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Full Length Research Paper

Analyses of moisture deficit grain yield loss in drought tolerant maize (*Zea mays* L.) germplasm accessions and its relationship with field performance

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Development of drought tolerant maize cultivars is prerequisite to achieving stable grain yield in drought–prone ecologies of Nigeria's Guinea savanna. However, success has been limited mainly due to lack of maize genotypes that show clear differences in response to well defined moisture deficit condition. Two sets of drought tolerant (DT) maize germplasm were evaluated under screenhouse and field conditions between 1999 and 2002. In the screenhouse study, performances of the genotypes were compared under well-watered condition and moisture deficit imposed at different growth stages. Under field conditions, the first set comprising 11 accessions along with a check were evaluated for 4 growing seasons while the second set which comprised 3 DT varieties were evaluated along with 2 check varieties using monthly plantings between April and August of 2001 and 2002, respectively. In the first set, post anthesis moisture deficit significantly reduced grain yield by 25 to 73.5% in the open pollinated varieties (OPVs) and by 20 to 64% in the hybrids. Grain yield under field conditions ranged from 2.48 to 3.49, 2.82 to 3.73 and 3.58 to 4.76 tons/ha^{-1} for 1999, 2000 and 2001 full growing seasons, respectively, and 2.03 to 2.50 tons/ha^{-1} for 2000 late growing season. In the second set, pre and post anthesis moisture deficits reduced grain yield by 77.6 and 95.8%, respectively, of well watered condition while in the field, grain yields in the genotypes were highest for plantings made in April and July (1.90 - 2.5 t/ha), lowest for August (0.7 -1.8 t/ha) when moisture deficit coincided with reproductive phase. Yield stability exhibited under moisture deficit and on the field by 8522-2, Oba super 2 and AK9943-DMRSR in the first set as well as DT-SR-Y C0 and DT-SR-W C0 in the second set, indicates their suitability either as cultivars *per se* or as potential source of DT alleles for development of DT maize varieties for Nigeria's savanna ecologies.

Key words: Drought tolerance, moisture deficit, germplasm accessions, planting dates, grain yield.

INTORDUCTION

Periodic drought caused by irregular rainfall, accentuated by low water holding capacity of tropical soils, as well as poor cultural practices and lack of appropriate varieties used by farmers, often cause maize crop losses (Karrou et al., 1996; Ashley, 1999). Estimated yield losses in sub-Saharan Africa have been put at 15% (Edemeades et al., 1997b). Apart from terminal drought, erratic rainfall pattern in Nigeria's southern Guinea savanna, often result in unpredictable mid-season drought, the consequence of which is also poor maize yields (Kim, 1997). Reconstituting crop genotypes to tolerate drought will achieve yield stability in drought-prone environments (Owonubi and Abdul-Mumini, 1983; Edemeades and Lafitte, 1987; Gresiak et al., 1991). Alternatively, improvement in productivity of existing maize cultivars can be achieved through introgression of genes for drought tolerance.

The initial step in utilizing germplasm is to screen for desirable characters, which can then be incorporated into existing cultivars. Drought tolerant (DT) maize germplasm can be assessed for DT capacity by evaluating them under well-watered and moisture deficit condition (Boyer, 1982; Landi et al., 1995; Menkir and Akintunde, 2001), using already identified traits that are directly or indirectly related to high grain yield under moisture deficit as index of selection in drought tolerant

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Table 1. Physico-chemical characteristics of the soil of the experimental site.

Physical characteristics	Amount
%Clay	10
%Silt	18
%Clay	72
Texture	Sandy loam
Chemical characteristics	
%Organic carbon	8.5 g/kg
%Nitrogen	0.4 9 g/kg
pH	6.0
Potassium	0.18 cmo/kg
Sodium	0.11 cmo/kg
Calcium	1.6 cmo/kg
Magnesium	1.3 cmo/kg
Available P	6.0 cmo/kg
Total acidity	1.3

breeding programme. These include rooting characteristics (O'Toole and Band, 1987), degree of leaf area loss/leaf rolling under drought (Bolaños and Edmeades, 1991), barrenness (Bolaños and Edmeades, 1993a), short anthesis-silking- interval (Edemeades et al., 1993) and delayed leaf senescence (Wolfe et al., 1988) among others. Previous study which assessed performance of progenies of 2 DT inbred parents (DT-S3-W and DT-S3-Y) crossed to 2 adapted cultivars (DMR-LSR-Y and AFO-W) under screen house condition (Olaoye, 2009), revealed differences in response of the progenies to moisture deficit imposed at different growth stages. However, the highest yield reduction of 66% was recorded when plants were subjected to post anthesis moisture deficit compared to well-watered condition, which is also consistent with reports from previous studies (Akyeampong, 1985; Basseti and Westgate, 1993). DT-S3-W and DT-S3-Y have been constituted into varieties and were therefore included in the 2 sets of DT germplasm accessions evaluated under screenhouse and field conditions in the current study. The objective was to evaluate the accessions with the view to increase the source of DT alleles in our breeding programme.

MATERIALS AND METHODS

Description of experimental materials

Two sets of DT maize germplasm accessions from the maize improvement programme of the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria were used for this study. The first set comprised 11 intermediate/late drought tolerant open pollinated varieties (OPVs) and hybrids with 1 adapted variety (DMR-LSR-Y) as additional check while the second set comprised 3 recently developed DT maize varieties with 1 adapted (DMR-LSR-Y) and 1 local variety (AFO) as checks.

Experimentation

Screenhouse and field trials were conducted between 1999 and 2002 growing seasons. The screenhouse study was carried out at the University of Ilorin Sugar Research Institute's screenhouse while the field trial was conducted at the Teaching and Research (T&R) farm of the university. The soil has been characterized as an alfisol and rainfall distribution is bimodal with peaks at June and September. The physico-chemical property of the soil is shown in Table 1.

Screenhouse study

Each set of experimental materials was evaluated under well-watered condition and moisture deficit imposed at different growth stages in the screenhouse. Soil used for the studies was collected from the site of the field trials, pulverized and sterilized. For each trial, 5 seeds were initially planted to a pot but later thinned to 2 most vigorous stands per pot. For the second set, 2 additional pots were also planted to each variety for collecting data on dry matter accumulation at seedling stage. Each experimental unit consisted of three 10 litre plastic pots. The design used for each experiment was a 3 replicate split plot with irrigation regime as the main plot and genotypes as sub-plot but arranged in a completely randomized design (CRD) on screenhouse benches. The test materials were subjected to vegetative, pre and post anthesis moisture deficits with full irrigation as the control. Moisture stress at vegetative phase was imposed for 2 weeks beginning from 3 weeks after planting (WAP) followed by resumption of normal watering till the termination of the experiments. Pre and post anthesis moisture stress were also imposed for a 2 week period as soon as any one of the 2 plants in a pot either attained tassel initiation (by feeling the whorls of the leaves) or shed pollen. Thereafter, normal watering was resumed for each treatment until the termination of the experiments. The well-watered treatment however received regular irrigation for the entire duration of each study. Fertilizer NPK (15 -15 -15) was applied in a split dosage at the rate of 7.0 g/pot, with the first dose at 2 WAP before the commencement of vegetative stress and 6 weeks after planting prior to commencement of pre anthesis moisture stress. Weed was controlled by hand as necessary throughout the duration of the experiments.

Data collection

Data were collected on individual plants in a pot from both experiments and the mean of the 6 values (that is, experimental unit) recorded for seedling height (cm), leaf length (cm) and leaf width (cm), days to anthesis and silking, grain weight (g/plant) and stover weight (g/plant). Data on seedling height and leaf measurements were collected on weekly basis beginning from the commencement of induced vegetative moisture stress. For leaf measurements, all leaves on a plant were measured and leaf area was calculated from the measurements using the formula:

Leaf Area = ¾ (L x B)

Where L = length of leaf and B = broadest width of the leaf.

Samplings for % dry matter yield were carried out at 5 and 8 WAP respectively by harvesting 2 plants/variety at each growth stage. Samples were weighed before and after oven drying to constant moisture content. Difference between the 2 values was used as estimate of dry matter accumulation at seedling stage. Grain weight/plant was adjusted to 12% moisture to estimate grain yield/plant while harvest index was calculated as a ratio of grain weight to total biomass yield (that is, grain weight + stover weight).

Field study

The first set of genetic materials was planted at the teaching and research (T&R) farm, university of Ilorin (Lat. 8^o 29'N and 8^o 30'N; Long. 4^o 30'E and 4^o 32'E) in a 4 replicate randomized complete block design (RCBD) over a 3 year period. 1999 and 2001 plantings were carried out during the full growing season while 2000 plantings were conducted during the full growing season as well as the late seasons respectively, thus giving a total of 4 environments. The second set was also evaluated at the T&R farm, in a 4 replicate RCBD using monthly plantings beginning from April until September each year in 2001 and 2002 respectively. Each plot consisted of 4 rows with plants spaced 0.75 m between and 0.50 m within the rows to give a plant population of approximately 53,333 plants/ha.

Data collection

Data were collected from the 2 inner rows per plot on crop establishment, agronomic and yield parameters including days to anthesis and silking, plant and ear heights (cm), stand count at harvest, ear aspect, cob weight and harvest moisture. Data on establishment count (after thinning), days to anthesis and silking, stand count at harvest, ear aspect and cob weight were obtained on a whole-plot basis from the 2 inner rows while other parameters were obtained from 5 randomly selected plants in a plot. Days to anthesis and silking were taken as the date when 50% of the plants in a plot had shed pollen grains and produced silk respectively. Anthesis-silking interval (ASI) was computed as the difference between days to anthesis and silking while plant and ear heights were also recorded as the distance from the ground level to the flag leaf and the node subtending the uppermost ear respectively. For ear aspect, the cobs were assessed at harvest on a scale of 1 (excellent) to 5 (poor) based on freedom from diseases and insect damage, ear size uniformity and cob filling. Additional plants were also sampled in the second study for dry matter (DM) at 3, 5 and 8 weeks after planting (WAP) respectively. 500 grain-samples were collected from each plot at harvest to determine grain moisture content at harvest. The samples were first weighed to obtain initial weight followed by drying to a constant weight in the oven at 80°C in the laboratory and the difference between the 2 weights recorded as moisture at harvest. Grain yield was obtained from cob weight per plot (assuming 80% shelling %) and was later converted to tones per ha^{-1} after adjusting to 12% moisture content. Due to early onset of terminal drought, reliable yield data could not be collected from September planting in 2002. Therefore, data in respect of that month for both years were excluded from analyses of the planting date trial.

Data analyses

Data collected in respect of both screenhouse and field studies were subjected to analyses of variance (ANOVA). Data in respect of 2 hybrids in the first set of germplasm accessions were excluded from the analyses for lack of yield data under post-anthesis moisture deficit. Similarly, data on genotypic performance in respect of pre anthesis moisture deficit were not presented due to failure of some accessions to either complete flowering sequence or produced yield at all.

Data collected in respect of field studies were first analyzed separately before a combined ANOVA over planting seasons or years as applicable. Pertinent means were separated using either least significance difference according to Steel and Torrie (1980).

RESULTS

Screenhouse study

Moisture deficit at vegetative phase significantly delayed days to flowering (anthesis, silking and ASI) with corresponding reduction in leaf area, plant and ear heights in the first group of accessions (Table 2). However, grain yield was not significantly affected. Post anthesis moisture deficit on the other hand significantly reduced grain yield by 39 and 37% of well-watered condition and moisture deficit at vegetative phase. Genotypic (G) differences were significant for all traits while G x moisture regimes (MR) interaction effects also differed significantly for all the traits except ASI, plant and ear heights respectively. Mean grain yield across moisture treatments in the accessions ranged from 5.0 g/plant in hybrid 9033-6 to 10.7 g/plant in AK9943-DMRSR. This accession along with 2 others (ACR9222-SR and Oba super 2) with shorter ASI had significantly higher grain yield than accessions 8522-2 and IWDCO with longer ASI.

The effects of different moisture regimes (MR) as well as genotypic (G) differences were also significant for all traits investigated in the second set of germplasm accessions (Table 3). However, G x MR interaction effect was significant only for ASI, root weight and grain yield. Days to silking was delayed by 3 days when accessions were exposed to moisture deficit at vegetative phase consequently significant reductions in leaf area and plant height respectively. Root weight under vegetative moisture deficit was higher compared to either pre or post anthesis moisture deficit but was similar to that of well-watered condition. Pre and post anthesis moisture deficits significantly decreased grain yield but values for

Table 2. Effects of induced moisture stress on grain yield and yield components in nine late/intermediate drought tolerant maize accessions at Ilorin, Nigeria (Screen house study).

Parameter	Days to pollen shed (no)	Days to silk (no)	Anthesis-silking-interval (no)	Leaf area (cm^2)	Plant height (cm)	Ear height (cm)	Grain yield (g/plt)
Irrigation schedule							
Well-watered	60	62	2	741.44	126.6	65.6	3.6
Vegetative stress	66	68	2	469.20	103.2	47.7	3.5
Post-anthesis	60	70	10	573.72	125.8	64.3	2.2
S.E. ±	0.40	0.61	0.08	8.86	9.5	5.8	0.66
Genotype							
AK9443-DMRSR	62	65	3	581.5	112.7	63.3	10.7
IWDCO	62	66	4	533.2	127.7	60.8	6.5
Sin93TZUTSR-W	64	68	4	603.0	119.2	58.3	7.8
ACR9222-SR	64	67	3	596.7	130.0	69.2	9.7
ACR9128-N	63	66	3	536.2	117.5	59.2	8.3
8522-2	63	68	5	643.2	118.0	62.5	7.0
9033-26	60	65	5	653.2	122.5	47.5	5.0
9111-1	60	64	4	591.0	98.3	44.2	8.5
Oba Super 2 (Check)	64	66	2	694.8	121.7	63.3	9.0
Mean	62	66	4	605.87	118.6	58.7	8.0
S.E. ±	1.17	1.06	0.36	36.17	8.31	6.24	1.5
F- Test							
Irrigation schedule (IR)	172.80**	70.9*	47.19*	332386.0**	166.2	1014.4	7.6**
Genotype (G)	15.63**	166.7**	29.17	15279.0**	513.5*	381.4*	0.97**
G x IR	13.11**	194.3*	18.98	14089.0**	291.1	128.4	0.44*
%CV	3.28	19.69	20.15	10.36	12.14	17.08	16.79

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

Table 3. Effects of induced moisture stress on grain yield and yield components in 5 open pollinated maize varieties at Ilorin, Nigeria (Screen house study).

Parameter	Days to silk (no)	Anthesis-silking -interval (no)	Leaf area (cm^2)	Plant height (cm)	Ear height (cm)	Root weight (g/plt)	Grain yield (g/plt)
Irrigation schedule							
Well-watered	65	2	573.5	123.0	16.1	23.38	9.42
Vegetative stress	68	4	520.3	100.9	17.9	28.43	3.02
Pre-anthesis stress	66	3	533.8	110.9	0.00	11.15	0.40
Post-anthesis	65	3	485.7	123.5	17.12	21.1	2.11
S.E. ±	3.9	0.10	72.4	14.2	1.2	7.2	1.5
Genotype							
TZE Comp3 DT	46	3	559.9	116.8	13.3	17.20	4.75
DT-SR-WC0	52	2	567.4	116.7	11.5	29.79	7.23
DT-SR-YC0	52	4	508.4	118.5	12.7	17.77	4.38
DMR-LSR-Y (Check 1)	55	3	542.1	124.4	15.1	17.20	5.06
AFO-Y (Check 2)	43	5	463.8	98.54	11.6	15.15	3.53
Mean	50	3	528.3	115.0	12.8	19.42	4.99
S.E. ±	4.5	0.23	82.7	16.2	1.4	8.2	1.8

Table 3. Contd…

F- Test							
Irrigation schedule (IR)	16351.04***	113.22***	19772.44*	1758.55**	1094.86***	790.11***	245.41***
Genotype (G)	291.80***	112.63***	21819.39*	1173.94*	24.45***	462.14**	22.72***
G x IR	0.712	25.12*	6305.20	65.41	0.72	180.29*	15.86***
%CV	8.01	16.80	13.94	12.53	9.80	35.64	31.34

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

Table 4. Grain yield (g/plt) in 2 sets of drought tolerant maize germplasm accessions under 3 moisture regimes at Ilorin (Nigeria).

	Irrigation schedule			%Reduction in grain yield*	
Genotype	Well-watered	Vegetative stress	Post-anthesis stress	Vegetative stress	Post-anthesis stress
Set I					
OPVs					
AK9443-DMRSR	4.00	3.80	3.00	5.00	25.00
IWDCO	3.30	1.80	1.10	45.50	66.67
Sin93TZUTSR-W	9.40	3.40	3.40	63.83	63.83
ACR9222-SR	3.40	3.30	0.90	2.94	73.53
ACR9128-N	1.80	1.50	1.20	16.67	33.33
Hybrids					
8522-2	6.30	4.70	3.80	25.40	39.68
9033-26	3.80	2.50	2.00	34.21	47.37
9111-1	5.20	2.30	1.85	55.767	64.42
Oba Super 2 (Check)	3.00	3.00	2.40	0.00	20.00
Mean	4.47	2.92	2.20		
LSD α 005		2.78			
Set II					
TZE Comp 3DT	11.07	6.33	1.60	42.82	85.55
DT-SR-W C0	15.87	9.47	3.57	40.33	77.51
DT-SR-Y C0	7.33	4.73	3.47	35.47	52.66
DMR-LSRY (check 1)	6.00	5.53	2.57	7.83	57.17
AFO (Check 2)	9.50	6.83	3.90	28.11	58.95
Mean	9.95	6.58	3.02		
LSD α 005		3.16			

*Reduction is a function of well-watered performance.

pre anthesis moisture deficit was significantly lower than other moisture regimes. Trend in plant morphology followed similar pattern as observed for set I. For example, plant height under moisture deficit at vegetative phase was reduced by 18.0, 9.0 and 18.3% of well watered, pre and post anthesis moisture deficits respectively. Vegetative, pre and post anthesis moisture deficits grain yield losses were also 67.9, 95.8 and 77.6% respectively of well-watered condition. Accession DT-S3-W C0 with shorter ASI and highest root weight, significantly yielded higher than others. Similarly, DM accumulation in this accession was the highest followed by DT-S3-Y C0 and AFO-Y in that order (Data not shown).

Response of the accessions in each set to different moisture regimes revealed that almost all the genotypes except 2 hybrids and 2 OPVs (Oba super 2, AK9943-DMRSR, Acr 9128-N and 9033-26 in that order) showed sensitivity to post-anthesis moisture deficit (Table 4). Differences among genotypes for days to anthesis was significant with a range of 0.0 days in AK9943-DMRSR to 11 days in Hybrid 9111-1 (Set I) and from 4 days in DT-SR-Y C0 and AFO-Y respectively to 10 days in DMR-LSR-Y in Set II (data not

Table 5. Genotypic means for grain yield (t/ha^{-1}) with ranking in parenthesis in each season for 12 intermediate/late maturing drought tolerant maize accessions at Ilorin (Nigeria).

	Growing season					
	1999 Normal	**2000 Normal**	**2000 late**	**2001 Normal**		
OPVs					**∑ RSI**	**Overall ranking**
AK9443-DMRSR	3.52(3)	3.41(4)	2.20(3)	4.19(7)	17	2nd
IWDCO	2.66(10)	2.95(11)	2.23(2)	3.60(10)	33	10th
Sin93TZUTSR-W	2.48(12)	2.82(12)	2.12(7)	3.75(9)	40	12th
ACR9222-SR	2.74(9)	3.19(10)	2.50(1)	3.76(8)	28	9th
ACR9128-N	3.67(2)	3.39(6)	2.03(10)	4.38(6)	24	5th
DMR-LSRY (check 1)	2.73(8)	3.22(9)	2.17(5)	4.76(1)	23	4th
Mean	2.97	3.16	2.21	4.07		
Hybrids						
9164-2	2.99(6)	3.28(7)	1.91(11)	4.72(2)	26	6th
8522-2	3.89(1)	3.47(2)	2.08(8)	3.60(10)	21	3rd
9111-1	2.79(7)	3.43(3)	1.89(12)	4.52(4)	26	6th
8981-5	3.49(4)	3.27(8)	2.03(9)	3.58(12)	33	10th
9033-26	2.63(11)	3.40(5)	2.14(6)	4.46(5)	27	8th
Oba Super 2 (Check)	3.31(5)	3.73(1)	2.18(4)	4.61(3)	13	1st
Mean	3.18	3.43	2.04	4.25		
LSD α 005	1.04					

shown). Genotypic performances for grain yield under well-watered and moisture deficit at vegetative phase was similar except for Sin93TZTUSR-W (set I) as well as TZE Comp 3DT and DT-S3-W C0 (set II). Post anthesis grain yield reduction ranged from 20% in Oba super 2 to 74% in Acr 9222-SR (Set I) and 53% in DMR-LSRY to 86% in TZE Comp 3DT (Set II).

Field study

Grain yield in the first set of germplasm accessions under field conditions are presented in Table 5. Grain yield was lowest in 2000 late cropping season compared to any of the 3 full growing seasons. Ranges in mean grain yields were 2.48 - 3.49; 2.82 - 3.73 and 3.58 - 4.76 tons/ha^{-1} for 1999, 2000 and 2001 full growing seasons and 2.03 - 2.50 tons/ha^{-1} for 2000 late growing season. Contrary to screenhouse performances (Table 2), hybrids as a group were higher yielding than the OPVs in each of the growing seasons except in 2000 late season where OPVs had a slight edge over the hybrids. However, differences between the 2 groups were non-significant. Genotypic ranking for grain yield changed in each season but Sin93TZTUSR-W (set I) remained consistently poor yielding except in 2000 late season. The hybrid check was the most stable, ranking first for grain yield followed by AK9943-DMRSR and 8522-2.

Seasonal variation in grain yield in the second set of accessions is shown in Figure 1. The growing seasons in 2001 had periods of severe moisture stress in May, June and August but rainfall distribution was stable throughout the growing seasons in 2002. Subsequently, grain yield was reduced by between 0.06 to 1.84 tons/ha^{-1}, depending on the month of planting in the 2 years. Grain yields were lowest for June and August plantings in 2001 with an average that was lower than 1.0t/ha^{-1}. However, plantings made in July, which usually is the beginning of the full growing season, recorded the highest yields in both years.

Grain yields in the accessions were higher for April planting as soon as the rains stabilized in 2001 and for July which usually is the beginning of the full growing season in Nigeria's southern guinea savanna (Figure 2). The accessions recorded their lowest grain yield in June and August of 2001 when rainfall decreased drastically during the reproductive phase for plantings made in those months. Differences in grain yield between the 2 favourable planting periods in 2001 were 66.8 and 74.3% of June planting. DT-S3-Y C0 showed superiority for grain yield in each of the planting periods except for August 2001 planting, where the extra-early maturing local check, showed superiority for grain yields over others. The adapted variety (DMR-LSR-Y) had grain yields that were comparable to DT-S3-W C0 and TZE Comp 3 DT-W.

Genotypic performance for grain yield was better in 2002 than 2001 (Figure 3). However, grain yields were highest for plantings made in the months of June and

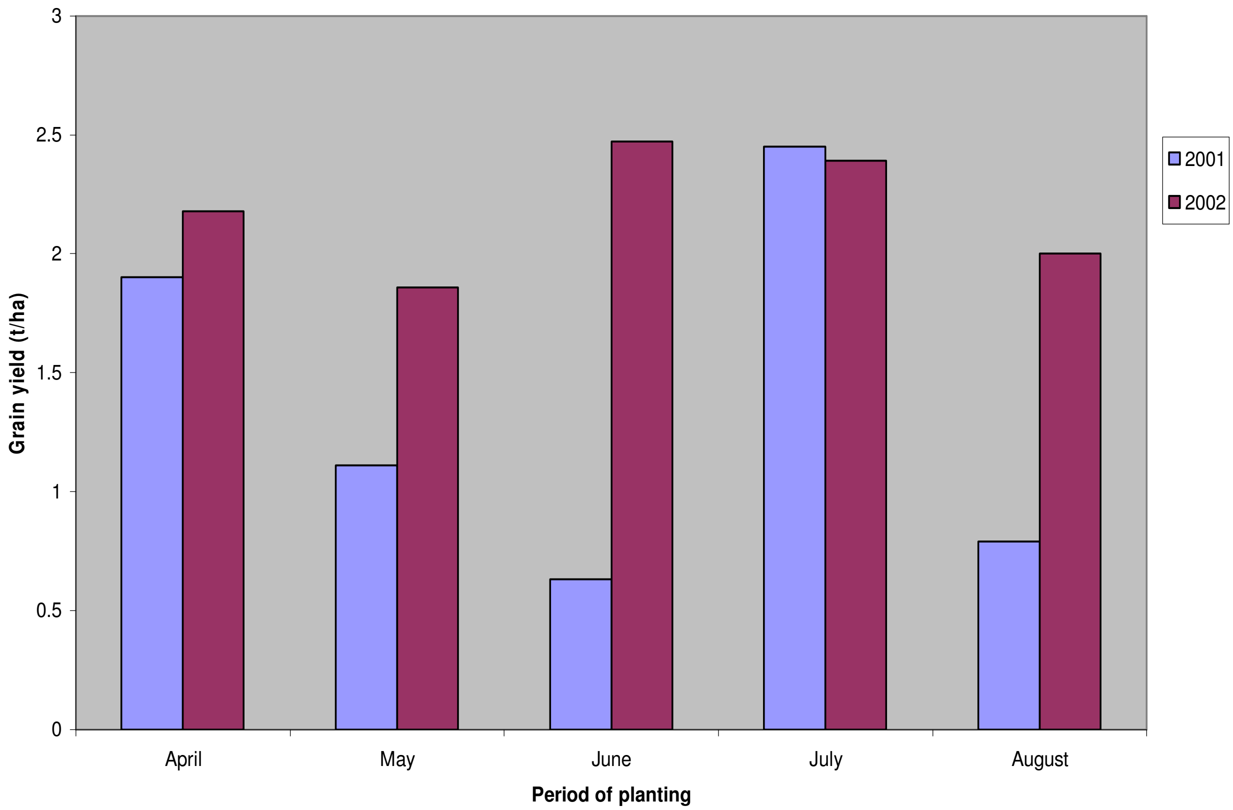

Figure 1. Effects of planting period on grain yield in 5 maize genotypes (Ilorin, Nigeria).

July. The accessions also expressed their yield potentials regardless of the planting period this year, because rainfall distribution was favourable for crop growth and productivity. DT-S3-Y C0 had the highest grain yield each month followed by DT-S3-W C0 and TZE Comp 3 DT-W. However, grain yields in the acce-ssions were comparable except that the extra-early maturing local check had the lowest mean yield.

Comparative performances of the accessions based on mean grain yield across irrigation treatments under screenhouse and across environments on the field (with rank summation index) are presented in Table 6. Among the first set of germplasm accessions, 2 hybrids (8522-2 and Oba super 2) and one OPV (AK9943-DMRSR) showed superiority for grain yield under screenhouse and field conditions. The adapted check (DMR-LSR-Y) also showed good performance under field conditions and ranked 4^{th} overall. One of the OPVs (Acr 9222-SR) which ranked second best under field condition however showed extreme sensitivity to post anthesis moisture deficit under screenhouse condition. In the second set, 2 of the DT accessions, DT-S3-W C0 and DT-S3-Y C0 exhibited similar superiority for grain yield under screenhouse and field environments. The local check also had comparable grain yield with DT-S3-Y C0 ranking second only to DT-S3-W C0 across planting dates, while the adapted check (DMR-LSR-Y) ranked lowest.

DISCUSSION

Moisture deficit occurring around anthesis could cause about 22% reduction in maize grain yield as opposed to moisture deficit at vegetative phase (Denmead and Shaw, 1960; Mcpherson and Boyer, 1977; John, 1990). Our results showed that grain yield in the 2 sets of germplasm accessions was significantly decreased by moisture deficit at anthesis compared to well-watered condition or moisture deficit imposed at vegetative phase. Previous studies (Westgate and Boyer, 1986; Basseti and Westgate, 1993) have also shown that grain development is often arrested due to sensitivity of emerging silks to drought stress. Conversely, grain yield under moisture deficit at vegetative phase was com-parable to that of well-watered condition in the second set of germplasm accessions and higher than in post-anthesis moisture deficit situation in both studies. In other words, moisture deficit at vegetative phase did not cause significant reduction in grain yield, although there was decrease in plant morphology (leaf area, plant height) accompanied by delayed flowering, which may

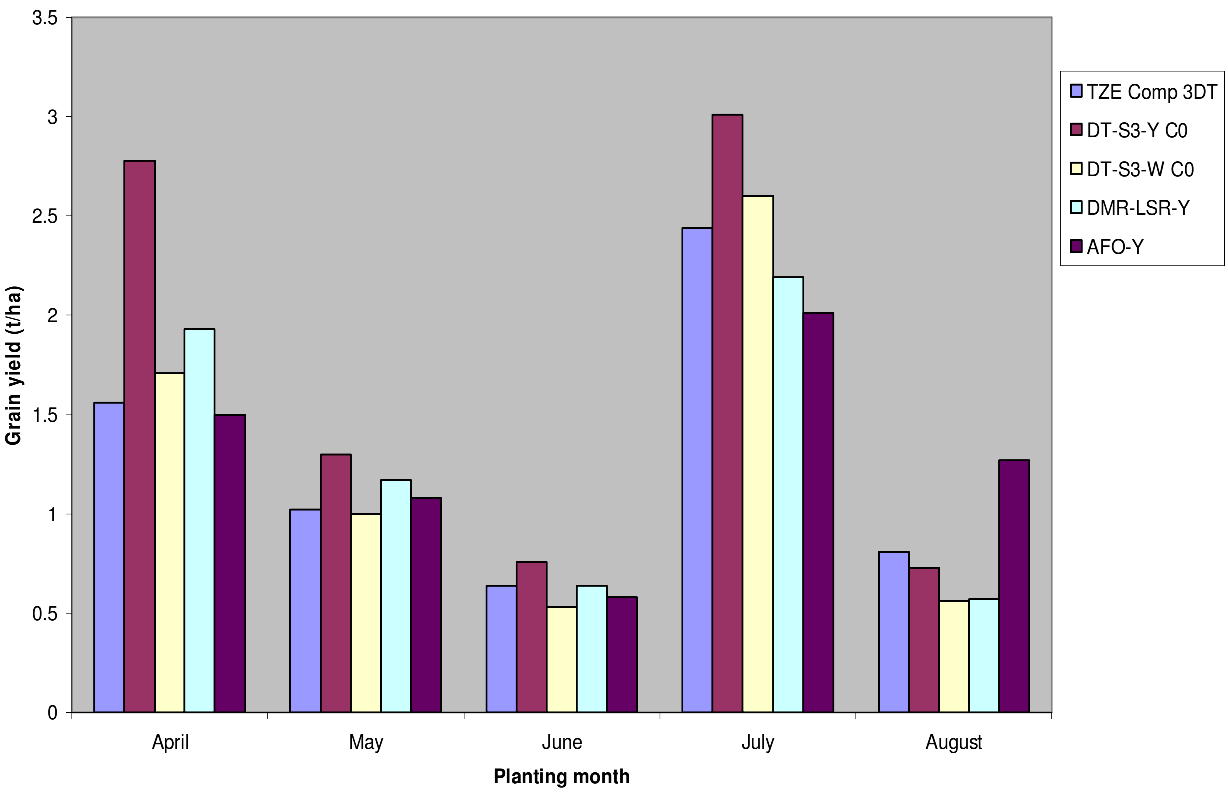

Figure 2. Response of 5 maize varieties to planting period in 2001 at Ilorin (Nigeria).

be due to moisture deficit early at the growth stage (Abbrecht and Carberry, 1993).

Drought tolerant species or varieties distinguish themselves from sensitive ones by their higher photosynthetic rates (Skingh and Tsunoda, 1978). Grain yield in the accessions differed depending on their response to available soil moisture regime. Among the first set of germplasm evaluated, Sin93TZSR-W showed superiority for grain yield/plant than others under well-watered condition and also had stable grain yields when subjected to vegetative and post-anthesis moisture deficits (although the values were lower than those of Hybrid 8522-2). This was because leaf area was not adversely affected by either moisture deficit condition (data not shown); consequently, photosynthetic activities were not hindered at any of the imposed moisture deficits in the genotype. Among the second set, DT-S3-W C0 was superior to others for grain yield under moisture deficits.

Hybrids as a group showed superiority for grain yield than OPVs either when subjected to moisture deficits in the screenhouse or under field conditions. For example, post-anthesis moisture deficit reduction in grain yield as a percentage of well-watered condition was generally higher in OPVs, ranging from 25% in AK9943-DMRSR to 73.5% in Acr922-SR, compared to a range of 20% in Oba super 2 to 64.4% in 9111-1 in the hybrids. Ranking of the genotypes for grain yield in each of the growing seasons as well as overall ranking also showed that hybrids were for the most part, superior to OPVs. This is an indication of yield stability under adverse cultural and/or environmental conditions which is contrary to earlier beliefs that hybrids only show superiority to OPVs under ideal growing conditions. However, the OPV check (DMR-LSRY) also demonstrated stable yield potential across seasons suggesting better adaptation to the ecology, having been cultivated for several years in the ecology.

Edemeades et al. (1997b) noted that early maturity usually allows cultivars to escape the consequences of terminal drought and also avoid coincidence between flowering and mid-season dry spell. Thus, performances of the extra-early maturing variety (AFO-Y) included in the second set of germplasm accessions for grain yield was due to escape of terminal and mid-season droughts of 2001 rather than drought tolerance.

Short ASI is an indicator of tolerance to drought imposed at flowering (Edemeades et al., 1989; Fischer et al., 1989; Bolaños and Edemeades, 1993b) and is therefore considered more valuable as a diagnostic trait of cultivar performance than silking date per se under moisture deficit (Edemeades et al., 1997b). ASI was the most important trait that determined differences in grain yield potential of the accessions under moisture deficit

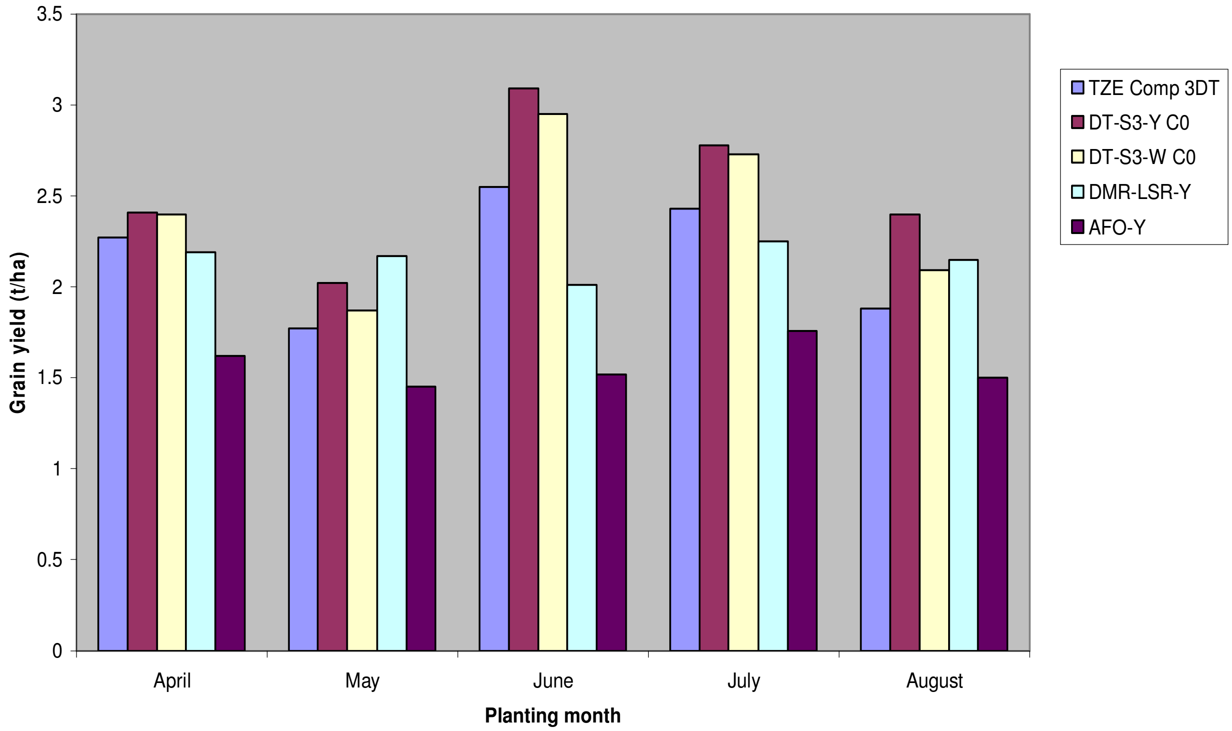

Figure 3. Response of 5 maize varieties to planting period in 2002 at Ilorin (Nigeria).

Table 6. Genotypic performance for grain yield (with ranking) under post-anthesis moisture deficit (screenhouse) and field environments for 2 sets of drought tolerant germplasm accessions at Ilorin (Nigeria).

Genotype	Grain yield (Set I)				Grain yield (Set II)				
	Screen house (g/plt)	Field condition (t/ha)+	∑R SI	Overall ranking	Genotype	Screen house (g/plt)	Field condition (t/ha) ++	∑R SI	Overall ranking
OPVs									
AK9443-DMRSR	3.00 (3)	3.33 (3)	6	3rd	TZE Comp 3DT	1.60 (5)	2.18 (3)	8	4th
IWDCO	1.10 (8)	3.08 (6)	14	9th	DT-SR-W C0	3.57 (2)	2.54 (1)	3	1st
Sin93TZUTSR-W	3.40 (2)	2.86 (9)	11	4th	DT-SR-Y C0	3.47 (3)	2.41 (2)	5	2nd
ACR9222-SR	0.90 (10)	3.37 (2)	12	7th	DMR-LSRY (check 1)	2.57 (4)	1.58 (5)	9	5th
ACR9128-N	1.20 (9)	2.79 (10)	19	10th	AFO (Check 2)	3.90 (1)	2.15 (4)	5	2nd
DMR-LSRY (check)	1.85 (6)	3.22 (5)	11	4th					
Hybrids									
8522-2	3.80 (1)	3.27 (4)	5	1st					
9033-26	2.00 (5)	3.16 (6)	11	4th					
9111-1	1.85 (6)	3.16 (6)	12	7th					
Oba super 2 (Check)	2.40 (4)	3.48 (1)	5	1st					

+Means across 4 environments.
++Means across 2 years and 5 planting dates.

either in the screenhouse or field environment. For example, Oba super 2 and AK9943-DMRSR (set I) as well as DT-S3-WC0 and DT-S3-YC0 (set II), yielded significantly higher than 8522-2 and 9033-26 (set I) and AFO-Y (set II) with longer ASI.

Root morphology (depth, intensity and health) under moisture deficit coupled with increased osmotic adjustment has been reported to enhance supply of assimilates to the plant by increasing water supply (O'Toole and Band, 1987; Ludlow and Muchow, 1980). Consequently, it has been identified as one of the secondary traits in selecting for drought tolerance (Edemeades et al., 1997a). Our results also showed a direct relationship between root weight and grain yield under the different moisture regimes. Similarly, DT-S3-W C0 with the largest root weight also had a significantly higher grain yield/plant than other genotypes under moisture deficit at vegetative phase and when averaged across moisture treatments.

Yield stability is a measure of variation between potential and actual yield of a genotype across changing environments and could result from genetic heterogeneity, yield component compensation, stress tolerance, capacity to recover rapidly from stress or a combination of these factors (Henrich et al., 1983). Oba super 2, 8522-2 and AK9443-DMRSR (set I) as well as DT-SR-W C0 and DT-SR-Y C0 (set II), showed superiority of performance under post anthesis moisture deficit (screenhouse) and field environments. These accessions could be used as cultivars per se in drought-prone ecologies of Nigeria's savannas or as sources of gene pool for drought breeding. Where earliness for avoiding terminal drought is desired, AFO-Y could be a source of alleles for development of early maturing DT genotypes.

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