1}	0.65
500 seed weight	0.00
Kernel numbers ear^{-1}	0.02

occasioned by water stress (Westgate and Boyer, 1986). Furthermore Herrero and Johnson (1981) observed a delay in silking after all or much of the pollen had shed creating large numbers of barren or poorly filled ears. As observed in this study some plants, in the dry conditions, had poorly filled ears as a result of water stress.

The differences between reciprocal crosses for some yield components in this study were observed only in dry conditions, and this indicates that selection can still be carried out under water stress conditions. This study failed to show significant differences for grain yield between reciprocal crosses. However significant differences, for this character, were found elsewhere and a suggestion was made that cytoplasmic inheritance was involved (Eagles and Hardacre, 1989).

Standability

Lodging was assessed in this study because of its importance and relation with yield. Significant differences were observed both under wet and dry conditions. The commercial hybrid DK 689 showed no lodging under both conditions. DK 72 and Page had a good standability under both irrigation treatments (Table 7).

Table 7. Mean lodging scores of twelve maize entries grown under wet and dry conditions

Genotype	Wet Lodging score	Dry Lodging score
P_2xP_3	3.5 a	3.1 abc
P_3	3.3 ab	3.6 a
P_2	3.2 ab	3.6 a
P_3xP_2	3.0 ab	3.2 ab
P_3xP_1	2.7 bc	2.5 c
P_2xP_1	2.7 bc	3.1 abc
P_1xP_3	2.5 cd	2.7 bc
P_1xP_2	2.3 cd	2.7 bc
P_1	1.8 de	2.5 c
Page	1.6 de	2.5 c
DK 72	1.1 f	1.0 d
DK 689	1.0 f	1.0 d
Mean	2.4	2.6

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Among the three populations P_1 had the best standability under both conditions, whereas P_2 and P_3 showed relatively high susceptibilty to lodging. Except for P_2xP_3, which displays a relative high susceptibility to lodging under stress and non-stress conditions, the other hybrid populations were moderately susceptible to lodging. From wet to dry conditions the genotype responses to lodging were very similar. A significant correlation ($r = 0.9$) was found between lodging score as observed in wet and dry conditions. The good standabilty of Page, DK 689, DK 72 genotypes may be attributable to the effect of selection applied to develop these strains. P_2 and P_3, which are susceptible to lodging, may need more improvement for this character.

Heterosis

a) Yield

Under wet conditions the genotypes P_3xP_2 and P_1xP_3 had a level of heterosis significantly greater than P_2xP_1 (Table 8). The differences between P_1xP_2, P_1xP_3, P_3xP_1 and P_2xP_1 were not significant. Under dry conditions the genotypes P_1xP_3 and P_3xP_2 also showed a heterosis for grain yield significantly greater than the genotye P_2xP_1. No significant reciprocal differences were noted under either of the two irrigation treatments.

Table 8. Mid-parent heterosis for grain yield of six hybrid maize populations grown under wet and dry conditions

Cross	Wet	% Heterosis	Dry
P_1xP_2	14.2 ab		10.8 ab
P_2xP_1	7.2 b		1.5 b
P_1xP_3	23.4 a		31.0 a
P_3xP_1	14.4 ab		10.4 ab
P_2xP_3	19.0 ab		18.5 ab
P_3xP_2	21.6 a		32.9 a
Mean	16.6		17.5
LSD	12.8		28.0

Means followed by the same letter within a column are not different at 0.05 level.

Heterosis, which may serve as a guide for genetic divergence between different populations (Lonnquist and Gardner, 1961), was not eliminated by water stress. The positive and significant correlations obtained for grain yield heterosis as observed in wet and dry conditions indicate that heterosis was well expressed in the different genotypes despite the water stress conditions that were imposed. Furthermore McWilliam and Griffing (1965) observed increased heterosis in certain maize hybrids grown at super-optimal temperatures. Also increased heterosis under stress conditions has been reported by Srivastava (1983). A "covering" of deleterious alleles within the three populations that were intercrossed could account for a heterosis value of the magnitude observed. Dominant favorable alleles present in one population may have masked deleterious alleles present in the other and vice-versa. Another reason for increased heterosis may arise from inter-allelic interactions of genes located at different loci.

A highly significant correlation ($r = 0.90$) was noted between heterosis for yield under drought conditions and relative yield (Fig. 2). A much lower correlation ($r = 0.77$) was obtained between heterosis under wet conditions and relative yield (Fig. 3). A high correlation ($r= 0.95$) was observed between heterosis in wet and in dry conditions (Fig. 4).

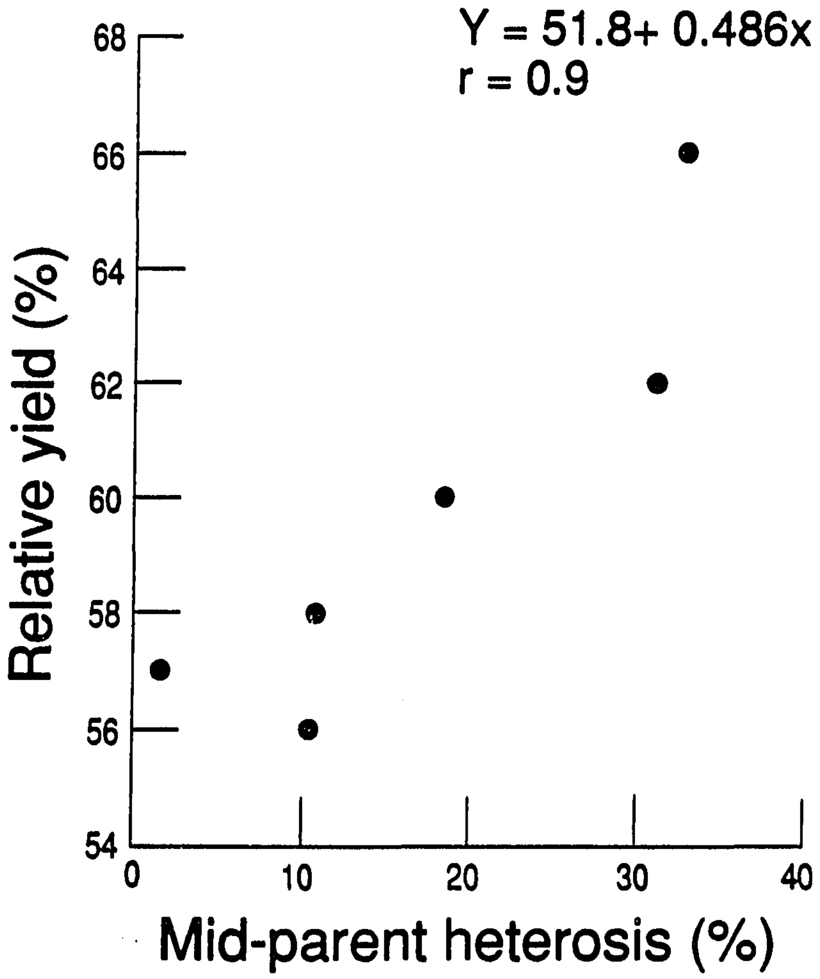

Fig. 2 Correlation between mid-parent heterosis for yield as observed in dry conditions, and relative yield in six maize hybrid populations.

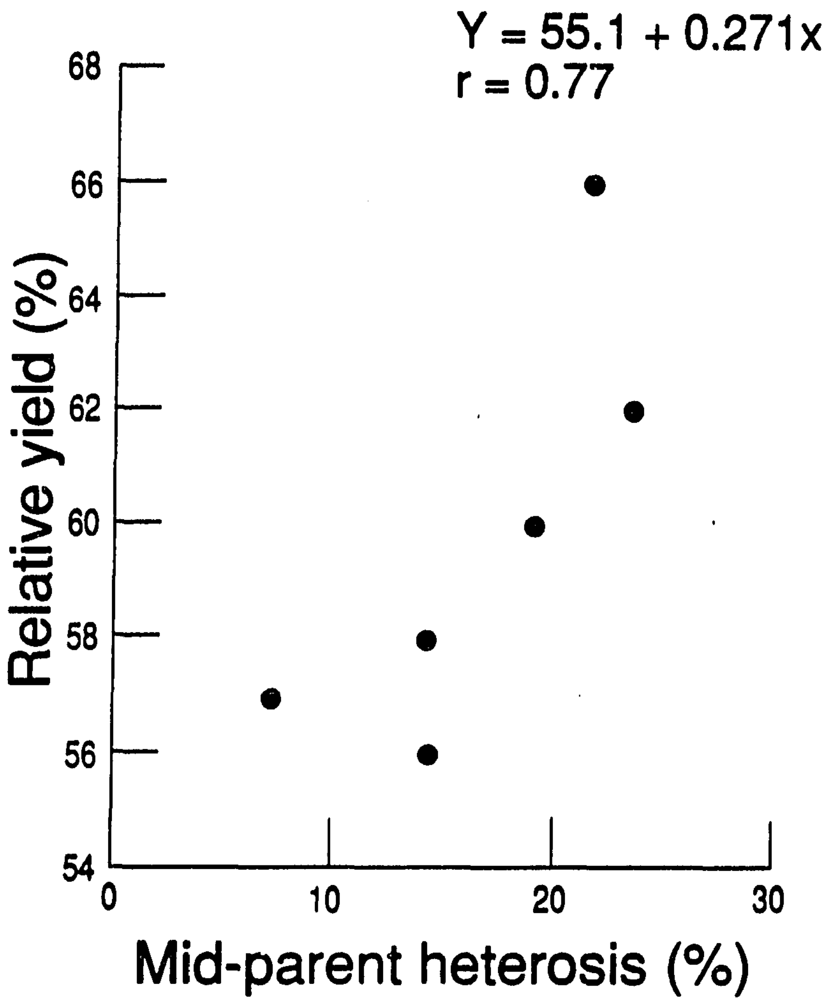

Fig. 3 Correlation between mid-parent heterosis for yield as observed in wet conditions, and relative yield in six maize hybrid populations.

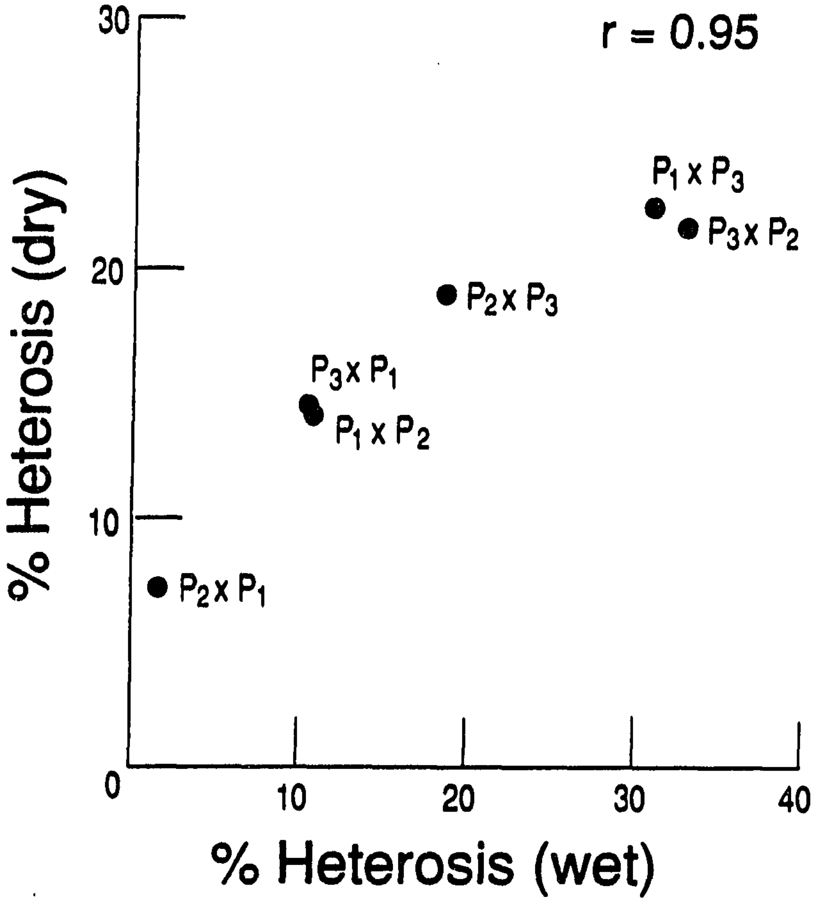

Fig. 4 Scatter diagram showing relationship of mid-parent heterosis for yield in six maize hybrid populations grown under wet and dry conditions.

Eagles and Hardacre (1989) found a level of heterosis of 9.1% on average basis for grain yield. In this study the level was much higher--16.6 and 17.5% respectively under wet and dry conditions. Lamkey et al. (1988) observed mid-parent heterosis for grain yield in the range of 9.4 to 20%. These observations indicate that an increase of heterotic loci, through recurrent selection, may favor genotypes with increased tolerance to drought since additive gene action appears to be an important factor contributing to the genetic control of drought-tolerance in maize (Williams et al., 1969); Trapani and Motto, 1984).

Johnson and Geadelmann (1989) found a gain of 7.1% per cycle in maize genotypes to which mass selection was applied under high moisture. Under low moisture, gains were very low (1.2%). Recurrent selection (full-sib) under high moisture gave a slightly higher result than mass selection; a gain of 7.9% per cycle was obtained. Under low moisture a gain of 6.2% was obtained with the full-sib method.

Because of the the high level of heterosis present in this material, more genetic progress can be expected from the three basic populations under study. The best use possible should be made of the favorable alleles present in the three basic populations and the open-pollinated variety as well, by forming a foundation population. The three basic populations and the open-pollinated variety may serve as source populations. They can be combined to form a segregating population from which lines with increased heterotic potential can be extracted. An alternative, outlined in Fig. 5, is to form a foundation population followed by recurrent selection using either the half-sib or full-sib method or both. The favorable genotypes will be self-pollinated to produce inbred lines that will be tested before release. Another option would be the crossing of promising inbred lines to form hybrids that will be released after testing. This testing could include yield stability analysis (Eberhart and Russell, 1969) to identify genotypes with the greatest phenotypic plasticity.

b) Yield components

1. Number of ears per plant

The genotype P_3xP_2 had, in wet conditions, a level of heterosis significantly greater than P_2xP_1, P_1xP_3 and P_3xP_1 (Table 9). No statistically significant differences were observed, in dry conditions, between P_1xP_2, P_1xP_3, P_3xP_1, P_2xP_3 and P_3xP_2. However significant differences were observed between P_1xP_2 and its reciprocal in dry conditions.

2. Seed weight

In dry conditions the genotypes P_1xP_3, P_3xP_2 and P_2xP_3 showed a heterosis which was significantly greater than that

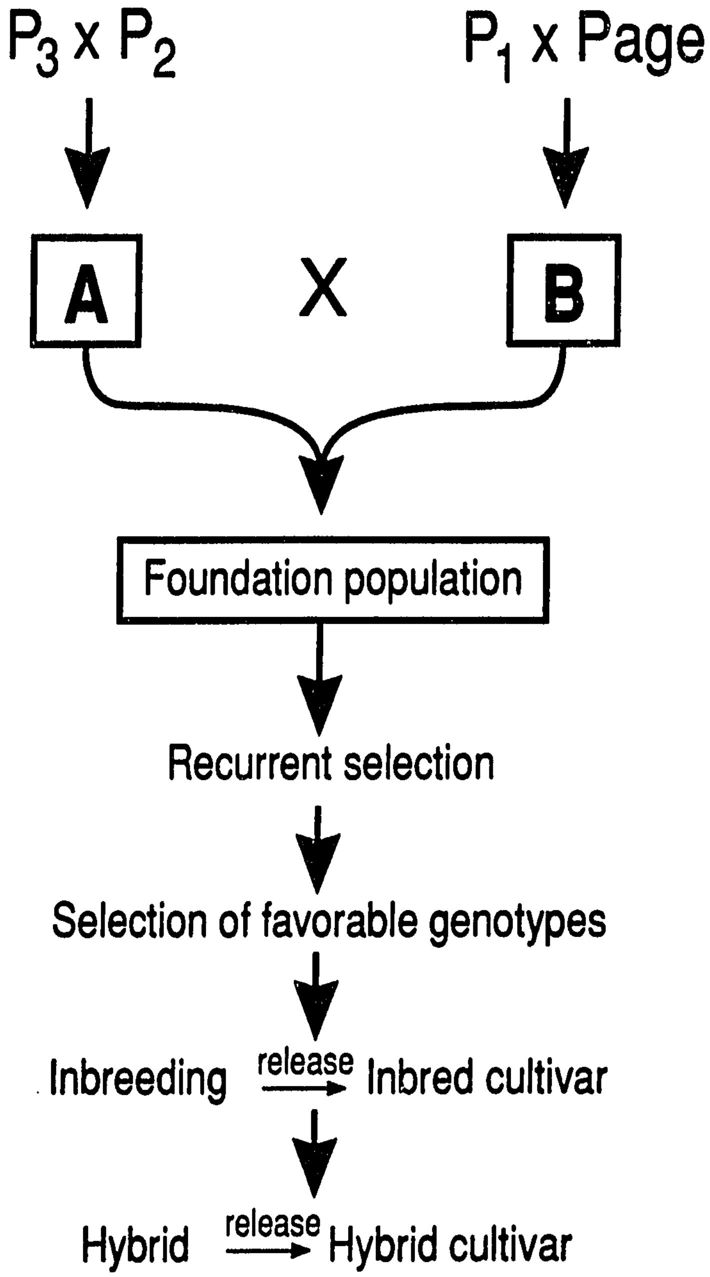

Fig. 5 An example of a formation of foundation population followed by recurrent selection

Table 9. Mid-parent heterosis for number of ears/plant of six hybrid maize populations grown under wet and dry conditions

Cross	Wet	% Heterosis	Dry
P_1xP_2	11.5 ab		13.2 a
P_2xP_1	2.5 b		-1.4 b
P_1xP_3	4.0 b		11.2 a
P_3xP_1	2.7 b		11.2 a
P_2xP_3	7.4 ab		8.0 a
P_3xP_2	17.9 a		16.1 a
Mean	7.6		10.2
LSD	10.5		11.4

Means followed by the same number within a column are not different at 0.05 level.

observed in genotypes P_2xP_1, P_3xP_1 and P_1xP_2. Significant differences existed between P_1xP_3, P_2xP_1 and their reciprocals (Table 10).

In wet conditions the genotype P_2xP_3 had a significant greater heterosis than all the other hybrid populations excluding its reciprocal P_3xP_2. Differences among the other entries were not significant.

3. Kernel number per ear

No statistically significant differences were observed in dry conditions, whereas in wet conditions the genotypes P_1xP_3 and its reciprocal showed a greater heterosis than the genotypes P_3xP_2, P_2xP_3 and P_1xP_2 (Table 11). No significant reciprocal differences were noted.

Mitochondria and chloroplast involvement provide a clue whether cytoplasmic or maternal inheritance would contribute to heterosis. This may explain some of the differences observed between reciprocal crosses. Therefore cytoplasmic inheritance should be considered when utilizing the three basic populations.

Based on what was observed in this study, the direction of crosses could be extremely determinant in genetic gains that can be expected from selection. However the probability of selecting genotypes with a high frequency of heterotic loci depends on the magnitude of heterosis that

Table 10. **Mid-parent heterosis for 500-seed weights of six hybrid maize populations grown under wet and dry conditions**

Cross	Wet	% Heterosis	Dry
P_1xP_2	2.0 b		-2.0 c
P_2xP_1	-0.4 b		6.0 b
P_1xP_3	2.0 b		9.0 a
P_3xP_1	2.0 b		5.0 b
P_2xP_3	10.0 a		8.0 a
P_3xP_2	4.0 b		8.0 a
Mean	3.2		5.6
LSD	5.5		1.1

Means followed by the same letter within a column are not different at 0.05 level.

Table 11. Mid-parent heterosis for kernel number/ear of six hybrid maize populations grown under wet and dry conditions

Cross	Wet	% Heterosis	Dry
P_1xP_2	0.1 c		-0.8 a
P_2xP_1	5.1 bc		-3.0 a
P_1xP_3	11.6 a		8.0 a
P_3xP_1	7.1 ab		4.4 a
P_2xP_3	0.2 c		-1.8 a
P_3xP_2	0.4 c		6.3 a
Mean	4.1		2.2
LSD	5.8		13.7

Means followed by the same letter within a column are not different at 0.05 level.

will result from crosses. In the future only mid-parent heterosis values that are in the favorable direction will be worthy of consideration. Data on plant characteristics showed significant differences within the irrigation treatments for all characteristics studied (Appendices A-I, A-II, A-III, A-IV, A-V and A-IV). Ear number per plot, ear weight, kernel weight per ear and ear length were reduced on an average basis from wet to dry treatment by 14.3, 40, 30.6 and 10.65% respectively. The reduction in ear number per plot, ear weight and ear length were positively correlated with the reduction in grain yield respectively, $r = 0.65$, $r = 0.96$ and $r = 0.27$. Heterosis, for ear weight, ear number per plot, kernel weight per ear and ear length, was well expressed under both irrigation treatments (Appendices B-I, B-II, B-III and B-IV). Some genotypes showed a negative heterosis for test weight and percent shelling (Appendices B-V and B-VI).

SUMMARY AND CONCLUSIONS

Drought tolerance in terms of yield and its components was studied in twelve maize (Zea mays L.) genotypes. Three populations developed for their ability to withstand drought and salinity, and their reciprocal crosses, were tested under induced water stress and normal moisture conditions at the Marana Agricultural Center in the summer of 1988. Two commercial hybrids and one open-pollinated variety were also included in the study.

Under water stress conditions, plots were irrigated less compared to non-stress conditions where plants did not experience any water restriction. Significant genotypic differences in grain yield and yield components were observed in both irrigation treatments. Also significant correlations were noted in grain yield as observed in wet and dry conditions. The genotypes with increased yield in wet conditions showed a similar response in dry conditions as well. The significant correlations found between the number of ears per plant and the grain yield indicate that prolificacy could be a selection criteria for increased grain yield under water stress conditions.

Data from populations that were intercrossed revealed a sizeable amount of heterosis and a high positive correlation was noted between mid-parent heterosis for yield and relative yield.

In the future a selection program based on a recurrent selection scheme, may be used to increase the frequency of heterotic loci and to identify genotypes with increased tolerance to drought. In this attempt the three basic populations as well as the open-pollinated variety (Page) could be used to form a foundation population followed by some form of recurrent selection.

Appendix A-I. Ear number per plot and percentages of ear number reduction of twelve maize entries grown under wet and dry conditions

Genotype	Wet Ear number	Dry Ear number	% Ear number reduction
DK 689	89 a	70 ab	21
P_1xP_2	84 ab	75 a	11
P_1	81 bc	65 b	20
P_2xP_1	78 bc	65 b	17
P_3xP_2	76 cde	69 ab	9
P_1xP_3	74 de	66 b	11
P_3xP_1	73 de	66 b	10
Page	71 de	65 b	8
P_2	70 def	66 b	5
P_2xP_3	70 def	65 b	7
DK 72	65 fg	37 d	43
P_3	61 g	55 c	10
Mean	74	64	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix A-II. **Ear weight (kg/ha) and percentages of ear weight reduction of twelve maize entries grown under wet and dry conditions**

Genotype	Wet Ear weight	Dry Ear weight	% Ear weight reduction
DK 689	9913.0 a	5749.3 ab	42
P_1xP_2	9018.9 b	5137.0 abcd	43
P_1	8480.9 bc	5002.6 abcd	41
P_1xP_3	8478.5 bc	5463.4 abc	36
Page	8254.8 bc	5946.9 a	28
P_3xP_1	8186.8 bc	4919.5 bcd	40
P_2xP_2	8132.8 bc	4889.6 bcd	40
P_3xP_2	7768.0 c	5302.1 abc	32
DK 72	7695.1 c	3245.5 f	58
P_2xP_3	7581.3 cd	4622.3 cd	39
P_2	6794.6 de	4223.8 de	38
P_3	6454.6 e	3570.8 ef	45
Mean	8063.0	4839.0	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix A-III. **Kernel weight ear^{-1} (g) and percentages of kernel weight reduction of twelve maize entries grown under wet and dry conditions**

Genotype	Wet Kernal Weight/ ear	Dry Kernal Weight/ ear	% Reduction kernal weight
P_1xP_3	93.2 a	66.1 abc	29
DK 689	92.3 a	66.8 abc	27
Page	92.1 a	72.6 a	21
DK 72	91.2 ab	70.0 ab	23
P_3xP_1	89.2 ab	56.0 de	37
P_2xP_3	86.7 abc	55.7 de	36
P_2xP_1	84.5 bcd	57.2 cde	33
P_1	83.5 cd	61.2 bcd	27
P_1xP_2	83.1 cd	54.6 de	34
P_3xP_2	83.1 cd	58.0 cde	29
P_3	78.5 d	49.8 e	37
P_2	77.6 d	50.6 e	35
Mean	86.2	60.0	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix A-IV. **Ear length (cm) and percent ear length reduction of twelve maize entries grown under wet and dry conditions**

Genotype	Wet Ear length	Dry Ear length	% Ear length reduction
DK 689	14.6 a	12.8 a	12
DK 72	13.9 ab	11.7 cd	16
P_3xP_2	13.5 bc	11.8 cd	17
Page	13.3 bc	12.7 ab	5
P_2xP_1	13.1 bc	11.7 cd	11
P_1xP_2	13.1 bc	11.8 bcd	10
P_1xP_3	12.9 c	11.9 bcd	8
P_3xP_1	12.9 c	11.6 cd	10
P_1	12.8 c	11.4 cd	11
P_2xP_3	12.8 c	11.5 cd	10
P_2	12.6 c	12.0 abc	5
P_3	12.6 c	11.0 d	13
Mean	13.0	12.0	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix A-V. Mean test weight (kgm^{-3}) and test weight ratio of twelve maize entries grown under wet and dry conditions

Genotype	Wet Test weight	Dry Test weight	Ratio (D/W)
P_2xP_3	809.6 a	813.7 a	1.01
P_2	795.8 ab	797.8 ab	1.00
P_1xP_3	795.3 ab	794.1 ab	0.99
P_3xP_2	794.1 ab	796.7 ab	1.00
P_3xP_1	793.1 ab	792.8 ab	1.00
P_2xP_1	790.1 ab	785.6 b	0.99
DK 689	789.7 ab	789.2 ab	1.00
P_1xP_2	787.7 ab	795.7 ab	1.01
Page	787.0 ab	793.0 ab	1.01
DK 72	780.6 b	786.8 b	1.01
P_1	779.7 b	785.1 b	1.01
P_3	777.5 b	789.5 ab	1.02
Mean	790.0	793.0	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix A-VI. Percent shelling and percent shelling ratio of twelve maize entries grown under wet and dry conditions.

Genotype	Wet % shelling	Dry % shelling	Ratio (D/W)
DK 689	83.2 a	82.2 a	0.99
P_1xP_3	81.7 ab	80.5 ab	0.99
P_2xP_1	80.2 ab	75.6 cd	0.94
P_3xP_1	79.7 ab	74.6 d	0.94
P_2xP_3	79.7 ab	77.3 bcd	0.97
P_3xP_2	79.6 ab	76.5 bcd	0.96
P_1	79.5 ab	79.1 abcd	0.99
P_2	79.5 ab	78.8 abcd	0.99
Page	79.3 ab	79.1 abcd	1.00
DK 72	77.3 bc	80.0 abc	1.03
P_1xP_2	77.2 bc	79.1 abcd	1.02
P_3	74.1 c	76.0 bcd	1.02
Mean	79.0	78.0	

Means followed by the same letter within a column are not different at 0.05 level based on Duncan's Multiple Range Test.

Appendix B-I. Mid-parent heterosis for ear weight of six hybrid maize populations grown under wet and dry conditions

Cross	Wet	% Heterosis	Dry
P_1xP_2	18		11.3
P_2xP_1	6.4		5.9
P_1xP_3	13.5		27.4
P_3xP_1	9.6		14.7
P_2xP_3	14.4		18.5
P_3xP_2	17.2		36.0
Mean	13.1		18.5

Appendix B-II. **Mid-parent heterosis for ear number per plot of six hybrid maize populations grown under wet and dry conditions**

Cross	Wet	% Heterosis	Dry
P_1xP_2	11.0		14.0
P_2xP_1	3.0		-0.7
P_1xP_3	4.0		10.0
P_3xP_1	2.0		10.0
P_2xP_3	6.0		7.0
P_3xP_2	16.0		14.0
Mean	6.8		9.0

Appendix B-III. Mid-parent heterosis for kernel weight/ear of six hybrid maize populations grown under wet and dry conditions

Cross	% Heterosis	
	Wet	Dry
P_1xP_2	3.1	-1.7
P_2xP_1	5.5	1.7
P_1xP_3	19.2	18.9
P_3xP_1	14.1	0.9
P_2xP_3	10.8	10.8
P_3xP_2	4.4	14.8
Mean	9.5	7.5

Appendix B-IV. Mid-parent heterosis for ear weight of six hybrid maize populations grown under wet and dry conditions

Cross	Wet	% Heterosis	Dry
P_1xP_2	3.1		0.8
P_2xP_1	3.1		0.0
P_1xP_3	1.5		6.2
P_3xP_1	1.5		3.5
P_2xP_3	7.1		0.0
P_3xP_2	7.1		2.6
Mean	2.9		2.2

Appendix B-V. **Mid-parent heterosis for test weight of six hybrid maize populations grown under wet and dry conditions**

Cross	% Heterosis	
	Wet	Dry
P_1xP_2	0.0	0.5
P_2xP_1	0.3	-0.7
P_1xP_3	2.1	0.8
P_3xP_1	1.8	0.6
P_2xP_3	2.9	2.5
P_3xP_2	0.9	0.3
Mean	1.3	0.6

Appendix B-VI. **Mid-parent heterosis for percent shelling of six hybrid maize populations grown under wet and dry conditions**

Cross	% Heterosis	
	Wet	Dry
P_1xP_2	-3.5	0.0
P_2xP_1	0.0	-3.7
P_1xP_3	6.4	4.5
P_3xP_1	3.8	-3.2
P_2xP_3	3.8	-0.6
P_3xP_2	3.8	-0.6
Mean	2.3	-0.6

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