
*Tropical and
Subtropical
Agroecosystems*

**SCREENING FOR MOISTURE DEFICIT TOLERANCE IN FOUR MAIZE
(*Zea mays* L.) POPULATIONS DERIVED FROM DROUGHT TOLERANT
INBRED X ADAPTED CULTIVAR CROSSES**

**[BÚSQUEDA DE TOLERANCIA A DEFICIT DE HUMEDAD EN
CUATRO POBLACIONES DE MAÍZ (*Zea mays* L.) DERIVADAS DE
CRUZAS ENDOGAMICAS DE CULTIVARES TOLERANTES A SEQUÍA]**

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SUMMARY

Efficiency of soil water utilization under moisture deficit condition can help reduce the adverse effects of drought stress in crops. Growth, physiological responses and grain yield loss due to moisture deficits around flowering, were investigated in maize populations derived by reciprocal crosses between two adapted maize cultivars (DMR-LSR-Y and AFO) and two drought tolerant (DT) inbred lines (DT-S3-Y and DT-S3-W) under glass house conditions. The crosses and their parents and crosses were subjected to irrigation treatments equivalent to 25, 50, 75 and 100% field capacity (FC) as well as water withdrawal for two weeks at vegetative, pre and post-anthesis stages respectively. Reduction in biomass yield (BMV) under low moisture regimes were within the range of 75 to 61% of BMV obtained under favourable irrigation treatments while Pre and post-anthesis moisture deficits also significantly reduced grain yield by 49 and 66% of well-watered condition. Reciprocal crosses between AFO and DT-S₃-Y consistently gave highest BMV under irrigation treatment equivalent to 75% FC and above with % gains ranging from 3.05 to 44.2 respectively. All crosses except two of them (DT-S3-Y x AFO and AFO x DT-S3-W) evidenced superiority for BMV and water use efficiency (WUE) over their respective better parents, under low moisture conditions. Heterotic response for grain yield differed among crosses depending on soil moisture condition. There was no direct association between drought sensitivity index (DSI) and grain yield in the populations but genotypes with short anthesis-silking-interval (ASI) under moisture deficit conditions showed superiority for grain yield over those with longer ASI. The above results suggest that short ASI when combined with high grain yield under moisture deficit conditions is a better selection tool for identifying drought tolerant genotypes than DSI.

Key words: Moisture regime; drought sensitivity index; grain yield; water use efficiency; harvest index.

RESUMEN

El uso eficiente del agua del suelo en condiciones de déficit de humedad puede ayudar a reducir el stress de la sequía de los cultivos. Se estudió el crecimiento, respuesta fisiológica y producción en condiciones de déficit de humedad durante la floración. Se estudiaron, en condiciones de invernadero, poblaciones de maíz derivadas de cruza recíprocas entre dos cultivares adaptados (DMR-LSR-Y y AFO), y dos líneas endogámicas tolerantes a la sequía (DT-S3-Y y DT-S3-W). Las cruza y líneas paternas fueron sujetas a tratamientos de irrigación equivalentes a 25, 50, 75 y 100% capacidad de campo (FC), así como el retiro de agua por semanas en la etapa vegetativa, pre y post floración. La reducción en la producción de biomasa (BMV) en las condiciones de baja humedad fluctuó en el rango de 61 a 75% de la BMV obtenida en condiciones de riego favorables. Déficit de humedad pre y post floración redujeron la producción de grano de 49 a 66%. Las cruza recíprocas entre AFO y DT-S₃-Y tuvieron una mayor producción con irrigación equivalente a 75% FC o superiores. Todas las cruza, excepto dos de ellas (DT-S3-Y x AFO and AFO x DT-S3-W) evidenciaron superioridad para BMV y eficiencia de uso de agua (WUE) sobre sus mejores líneas paternas respectivas, en condiciones de baja humedad. Respuesta de heterosis se encontró para producción de grano en varias cruza dependiendo de las condiciones de suelo y humedad. No se encontró asociación directa entre el índice de sensibilidad a sequía (DSI) y producción de grano, pero los genotipos con períodos cortos de floración-llenado (ASI) en condiciones de reducción de humedad mostraron superioridad sobre aquellas con ASI mayores. Los resultados sugieren que ASI cortos combinados con producciones altas de grana en condiciones de déficit de humedad son un mejor criterio de selección para identificar genotipos tolerantes a sequía en comparación con DSI.

Palabras clave: Régimen de humedad; índice de sensibilidad a sequía; producción de grano; eficiencia de uso de agua; índice de cosecha.

INTRODUCTION

Growth and yield of crops are generally restricted under soil water deficits. Maize (*Zea mays* L.) suffers from soil moisture deficit which may cause drastic yield reduction, especially if it occurs during the reproductive phase (Hall *et al.*, 1981; Westgate and Boyer, 1986; Sinclair *et al.*, 1990; NeSmith and Ritchie, 1992; Basseti and Westgate, 1994). In the Nigerian savannas, where rainfall distribution is erratic and soil is characterized by low moisture holding capacity (Fakorede *et al.*, 2001), maize yields are usually low even under well-managed experiments (Olaoye and Omuetti, 2006). In these ecosystems, the representative annual rainfall ranges from 400-6000mm in the Northern Savanna and 1100-1400mm in the Southern Guinea Savanna with a high probability of the occurrence of a drought period for five months. Since reduction in drought susceptibility will provide added stability to rural economics and reduce level of chronic food deficit in more marginal production areas (Edemeades *et al.*, 1997), development of drought tolerant (DT) maize varieties for cultivation in the drought prone ecologies, will likely boost maize production beyond its present level.

Grain yield under drought is dependent upon many phenological, morphological and physiological characters (Ludlow and Muchow, 1990) including total water use (TWU) and water use efficiency (WUE). WUE which is the ratio of grain yield (GY) to total amount of water used is an important physiological trait involved in crop adaptation to drought, which according to Kumudini *et al.*, (2001), is composed by evapotranspiration efficiency and harvest index (HI). A earlier study reported performance of two sets of drought tolerant maize germplasm comprising open pollinated varieties (OPVs) and hybrids under well-watered and post-anthesis moisture deficit situations (Olaoye *et al.*, 2004). Moisture deficit at post-anthesis phase reduced grain yield between 25 to 73.5% in the OPVs and 20 to 64% in the hybrids, as compared to either vegetative or pre-anthesis moisture deficits, suggesting variation in drought tolerant capacity within each group. However, hybrids still appeared to be more productive under tolerant of post-anthesis moisture deficit than the OPVs.

The benefits of growing DT maize varieties to avoid total crop failure or for enhanced crop productivity in dry environments, is well documented in the USA (Jensen, 1994), East and Central Africa (Ngure, 1994; Njoroge, 1994), and also for the driest areas of the West and Central Africa (Anonymous, 1999). In each case, the authors reported gains in maize yields attributable to either the use of DT maize genotypes or the adoption of early and extra-early maize varieties for cultivation in marginal rainfall environment. The initial step in developing DT maize varieties is to identify genotypes that can

survive during moisture stress and/or recover after such stress. This can be done by comparing genotype performance under well-watered and moisture-stressed conditions. An alternative but equally effective approach is to subject genotypes to induced moisture stress at specific growth stages. The objectives of this study were to determine their efficiency in water use for dry matter production under different moisture regimes, and also gain information on relative yield loss of the genotypes under moisture deficit conditions. It is believed that understanding of their response to soil-water deficits through measurement of crop-water status and associated morpho-physiological responses (Cox and Jolliff, 1987), as well as assessment of grain yield loss under moisture deficits will help to identify populations that could be used to develop drought-tolerant maize varieties for the Nigeria's savanna environment.

MATERIAL AND METHODS

Description of experimental materials

Two intermediate maturing drought-tolerant (DT) inbred lines (DT-S₃-W and DT-S₃-Y) and two adapted maize varieties (DMR-LSR-Y and AFO-W) were intercrossed in a reciprocal fashion to form the maize populations used for the study. Both inbreds were selected from a set of DT inbred lines from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, which were evaluated for two years (1997 and 1998) under residual soil moisture at the Teaching and Research (TandR) farm, University of Ilorin (Lat. 8° 29'N and 8° 30'N; Long. 4° 30'E and 4° 32'E). They were selected as parents based on their performance for grain yield and desirable agronomic characteristics. DMR-LSR-Y is an earlier version of downy mildew (DM) and streak resistant (SR) maize variety also developed at the IITA; it is late maturing genotype. However, it is adapted to the ecology having been cultivated for many years. AFO-W is a popular short height, extra-early maturing local maize variety with upright leaf orientation, thus making it amenable for intercropping, which is a major farming system in Nigeria. The initial source of seeds, obtained from a farmer's field, was increased by bulk pollination and thereafter improved for uniformity especially for days to flowering. Reciprocal crosses were made in the breeding nursery between both DT inbreds and both adapted varieties during the 2000 growing season to generate the F₁ progenies.

Experiment I

Both experiments were carried out at the University of Ilorin Sugar Research Institute's screen house, Ilorin. In the first experiment, crosses and their parents were subjected to four different simulated soil moisture regimes equivalent to 25, 50, 75 and 100 percent (%) field capacity (FC) respectively in

the screen house. However, before the starting the study, the moisture content of soil was determined by the oven-dry method in order to determine the quantity of water needed to apply the required water equivalent to intended FC. A split-plot design with three replicates was used. Main plots consisted of four moisture regimes, while the split-plots consisted of the populations and their respective parents. Two plants were grown in five Litre plastic polythene pots that were half filled with top soil and arranged on the screen house benches in a completely random array within each moisture regime. Soil was a sandy loam with 72% sand, pH of 6.0 and chemical properties of 8.5 cmo/kg Organic carbon, 0.49 cmo/kg N, 0.11 cmo/kg Potassium Sodium, 6.0 mg/kg available P, 1.6 cmo/kg Ca, 1.3 cmo/kg Mg and total acidity of 1.3. Each unit within a moisture regime was represented by five pots. Three (3) maize seeds were initially planted in a pot but later thinned to one most vigorous seedling/pot after data on emergence count had been collected. A graduated measuring cylinder placed at the centre of the screen house, was used to determine the quantity of daily water evaporation. Measurements were taken every morning and amount of water evaporated was used as basis to calculate quantity of water required to meet water requirement for each soil moisture treatment. Plants were thus watered regularly to the designated field capacity by adding the quantity of water required. Plants were thinned to one stand/per pot by selecting the most vigorous plant based on appearance seven days after planting (DAP).

Experiment II

In the second experiment, induced moisture deficit at vegetative, pre and post-anthesis growth phases respectively was achieved by withdrawing water for two weeks as plants attained each phase, followed by resumption of normal watering at the end of each moisture stress period. Five seeds were initially planted in a pot but later thinned to two most vigorous seedlings/pot, two weeks after planting (WAP). All pots initially received normal watering every other day to field capacity until the commencement of first water stress treatment at 3WAP. However, the control plots received normal watering throughout the duration of the study.

Fertilizer application to the first experiment was a single dose of compound fertilizer N.P.K. (15: 15: 15) at the rate of 7.0g per pot two weeks after planting. In the second study, a starter dose of compound fertilizer N.P.K. (15: 15: 15) of same quantity was first applied at 2WAP before the commencement of water stress at vegetative phase (i.e. 3WAP), followed by the second dose at 6WAP before the commencement of pre-anthesis induced moisture stress. Weed was controlled by hand throughout the duration of the experiments.

Data collection

Data were collected from the first experiment on days to germination, seedling height and leaf production/plant. Whole plants were harvested seven weeks after planting and the above ground part was dried to a constant weight to determine dry matter yield/plant (BMY). Data on seedling height and leaf production/plant were collected from each plant on weekly basis while BMY was determined at the termination of the experiment. The averages of these measurements were recorded for each experimental unit. Leaf area was estimated as:

$$\frac{3}{4} [L \times B]$$

Where

L: - Leaf length, and

B: - greatest width of the leaf respectively. Leaf extension rate (LER) and stem extension rate (SER) were estimated from weekly measurements on seedling height and leaf length respectively using the formula:

$$[AP - AL]/D$$

Where

AP = Present measured seedling height or leaf length,

AL = Last measured seedling height or leaf length and

D = Measurement interval in days

Water use efficiency (WUE) was also estimated using the formula:

$$WUE = [\text{Dry Matter production}/\text{Amount of H}_2\text{O used}]$$

In the second experiment, data were collected on days to flowering (tasseling, anthesis and silking), plant and ear heights and grain yield respectively. At the termination of the experiment, ears were harvested, dehusked and dried before shelling to determine grain yield/plant after adjusting to 12% moisture content. The above ground shoot were also harvested and dried to a constant weight to determine the Stover weight. Anthesis-silking interval (ASI) was computed as the interval (days) between pollen shed and silking while harvest index (HI) was calculated as the proportion of shoot dry matter that is grain to the above ground dry matter using the formula:

$$HI = [\text{Weight of grains}/\text{Weight of above ground dry matter}]$$

Since empirical evidence has shown that grain yield is mostly depressed by moisture deficit around flowering (Grant *et al.*, 1989; Basetti and Westgate, 1993; Edmeades *et al.*, 1997), performance of parents and crosses for grain yield, ASI and harvest

index were restricted to full irrigation as well as pre and post-anthesis deficits respectively. Drought sensitivity index (DSI) due to moisture deficit during pre and post-anthesis phase was therefore calculated from genotype means using a generalized formula (Fisher and Maurer, 1978; Clarke *et al.*, 1984) in which $DSI = [1 - YD/YP]D$ where $YD = \chi Yld$ (KRWT) at post-anthesis moisture deficit, $YP = \chi Yld$ (KRWT) in well-watered situation = Potential Yld (KRWT) and $D = \text{environmental stress intensity} = 1 - (\text{Mean YD of all genotypes} / \text{Mean YP of all genotypes})$. Yield and kernel weight potential (Yp) of each genotype was defined as the maximum mean response of each genotype in well-watered situation (Bruckner and Frohberg, 1987). Similarly, superiority of a cross for grain yield within the three moisture regimes was estimated as the proportion of the difference between a cross and that of either the mid-parent or better parent using the formula:

$$100[XF_1 - XMP_i / XMP_i] \text{ or } 100[XF_1 - XP_i / XP_i]$$

Where

XF_1 , XMP and XP_i are mean performance of the cross, mid-parent value and that of the better parent, respectively.

Data on heterosis was transformed using the Arcsine transformation (Snedechor and Cochran, 1980) to remove skewness. Data collected or estimated for both experiments were thereafter subjected to analyses of variance (Steel and Torrie, 1980).

RESULTS

Experiment I

Seedling emergence was delayed by soil moisture lower than 75% field capacity (FC) by one day while there was no difference between full and 75% irrigation treatments (Table 1). Two crosses - DMR-LSR-Y x DT-S₃-Y and DT-S₃-W x DMR-LSR-Y also exhibited similar delayed germination of one day relative to their parents while other crosses did not differ from their parents for this trait. One of the adapted parents (DMR-LSR-Y) failed to germinate at the lowest soil moisture regime indicating either extreme sensitivity to soil moisture deficit or higher moisture requirement for germination. At this moisture regime, another parent (DT-S₃-Y) and three crosses (DT-S₃-W x DMR-LSR-Y; DMR-LSR-Y x DT-S₃-Y and AFO x DT-S₃-W), exhibited moderate sensitivity, with 1-day delay in germination relative to others. AFO-W, (an unimproved parent), exhibited the fastest germination rate showing superiority to other crosses except AFO-W x DT-S₃-W and DMR-LSR-Y at maximum field capacity. Difference in seedling emergence between reciprocal crosses involving DT-S₃-W and DMR-LSR-Y was approximately 2 days at 75%FC, while there was no difference between crosses involving DT-S₃-Y and DMR-LSR-Y. None of the crosses

showed superiority over their respective parents at 50%FC although DT-S₃-Y and DMR-LSR-Y as well as DT-S₃-Y x AFO-W exhibited delayed germination of 1 day relative to crosses involving DT-S₃-W and the two adapted parents.

Plants which received irrigation treatment above 50% FC had significantly larger leaf area than those of other soil moisture regimes (Table 1), with values being significantly higher, beginning from 4WAP until 7WAP when leaf area, in genotypes that received moisture treatment equivalent to 75%FC, declined as compared to those which received full and 50% irrigation treatments respectively. Differences in leaf area between genotypes which received full and 75% irrigation treatments were significant to those which were exposed to moisture stress. Leaf area in each cross also increased with increase in growth but in crosses involving DMR-LSR-Y and DT-S₃-Y, having significantly larger leaf area, as compared to crosses between DMR-LSR-Y x DT-S₃-W (Fig. 1). However, there were no reciprocal differences between the different populations. Progenies of crosses between AFO-W and the two DT parents had larger leaf area which also increased at every growth stage until the end of the study (Fig. 1a) compared to crosses between DMR-LSR-Y and the two DT parents (Fig. 1b) while differences among parents were not significant. However, at the termination of this study, crosses involving AFO-W and the two DT-inbred parents had the largest leaf area.

Leaf extension ratio (LER) was significantly reduced by low soil moisture regime (Table 1) and differences among genotypes were also significant with one of the crosses- DT-S₃-Y x DMR-LSR-Y having a significantly higher value than all others. Notwithstanding, the parents except DMR-LSR-Y were superior to their respective crosses for this trait. SER did not follow a definite pattern among the genotypes (Fig. 2) as it increased sharply in DT-S₃-W x DMR-LSR-Y (Fig. 2b) and AFO (Fig. 2c) followed by a sharp decline in the two genotypes in the following week. However, SER remained relatively constant in DT-S₃-Y beginning from 3WAP.

Seedling height increased as available moisture increased throughout the duration of the study (Table 1). Although final height measurements in genotypes that received full and 75% irrigation treatments were superior to those of other moisture regimes, differences between seedling heights at 100 and 75%FC as well as between 50 and 25%FC were similar. Overall, crop growth was best under 75% moisture content with differences between seedling height of genotypes at this moisture level and those of other moisture regimes being 2.12, 14.54 and 22.81cm respectively. Differences in seedling height of genotypes under 50 and 25% irrigation were significant at every measurement beginning from

2WAP until the termination of the experiment. Many of the crosses were generally taller than their respective parents although one of the adapted parents-DMR-LSR-Y was the tallest.

Stem extension ratio (SER) was also significantly reduced by low soil moisture regime especially when compared with maximum and 75% irrigation treatment (Table 1). Although, there was no particular trend for this character either among the genotypes, crosses involving AFO-W and the two

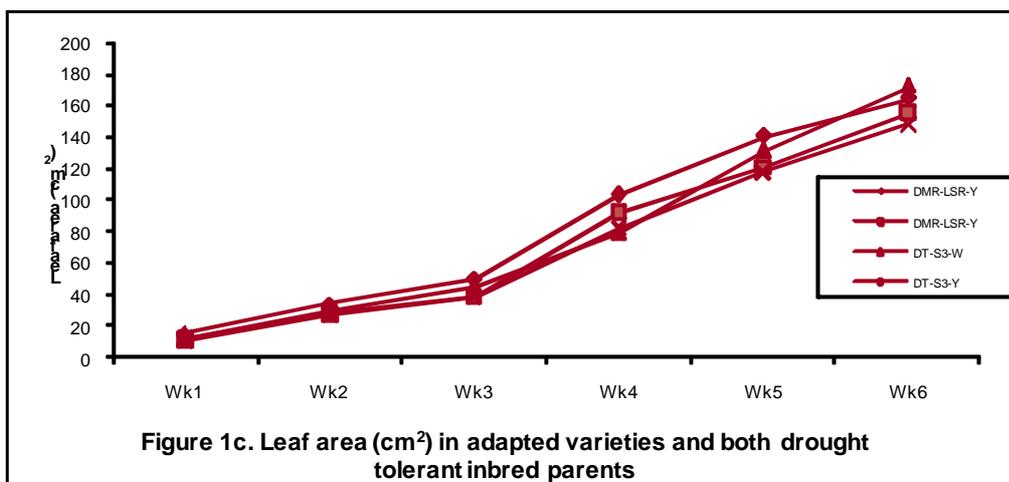
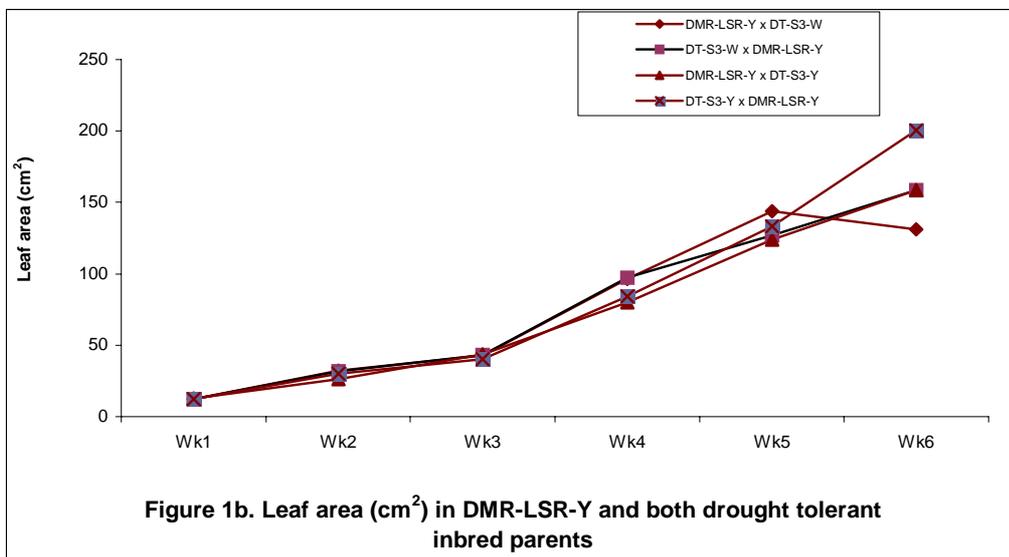
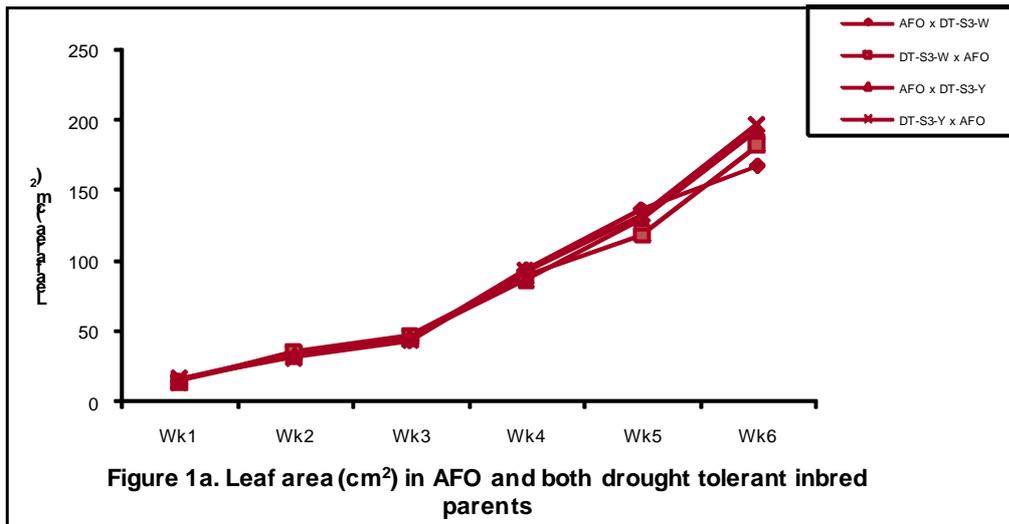
DT-inbred parents were superior to others for this trait. There was also no particular trend in SER among crosses relative to the different growth stages (Fig. 3) except that three crosses (AFO-W x DT-S3-W, DT-S3-W x AFO and DT-S3-W x DMR-LSR-Y) and one parent (AFO) had a significantly higher SER values towards the termination of the study. SER in Cross DMR-LSR-Y x DT-S3-Y (Fig. 3b) and AFO (Fig. 3c) however remained relatively constant beginning from 3WAP.

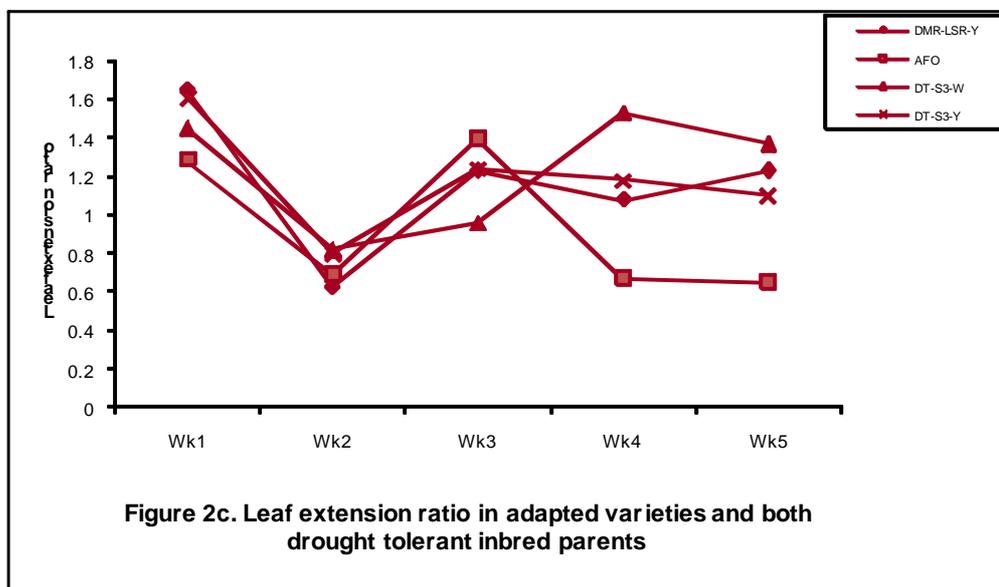
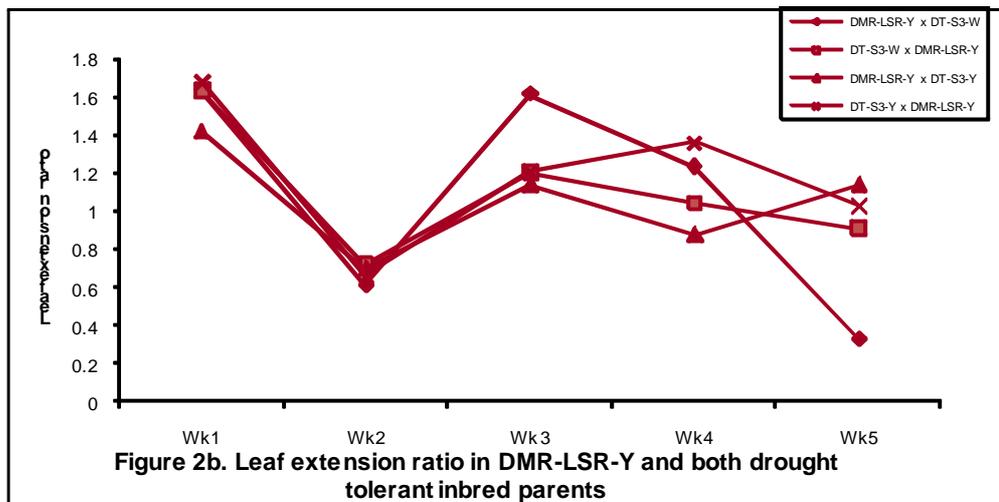
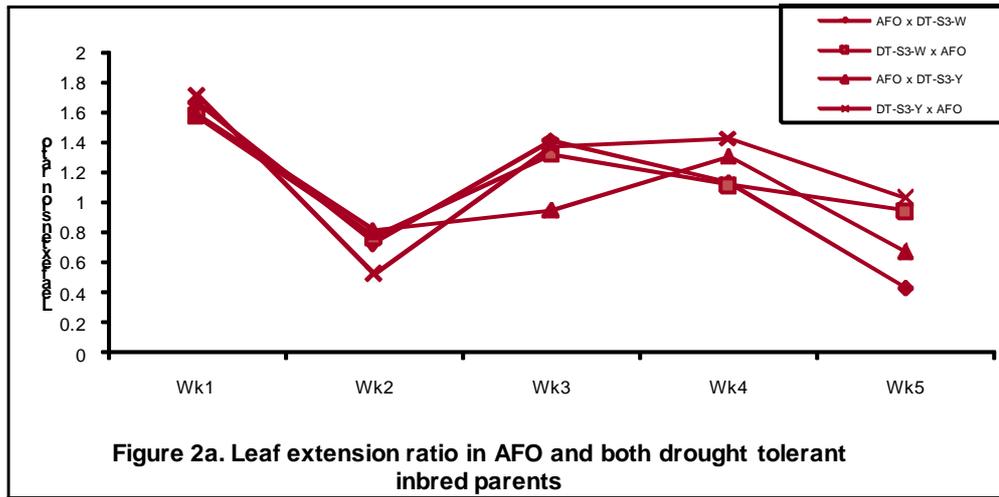
Table 1: Days to germination, morpho-physiological characteristics and biomass yield for parents and crosses of drought tolerant inbreds x adapted maize varieties under four simulated moisture regimes.

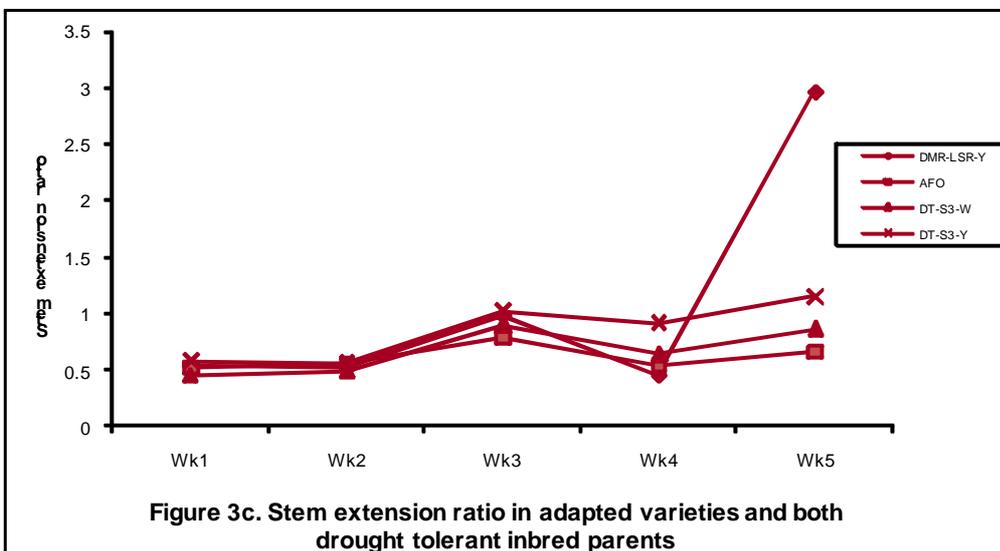
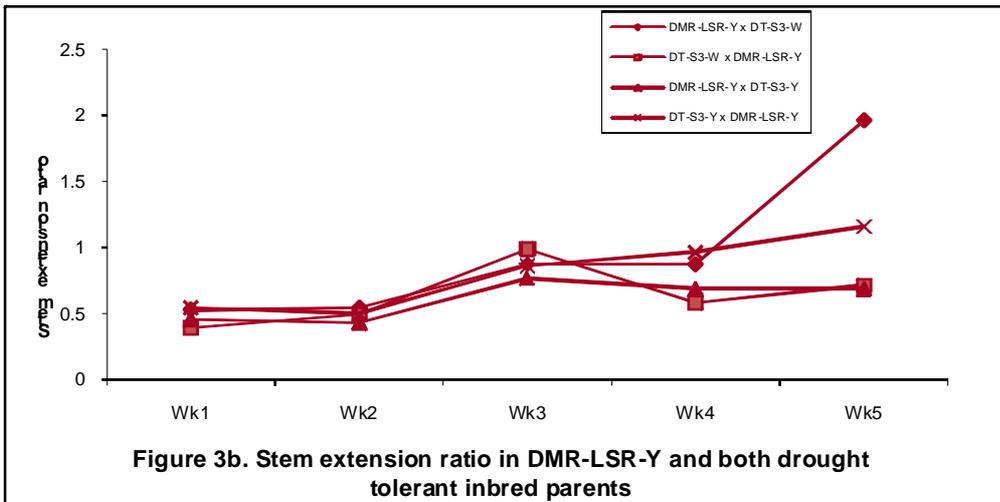
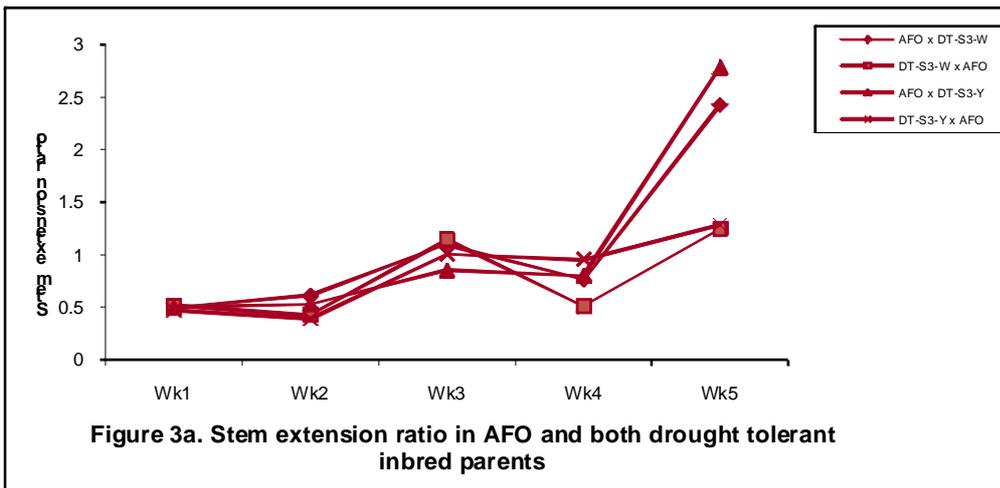
Moisture regime	Days to germination	Plant height (cm)	Leaf area (cm ²)	Stem extension ratio	Leaf extension ratio	Biomass yield (g/plant)	Water use efficiency (g cc ⁻¹)
100% Field capacity	4	45.38	233.90	1.27	1.11	19.28	0.060
75% Field capacity	4	47.50	234.08	1.20	0.95	12.47	0.031
50% Field capacity	5	32.96	111.09	1.19	0.75	12.40	0.048
25% Field capacity	5	24.69	97.98	0.85	0.54	4.81	0.043
AFO-W x DT-S ₃ -W	4	47.75	168.09	2.429	0.425	11.55	0.038
AFO-W x DT-S ₃ -Y	4	45.88	193.53	2.785	0.665	13.92	0.044
DMR-LSR-Y x DT-S ₃ -W	4	44.19	131.19	1.964	0.331	12.03	0.041
DMR-LSR-Y x DT-S ₃ -Y	5	29.25	158.60	0.688	1.136	12.85	0.081
DT-S ₃ -W x AFO-W	4	36.25	182.79	1.249	0.944	11.31	0.041
DT-S ₃ -W x DMR-LSR-Y	5	31.45	158.77	0.714	0.906	12.10	0.073
DT-S ₃ -Y x AFO-W	4	37.63	197.56	1.286	1.026	13.48	0.040
DT-S ₃ -Y x DMR-LSR-Y	4	33.21	200.70	1.158	1.540	12.56	0.040
AFO-W	4	26.75	164.16	2.955	1.230	12.20	0.040
DMR-LSR-Y+	4	49.13	155.66	0.661	0.651	9.94	0.028
DT-S ₃ -W	4	30.25	171.99	0.856	1.369	11.98	0.038
DT-S ₃ -Y	4	39.75	148.13	1.499	1.098	11.83	0.039
Overall mean	5	37.63	82.03	0.84	1.13	12.24	0.045
SE±	0.23	1.06	23.31	0.12	0.09	2.96	0.004
F-Test							
Moisture regime (MR)	1.485***	2773.01***	134758.4***	7.93*	7.15***	833.91***	0.003*
Genotype (G)	1.178***	474.05***	3564.64	5.43**	1.09*	5.91	0.002*
G x MR	1.168***	159.64*	4002.37	2.44**	0.56	9.30***	0.002*

*, ***, Significant F-Test at 0.05 and 0.001 levels of probability respectively.

±; Mean across three moisture regimes due to zero germination at 25% Field capacity.







Mean BMV was reduced by low moisture content within the range of 75 to 61% of BMV obtained under favourable irrigation treatments (Table 2). Many of the crosses produced higher BMV than their parents across moisture levels although differences were nonsignificant. However, reciprocal crosses between AFO-W and DT-S₃-Y gave higher BMV than others and differences between the crosses and those involving AFO-W and DT-S₃-W was approximately 17%. Reciprocal

crosses between AFO-W and DT-S₃-Y consistently gave highest BMV under irrigation treatment equivalent to 75%FC and above with %gains ranging from 3.05 to 44.2 respectively (Table 2). These values were superior to those obtained for the parents as well as any of the crosses involving DT-S₃-W and the two adapted varieties. BMV for three crosses -DT-S₃-W x AFO-W, DT-S₃-Y x AFO-W and DMR-LSR-Y x DT-S₃-W were higher than for others at lower soil moisture content of 50 and

25%FC respectively while crosses involving DMR-LSR-Y and DT-S₃-Y as well as those between AFO-W and DT-S₃-Y were superior to their better parents for BMY under full irrigation. Reciprocal crosses between AFO-W and DT-S₃-Y also gave significantly higher BMY than their better parent at 75%FC.

Consumptive water use for biomass production (WUE) was significantly reduced under low soil moisture regime than under favourable growing conditions (Table 2). Genotype and genotype x moisture regime were also significant for this character. Crosses were generally more efficient in water utilization for biomass production than their parents. Two crosses DMR-LSR-Y x DT-S₃-Y and DT-S₃-W x DMR-LSR-Y in particular, had significantly higher WUE than other genotypes. Reciprocal crosses between AFO-W and DT-S₃-Y was superior over other genotypes for WUE under favourable moisture condition with advantage of 26.19 and 33.25 percent respectively over the better parent at maximum irrigation schedule (Table 2). However, crosses were similar to their parents for WUE at 50%FC while three crosses (DT-S₃-W x DMR-LSR-Y, DT-S₃-W x AFO-W and DMR-LSR-Y x DT-S₃-W) utilized water most efficiently at very low soil moisture content although differences were not significant from those of other crosses.

Experiment II

The effects of the different irrigation (IR) treatments as well as differences due to the genotypes (G) were significant for all the traits ($P < 0.05$ or 0.01), except ASI (Table 3). G x IR interaction effect was also significant ($P < 0.05$ or 0.01) for all the traits, indicating differences in the responses of the genotypes to the different soil moisture conditions. Compared to well-watered condition, days to silk was earlier by 19 and 9 days in genotypes subjected to vegetative and pre-anthesis deficits respectively. Although, differences in days to silk were not significant between genotypes that received normal irrigation and those that were subjected to post-anthesis deficit, ASI in the latter was delayed by 2 days. Leaf area was significantly reduced under pre and post-anthesis deficits by 54 and 58% of well-watered condition while ear height suffered 50 and 28% reduction due to moisture deficits at the vegetative and pre-anthesis phases. Pre and post-anthesis moisture deficits also significantly reduced grain yield by 49 and 66% of well-watered condition but harvest index did not follow a definite trend since values obtained for pre-anthesis deficit was significantly higher than at vegetative and post-anthesis phases.

Table 2: Biomass yield and water use efficiency in parents and crosses of drought tolerant inbreds x adapted maize varieties grown under four simulated moisture regimes.

Crosses*	Biomass yield (g/plant)				Water use efficiency (g ^{cm})			
	100%FC	75%FC	50%FC	25%FC	100%FC	75%FC	50%FC	25%FC
AFO-W x DT-S ₃ -W	18.56	11.26	11.57	4.80	0.034	0.028	0.045	0.044
AFO-W x DT-S ₃ -Y	22.23	14.43	14.11	4.90	0.041	0.036	0.055	0.044
DMR-LSR-Y x DT-S ₃ -W	17.98	10.94	13.41	5.81	0.033	0.027	0.052	0.052
DMR-LSR-Y x DT-S ₃ -Y	21.15	13.53	11.24	5.47	0.200	0.033	0.044	0.049
DT-S ₃ -W x AFO-W	12.79	11.62	14.81	6.4	0.024	0.029	0.058	0.054
DT-S ₃ -W x DMR-LSR-Y	19.09	11.52	11.85	5.95	0.165	0.029	0.046	0.054
DT-S ₃ -Y x AFO-W	24.60	15.42	9.37	4.53	0.045	0.038	0.036	0.041
DT-S ₃ -Y x DMR-LSR-Y	21.09	12.35	11.37	5.44	0.039	0.031	0.044	0.049
Parents								
AFO-W	16.34	13.98	13.70	4.78	0.030	0.034	0.054	0.043
DMR-LSR-Y+	20.01	10.05	13.79	0.00+	0.036	0.025	0.054	0.000+
DT-S ₃ -W	19.92	19.92	11.36	4.91	0.036	0.029	0.044	0.044
DT-S ₃ -Y	17.05	12.91	12.31	5.04	0.021	0.032	0.048	0.045
SE+	8.88				0.012			

*The first parent in a cross is the pollen parent. +; Parameters not estimable due to zero germination.

Table 3: Grain yield and related traits for parents and crosses of drought inbreds x adapted varieties under different irrigation treatments.

	Days to silk (no)	Anthesis silking interval (no)	Leaf area (cm ²)	Ear height (cm)	Grain yield (g/plant)	Harvest Index
Irrigation regimes (IR)						
Well-watered	54	2	233.90	62.68	39.52	0.545
Vegetative stress	35	2	234.08	31.11	26.47	0.200
Pre-anthesis stress	46	4	108.08	45.28	20.17	0.314
Post-anthesis stress	55	4	97.98	62.69	13.52	0.242
Mean	48	3	168.56	50.44	19.83	0.325
SE _±	1.21	0.43	3.14	1.22	1.36	0.147
F-Test						
IR 10 ³	2.97***	0.054	306.83***	8.94***	4.42***	0.002***
Genotypes (G) 10 ³	0.94***	0.006	28.99**	1.18***	0.76***	0.0005***
G x IR 10 ²	0.49***	0.17**	152.46*	5.48*	3.56***	0.004***

+The first parent in a cross is the pollen parent.

*, **, ***; Significant F-Test at 0.05, 0.01 and 0.001 levels of probability respectively.

Genotypic response to irrigation treatments varied depending on the soil moisture condition (Table 4). Inbred parent -DT-S₃-W and its cross to AFO-W (as female parent) showed extreme sensitivity to moisture stress at vegetative phase as none of the plants recovered following resumption of irrigation treatment (data not shown). Progenies from crosses involving DMR-LSR-Y and DT-S₃-W attained days to silking earlier following water withdrawal at pre-anthesis phase but most crosses were similar for these traits under normal irrigation and post-anthesis deficit. Progenies from AFO-W x DT-S₃-W, silked earlier by 10 days while those from DT-S₃-W x AFO-W, DT-S₃-Y x DMR-LSR-Y and DT-S₃-W x DMR-LSR-Y had delayed silk extrusion by 10, 6 and 5 days respectively when subjected to moisture deficits (data not shown). ASI ranged from 10 to 7 days in parents and 1 to 8 days in crosses. Synchrony between male and female inflorescence was also erratic in genotypes under pre and post-anthesis deficits. ASI was longest in three crosses viz: DT-S₃-W x DMR-LSR-Y, DT-S₃-Y x AFO-W and DT-S₃-Y x DMR-LSR-Y under post-anthesis deficit and in progenies from DMR-LSR-Y x DT-S₃-W and DMR-LSR-Y x DT-S₃-Y in response to pre-anthesis moisture deficit.

Drought sensitivity index (DSI) at pre and post-anthesis deficits and grain yield under the three irrigation treatments showed no definite pattern between DSI and grain yield either at pre or post-anthesis deficits (Table 4). However, AFO-W x DT-S₃-W showed superiority over either parent for both traits at the pre-anthesis phase while progenies from DT-S₃-Y x DMR-LSR-Y were superior only to the DT-inbred parent at the post-anthesis deficit phase. Progenies from DMR-LSR-Y as the pollen parent had a yield advantage over their DT-S₃-W and DMR-LSR-Y parents but yields were comparable to that of the DT-S₃-Y parent. Surprisingly, genotypes with significantly low DSI values also yielded significantly lower (see for example, DT-S₃-Y x

AFO-W, DT-S₃-Y x DMR-LSR-Y and DMR-LSR-Y) suggesting that different genes control both traits.

Mid parent (MP) and high parent (HP) heterosis (%) for grain yield under the three irrigation treatments are presented in Table 5. Heterotic response for grain yield differed among crosses depending on the soil moisture condition and it ranged from superiority of AFO-W x DT-S₃-Y over mid-parent or better parent in each of the irrigation treatments to superiority either at pre-anthesis moisture deficit (see for example AFO-W x DT-S₃-W and AFO-W x DT-S₃-Y) or post-anthesis moisture deficit superiority in four crosses (DT-S₃-Y x AFO-W, DT-S₃-Y x DMR-LSR-Y, DMR-LSR-Y x DT-S₃-W and AFO-W x DT-S₃-Y). Reciprocal crosses between DMR-LSR-Y and DT-S₃-Y gave negative heterosis for grain yield across irrigation treatments indicating that the crosses are inferior (Table 5).

DISCUSSION

Soil moisture regimes had pronounced effects on all the characters measured in both studies but with no consistent trend in performance of the genotypes either with respect to seedling emergence, yield parameters or efficiency of water utilization. G x irrigation treatment effects were also significant for most of the traits measured and this is exemplified by the response of the genotypes when subjected to lower moisture regimes (50 and 25%FC) or moisture deficit around flowering period compared to well-watered conditions. For example, one of the adapted parents –DMR-LSR-Y failed to germinate at the lowest moisture regime while most of the crosses except AFO-W x DT-S₃-W and DMR-LSR-Y x DT-S₃-W, experienced delayed germination. Furthermore, drastic reduction in maize yields and related traits as well as high WUE for dry matter production was observed at each of these moisture regimes.

Table 4: Drought sensitivity index, grain yield and related traits for parents and crosses of drought tolerant inbreds x adapted varieties under different irrigation treatments.

	Full Irrigation (No stress)			Pre-anthesis moisture deficit				Post-anthesis moisture deficit			
	Anthesis silking interval (no)	Grain yield (g/plant)	Harvest Index	Anthesis silking interval (no)	Drought sensitivity index	Grain yield (g/plant)	Harvest Index	Anthesis silking interval (no)	Drought sensitivity index	Grain yield (g/plant)	Harvest Index
Genotypes											
Crosses+											
AFO-W x DT-S ₃ -W	3	51.7	0.69	4	0.47	46.06	0.61	7	1.69	6.70	0.16
AFO-W x DT-S ₃ -Y	2	42.54	0.67	4	0.10	40.69	0.17	2	1.30	18.16	0.28
DMR-LSR-Y x DT-S ₃ -W	2	38.53	0.74	6	0.18	1.37	0.01	1	1.07	16.22	0.27
DMR-LSR-Y x DT-S ₃ -Y	2	36.68	0.49	4	0.72	29.71	0.61	3	1.19	12.67	0.36
DT-S ₃ -W x AFO-W	1	51.81	0.62	4	1.17	19.50	0.13	1	1.51	10.70	0.19
DT-S ₃ -W x DMR-LSR-Y	3	43.63	0.55	4	1.35	11.34	0.07	4	1.17	17.16	0.28
DT-S ₃ -Y x AFO-W	2	16.46	0.18	3	0.67	11.85	0.74	6	0.63	12.67	0.22
DT-S ₃ -Y x DMR-LSR-Y	3	43.60	0.62	2	0.40	33.38	0.56	3	0.85	20.58	0.16
Parents											
AFO-W	0	22.95	0.50	6	1.51	5.10	0.07	2	1.40	11.64	0.21
DMR-LSR-Y	2	20.73	0.35	4	1.03	20.72	0.46	4	0.91	11.17	0.16
DT-S ₃ -W	3	18.72	0.49	7	1.67	2.11	0.16	8	1.18	8.85	0.22
DT-S ₃ -Y	1	18.94	0.74	2	1.06	20.20	0.19	1	1.3	15.68	0.37
Mean	2	33.86	0.55	4	0.861	24.92	0.315	4	1.163	13.52	0.24
SE _±	0.91	1.40	0.21	0.91	0.09	2.30	0.21	0.91	0.06	1.40	0.21

+The first parent in a cross is the pollen parent.

Table 5: Mid parent (MP) and high parent (HP) heterosis for grain yield in crosses of drought tolerant inbreds x adapted varieties under different irrigation schedules.

	Mid-parent heterosis (%)			High-parent heterosis (%)		
	Well-watered	Pre-anthesis moisture deficit	Post-anthesis moisture deficit	Well-watered	Pre-anthesis moisture deficit	Post-anthesis moisture deficit
Crosses+						
AFO-W x DT-S ₃ -W	64.17	89.43	-35.88	43.53	79.38	-46.88
AFO-W x DT-S ₃ -Y	5.19	80.56	41.38	-13.19	56.83	14.40
DMR-LSR-Y x DT-S ₃ -W	67.96	-78.42	50.22	55.71	-80.15	23.86
DMR-LSR-Y x DT-S ₃ -Y	-0.91	-30.30	-9.90	-17.70	-36.44	-24.08
DT-S ₃ -W x AFO-W	70.63	25.22	9.50	47.19	-13.15	-21.31
DT-S ₃ -W x DMR-LSR-Y	76.02	-39.51	-4.96	73.93	-46.62	-13.94
DT-S ₃ -Y x AFO-W	-52.42	-54.43	53.29	-54.05	-60.39	29.68
DT-S ₃ -Y x DMR-LSR-Y	21.34	-2.03	39.82	-14.56	-30.79	25.54
SE±		6.42			5.93	

+The first parent in a cross is the pollen parent

In consonance with growth as a function of moisture availability, increase in seedling growth and leaf area under favourable moisture conditions in this study resulted in higher maize yields thus corroborating earlier report of Bänzinger *et al.*, (2000) that leaf area affects water use in plants by reducing evaporation/transpiration ratio and weed competition especially at full canopy.

WUE, which is the ratio between assimilation and transpiration in the process of dry matter production as well as response to and performance under drought stress, is genotype dependent (Blum *et al.*, 1990) rather than on heterotic response. Thus, the challenge in breeding for drought tolerance is to ensure efficient water utilization in grain production in genotypes intended for cultivation in drought prone ecologies. Three crosses (DT-S₃-W x DMR-LSR-Y, DT-S₃-W x AFO-W and DMR-LSR-Y x DT-S₃-W) showed superiority for WUE. Relationship between BMY and WUE at the different soil moisture content also showed that crosses involving DT S₃-Y used moisture efficiently in dry matter production at 75%FC compared to others. Thus, it appears that both traits are conditioned by the same genes, which implies that simultaneous improvement for BMY and WUE may be feasible in the populations studied.

Maize response to soil moisture deficit vary depending on the stage of growth at which it occurred and often include reduction in growth rate, plant and ear heights (Saheed *et al.*, 1996), delayed flowering and increase in ASI (Dow *et al.*, 1984; Bolanos and Edmeades, 1993; Edmeades *et al.*, 1992; Bänzinger *et al.*, 2000) as well as reduction in

grain yield or complete barrenness (Grant *et al.*, 1989; Basetti and Westgate, 1993; Edmeades *et al.*, 1997). Genotypic response to moisture deficits in this study, ranged from reduction in ear height, but increase in ASI, delayed tassel emergence and/or dead tassel, failure to shed pollen, production of tassel ear, abnormal ear, complete barrenness and also the susceptibility to stem borer attack in response to moisture deficit imposed either at vegetative or pre-anthesis stage. These responses were however common for crosses in which the two adapted varieties served as the pollen parent.

Grain yield under full irrigation in the second study was superior to those of pre and post-anthesis deficit conditions while post-anthesis moisture deficit reduced grain yield by 33% of pre-anthesis deficit and 66% of well-watered conditions due to asynchrony between male and female inflorescence (Edmeades *et al.*, 1992). However, crop productivity under moisture deficits appeared to be genotype dependent rather than a function of leaf area as crosses involving AFO-W (with smaller leaf area) and the DT-inbred parents exhibited better heterosis for grain yield than crosses between DMR-LSR-Y and the inbred parents under pre and post-anthesis deficits respectively. This observation agree with earlier report of Bänzinger *et al.*, (2000) who noted that once complete crop cover has been achieved; further increases in leaf area have little effect on crop water usage for grain production.

Increase in ASI is an indication of maize susceptibility to moisture deficit at flowering and is regarded as a symptom of reduced assimilate flux rather than direct cause of barrenness with the

consequence of low HI (Bäzinger *et al.*, 2000). Genotypes with low DSI values on the other hand are expected to exhibit smaller yield loss under drought compared with performance in favourable growing conditions (Bruckner and Frohberg, 1987). However, there was no direct association between DSI values and grain yield under the two moisture deficits either in the crosses or their parents while genotypes with short ASI under moisture deficit conditions (AFO-W x DT-S3-W, AFO-W x DT-S3-Y, and DT-S3-Y x DMR-LSR-Y) showed superiority for grain yield over those with longer ASI. In other words, ASI when combined with high grain yield in moisture deficit conditions is a better selection tool in drought research (Fischer *et al.*, 1983) than DSI.

Moisture deficit up to and after anthesis generally decreased grain yield in cereals with subsequent decrease in HI (Passioura, 1977; Day *et al.*, 1978; Innes and Blackwell, 1981). HI under non-moisture stress was significantly higher than either at pre or post-anthesis moisture deficits. Differences in HI among genotypes under non-moisture stress were only significant between DT-S₃-Y x AFO-W (lowest) and either DT-S₃-Y or DMR-Y x DTY-S₃-W. Pre-anthesis moisture deficit also significantly decreased HI in the two inbred parents as well as two crosses (AFO-W x DT-S₃-Y and DT-S₃-W x AFO-W). Similar to grain yield/plant, crosses involving DMR-Y and DT-S₃-W as well as those involving DT-S₃-W and AFO-W showed heterotic advantage ranging from 12.24 to 51.02% over the respective better parent.

CONCLUSION

Drought affects maize grain yield to some degree at almost all growth stages but moisture deficit occurring at post anthesis phase significantly reduced grain yield than either at vegetative or pre-anthesis phase (Grant *et al.*, 1989; Basetti and Westgate, 1993; Edmeades *et al.*, 1997). Results for grain yield corroborate these findings as the highest yield loss was obtained under post-anthesis deficit. However, early maturity (a drought escape mechanism) or synchrony between male and female inflorescence is an important strategy of matching phenological development with period of soil water availability to minimize the impact of drought stress on crop production. This was exemplified in the performance of AFO-W x DT- inbred parents especially for high grain yield at pre-anthesis moisture deficit. Similarly, heterosis for grain yield was observed with crosses involving DT-S₃-W and the two adapted parents either at full irrigation, pre or post-anthesis deficits respectively. The superiority of these crosses especially under moisture deficit situation therefore suggests that the populations could serve as sources of genes for extracting superior inbred lines for the development of drought

tolerance varieties for cultivation in the Guinea Savanna ecology.

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