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TOLERANCE TO DROUGHT AT FLOWERING STAGE of 28 MAIZE HYBRIDS AND POPULATIONS

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ABSTRACT

In order to identify genotypes of high water efficiency and responsiveness, this study was conducted to determine the differential performance under drought stress and non-stress conditions at flowering stage among 3 groups of maize genotypes of narrow- (single crosses), medium- (3-way crosses) and broad- (populations) genetic base backgrounds in two seasons, i.e. 2009 and 2010. Performance of genotypes varied with water supply and season. Water stress caused significant decreases in grain yield/plant (GYPP), grain yield/fed (GYPF), ears/plant (EPP), kernels/plant (KPP), and 100-kernel weight (100KW) and significant increase in anthesis-silking interval (ASI), barren stalks (BS), leaf rolling (LR) and leaf senescence (LS). The largest reduction was reached by GYPP (≈ 38 %), but the largest increase was reached by LR (≈ 311 %) as a result of water stress. Narrow genetic base genotypes exhibited the highest means for GYPP and GYPF. Medium- and broad- genetic base genotypes came in the 2nd and 3rd rank, respectively for same traits. Superiority of tolerant (T) over sensitive (S) genotypes under drought in GYPP (118.3 %) was due to superiority in all yield components, i.e. KPP (25.78 %), EPP (24.71 %) and 100KW (3.89 %) as well as in drought adaptive traits, i.e. lower values in BS, LR, LS, ASI, days to anthesis and to silking and plant and ear height. Single crosses SC 128, SC Ageeb, SC 101, SC 124, followed by SC 30D80, SC 3062, SC 30K08, and SC 10 were considered water efficient and responsive, while most of populations were considered non-efficient and non-responsive. The superiority of SC 128, SC 101 and SC 3062 in GYPP could be attributed to superiority in EPP, KPP, ASI and LS while superiority in GYPP of SC D80 and SC 30K08 could be due to superiority in ASI and LS and that of SC 10 due to superiority in EPP and KPP. Further studies should be conducted to determine the underlying plant mechanisms contributing to the water efficient selected hybrids of maize.

Key words: ***Zea mays, Drought tolerance, Anthesis silking interval; Water efficiency, Responsiveness, Genotypic differences.***

INTRODUCTION

Growing maize under poor rainfed conditions or in the sandy soils of low water-holding capacity would expose maize plants to drought stress, which could result in obtaining low grain yields under such conditions. Moreover, the expected future shortage in irrigation water necessitates that maize breeders should pay great attention to develop drought tolerant maize cultivars that could give high grain yield under both water-stress and non-stress conditions. Maize crop was found to be particularly susceptible to drought at flowering stage (Chapman *et al* 1996). Loss in grain yield is particularly severe when drought stress occurs at this stage (Claassen and Shaw 1970, Grant *et al* 1989 and El-Sayed 1998).

During the last decades, considerable efforts have been devoted to improve yield performance of maize under drought stress conditions through breeding, and to understand the mechanisms involved in drought tolerance (Edmeades *et al* 1992). In that context, CIMMYT has improved some tropical maize populations for drought tolerance while maintaining their yield potential under favorable conditions (Bolanos and Edmeades 1996). The problems have been the adoption of proper techniques of identifying and selecting tolerant genotypes to soil water stress. This also requires determining which trait should be recommended to the maize breeders as most suitable for breeding drought tolerant maize.

Several investigators emphasized the role of maize genotypes in drought tolerance. Tolerant genotypes of maize were characterized by having shorter anthesis-silking interval (ASI) (Bolanos and Edmeades 1993) higher number of ears/plant (Edmeades *et al* 1993 and Ribaut *et al* 1997) and higher number of kernels/ear (Hall *et al* 1982 and Ribaut *et al* 1997) than susceptible ones. The existence of genotypic differences in drought tolerance would help plant breeder in initiating a successful breeding program to improve such a complicated character.

Many investigators studied the correlations between yield and other plant attributes under soil moisture stress in order to determine rapid and accurate indirect selection criteria for drought tolerance. A strong negative association was reported between grain yield and each of anthesis –silking interval (Bolanos and Edmeades 1993) and barren stalks (Edmeades *et al* 1993). While a strong positive association was found between grain yield yield and each of the number of ears/plant (Guei and Wassom 1992, Terrazas *et al* 1995 and Ribaut *et al* 1997) and number of kernels/row (Weerathaworn *et al* 1992 and Ribaut *et al* 1997). These investigators suggested that mentioned traits could be used as indicators of drought tolerance in maize.

To start a successful breeding programme for improving drought tolerance, available maize germplasm should be screened under drought stress and non-stress conditions to identify the best ones for further use in extracting the best parental inbred lines for developing drought tolerant single and three way cross hybrids. The objectives of the present investigation were to examine the differential tolerance to drought at flowering stage among three groups of maize genotypes, i.e. narrow, medium and broad genetic base background, identify genotypes of high water efficiency and responsiveness, estimate the magnitude of water stress effect and identify characters of the strongest association with grain yield under water stress.

MATERIALS AND METHODS

Materials

Twenty eight maize (*Zea mays* L.) hybrids and populations were used, namely 12 single cross (SC) and 8 three-way cross (TWC) hybrids and 8 open-pollinated populations as follows: SC 10 (1), SC 128 (2), SC 155 (3), SC 162 (4), SC Ageeb (5), SC 101 (6), SC 124 (7), SC 30K09 (8), SC 30N11 (9), SC 30D80 (10), SC 3062 (11), SC 30K08 (12), TWC 352 (13), TWC 329 (14), TWC 324 (15), TWC 314 (16), TWC 321 (17), TWC 310 (18), TWC 323 (19), TWC Majed (20), Cairo-1 (21), Pop-59E (22), DTP-1-C-7 (23), Pop-45 (24), Comp-21 (25),Tep-5 (26), American Early Dent (AED) (27) and Pop-Local yellow (28). These materials were kindly provided by Pioneer International Co. (SC 30K09, SC 3011, SC 30D80, SC 3062, and SC 30K08), Fine Seed International Co. (SC Ageeb and SC 101), Nile Seed Co. (TWC Majed), Agronomy Dept., Fac. Agric., Cairo Univ., Egypt (Cairo-1) and the rest (19 entries) by Maize Res. Dept. of Agric. Res. Center (ARC), Egypt.

Experimental Procedure

This study was carried out in the summer seasons of 2009 and 2010 at the Experimental Station of the Faculty of Agriculture, Cairo University, Giza, Egypt. Seed of the 28 cultivars and populations of maize were sown under two irrigation regimes, i. e. well watering (WW) (control treatment) where irrigation was added at 12 to 13 day intervals and drought stress (DS) (stress treatment) by withholding the 4th and 5th irrigations; the irrigation interval between the 3rd and next irrigation was 40 days, so water stress period was 25 days just before and during flowering stage.

The soil of the experimental site was clayey loam, containing 35% clay, 22% silt, 37% fine sand and 6% coarse sand with a PH of 7.8 (according to the analysis done at Soil and Water Res. Inst., ARC, Egypt).

Each main plot was surrounded with a wide ridge (1.5 m width), to avoid leaching of water. Sowing date was May 1st in the 1st season and April 4th in the 2nd season. Seeds were sown in hills at 25 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill. All other agricultural practices were done according to the recommendations of ARC, Egypt.

Data were recorded on: number of days from planting to 50 % anthesis (DTA), days from planting to 50 % silking (DTS), anthesis-silking interval (ASI), plant height (PH) in cm, ear height (EH) in cm, barren stalks percentage (BS %), leaf rolling (LR) at the end of stress according to O'toole and Moya (1978) (scale from 1 to 5; where 1= unrolled and 5 = tightly rolled leaves), leaf senescence (LS) at the end of stress (scale from 1 to 10, where 1 = no senescence and 10 = complete death), number of ears/plant (number of ears per plot/number of plants/plot at harvest), number of rows/ear (RPE), number of kernels/row (KPR), 100- kernel weight (100 KW) in g, grain yield per plant (GYPP) in g and grain yield per feddan (fed) (GYPF) in ardab (ard) (one fed = 4200 m^2 and one ard = 140kg). Both GYPP and GYPF were adjusted at 15.5% grain moisture.

Biometrical analysis

Combined analysis of variance of the split plot design across the two years was computed if the homogeneity test was non-significant and LSD values were calculated to test the significant of differences between means according to Snedecor and Cochran (1989). Simple correlation coefficients were calculated between grain yield/plant and other studied traits under each environment (well or drought irrigation).

RESULTS AND DISCUSSION

Analysis of variance

Combined analysis of variance (Table 1) showed that mean squares due to genotypes (28 hybrids and population) were highly significant for 12 out of 15 studied traits; the exceptions were barren stalks (BS) leaf rolling (LR), kernels/row (KPR) and rows/ear (RPE) traits, where differences between genotypes were not significant. Mean squares due to irrigation regimes were highly significant for all studied characters, except for days to anthesis (DTA) and KPR, indicating that soil moisture stress had a significant effect on most studied traits. Mean squares due to years were significant or highly significant for all studied traits, indicating the presence of differences among 2009 and 2010 seasons in weather conditions; especially temperature, since date of planting was on May 1st in the 1st season and April 4th in the second one.

Mean squares due to genotype x irrigation regime interaction were significant and highly significant for ears/plant (EPP), 100-kernel weight (100KW), kernels/plant (KPP), grain yield/plant (GYPP) and grain yield/fed (GYPF), indicating that means of grain yield and its components of genotypes varied with water supply, confirming previous results (Denmead and Shaw 1960, Moss and Downey 1971, El-Sayed 1998, Atta 2001 and Al-Naggar *et al* 2004 and 2008).

Mean squares due to genotype x year interaction were highly significant for 10 out of 15 studied characters and non-significant for DTA, BS, leaf rolling (RL), KPR and RPE. Mean squares due to genotype x irrigation regime x year interaction were significant and highly significant for leaf senescence (LS), 100KW, GYPP and GYPF, suggesting that the performance of genotypes varied with water supply and season for these traits.

Table 1. Combined analysis of variance across two years for studied traits of maize genotypes evaluated under well watering (WW) and drought stress (DS).

SOV	df	Mean Squares				
		DTA	DTS	ASI	PH	EH
Years (Y)	1	2263.05**	466.71**	602.68**	5146.50**	11904.76**
Year/Reps	4	21.05	51.61	12.53	2398.96	301.19
Irrigation (I)	1	18.11	243.44**	107.44**	18975.07**	17574.11**
Y × I	1	28.58	72.43*	4.76	9589.36**	344.05
Error (a)	4	41.99	67.90	4.43	1508.78	962.65
Genotypes(G)	27	57.12**	85.01**	11.18**	1542.80**	727.39**
G × Y	27	59.18	68.23**	13.07**	1422.43**	585.78**
G ×I	27	4.71	7.42	3.50	370.75	207.59
G × I × Y	27	6.27	8.73	4.83	336.89	185.25
Error (b)	216	4.63	6.72	4.92	342.45	174.51
		BS	LR	LS	EPP	KPR
Years (Y)	1	249.81*	162.96**	276.86**	2.61**	2010.96**
Year/Reps	4	73.89	3.23	0.91	0.15	210.94**
Irrigation (I)	1	3605.78**	1226.68**	923.36**	3.56**	1296.43
Y × I	1	457.71**	260.76**	71.50**	0.35*	619.94*
Error (a)	4	69.05	1.68	2.77	0.45	165.38
Genotypes(G)	27	17.46	1.82	5.71**	0.10**	38.20
G × Y	27	9.66	3.68	3.25**	0.07**	30.56
G ×I	27	14.23	1.54	1.48	0.05*	37.60
G × I × Y	27	15.74	3.68	2.42*	0.03	24.11
Error (b)	216	13.77	2.98	1.47	0.03	29.26
		RPE	100 KW	KPP	GYPP	GYPF
Years (Y)	1	52.01**	2129.55**	686962.35**	7837.35**	176.33**
Year/Reps	4	5.38	0.08	122197.98	229.49	5.16
Irrigation (I)	1	55.86**	477.52**	876898.55**	98533.14**	2217.14**
Y × I	1	3.01	526.78*	686962.35**	9815.05**	220.76**
Error (a)	4	2.75**	0.08	58708.15**	407.66	9.17
Genotypes(G)	27	2.75	67.01**	57803.34**	3576.21**	80.45**
G × Y	27	3.83**	44.45*	9277.11	762.30**	17.15**
G ×I	27	1.76	30.45*	25278.38**	848.19**	19.09**
G × I × Y	27	1.99	24.64*	9277.11	589.43**	13.26**
Error (b)	216	1.63	0.06	13345.23	326.67	7.35

* and ** indicates significance at 0.05 and 0.01 probability levels, respectively

Effect of drought stress

Water stress conditions imposed during flowering stage caused a significant reduction; across the two studied years, in grain yield/plant (37.93%) and grain yield/fed (30.96%) (Table 2). Yield reductions due to drought were accompanied by significant losses in 100KW (7.74%), KPP (31.13%), KPR (10.47%), RPE (5.58%) and ears/plant (21.52%), i.e. in all yield components. Reduction in each yield component separately was not as high as reduction in grain yield/plant. Reduction due to water deficit at flowering stage in number of kernels/plant was much greater than that in the kernel weight, confirming results of Claassen and Shaw (1970), Grant *et al* (1989), Nesmith (1991), El-Sayed (1998), Atta (2001) and Al- Naggar *et al* (2008).

Table 2. Summary of means and ranges of studied traits for 28 maize cultivars and populations under well watering (WW) and drought stress (DS) conditions (Data are combined across two years).

Trait	Mean			Range				LSD$_{0.05}$		
				WW		DS				
	WW	DS	Red %	Highest	Lowest	Highest	Lowest	I	G	G×I
DTA	68.43	65.07	4.91	73.50	58.34	73.50	60.00	0.74	1.73	3.89
DTS	73.63	71.86	2.40	78.50	61.67	80.17	66.34	0.93	2.09	4.92
ASI (day)	4.87	6.04	-23.92	7.17	2.50	9.00	3.17	0.48	1.79	2.53
PH(cm)	229.89	214.74	6.59	250.84	192.50	245.00	174.17	5.62	14.89	29.76
EH(cm)	114.52	100.07	12.62	131.67	98.33	117.50	74.17	3.67	10.63	19.40
BS%	4.82	11.37	-136.14	6.53	3.76	15.85	7.07	0.80	2.99	4.22
LR	1.23	5.06	-311.38	1.84	1.00	8.00	3.50	0.73	1.39	3.87
LS	1.76	5.07	-188.07	3.17	1.00	6.84	3.33	0.44	0.98	2.33
EPP	0.79	0.62	21.52	1.22	0.70	1.02	0.46	0.06	0.18	0.32
RPE	14.52	13.71	5.58	16.90	13.40	15.14	12.20	0.41	1.03	2.20
KPR	37.33	33.42	10.47	40.80	32.90	38.67	28.64	1.77	4.35	187.12
KPP	485.03	334.05	31.13	620.57	373.55	454.91	244.80	35.36	92.96	0.42
100KW(g)	30.89	28.50	7.74	40.45	26.62	34.44	22.84	0.08	0.21	23.47
GYPP(g)	112.54	69.85	37.93	148.50	66.84	102.14	36.56	4.44	14.54	23.47
GYPF(ard)	16.54	11.42	30.96	23.35	11.12	16.05	7.97	0.67	2.18	3.01

Red= reduction = 100 (WW- DS)/WW, I= irrigation regimes and G= genotypes

A significant decrease was also recorded due to water stress in number of days to anthesis (3.36 days or 4.91%), days to silking (1.77 days or 2.40%), plant height (6.59%) and ear height (12.62%).

On the contrary, a significant increase was shown by anthesis-silking interval (1.17 days or 23.92%), BS (136.14%), LR (311.38%) and LS (188.07%) due to water stress at flowering stage (Table 3). Elongation of ASI in maize as a result of drought stress was reported by several investigations (Bolanos and Edmeades 1993, El-Sayed 1998 Atta 2001 and Al-Naggar *et al* 2004 and 2008). It is interesting to record that reductions in means of the 28 genotypes due to drought were accompanied by reductions (narrowness) in their ranges (for GYPP, GYPF, KPP, KPR, DTA and DTS), while increases in means due to drought were associated by broadness in their ranges (for ASI, BS, LR and LS).

Genotypic differences under drought

Means of the 28 maize hybrids and populations showed a wide range under well and drought stress conditions (Table 2). The four highest and four lowest genotypes are presented in Table (3). Under drought conditions, the highest mean grain yield/feddan (16.05 ardab) was achieved by the single cross SC 128 (developed by ARC, Egypt). The same cross was among the four highest hybrid genotypes and populations for GYPP, KPP, 100KW and EPP and the four lowest (favorable) genotypes for LR, BS, DTA and DTS under drought irrigation and GYPF, GYPP, KPP, 100KW and EPP and the four lowest for LS and DTA under well watering conditions.

Under drought stress conditions, the single crosses SC 124 and SC 128 (developed by ARC), SC Ageeb (developed by Fine Seed Co.) and SC 3062 (developed by Pioneer Intern. Co.) ranked 1st, 2nd, 3rd and 4th, respectively for grain yield/plant. These four crosses (SC 128, SC 124, SC Ageeb and SC 3062) were considered the most tolerant genotypes to drought in this study. Drought tolerance of single crosses expressed by grain yield could be attributed to their advanced rank in earliness (DTA and DTS) (SC 128), shortness of ASI (SC 3062), shortness of plant height (SC 3062), lowest ear position (SC 30k-8 and SC 101), lowest barren stalks (SC 128), lowest LR (SC 3062 and SC 128), highest number of ears (SC 3062, SC128 and SC 101), highest number of kernels/plant (SC 3062, SC 128, and SC 101) and heaviest kernels (SC 128) (Table 3).

In contrast, Tep-5, DTP-1, Cairo and AED, all open-pollinated populations, were the lowest for GYPP and GYPF. These genotypes were therefore considered as the most sensitive genotypes to drought at flowering stage.

Table 3. The four highest and four lowest hybrids and populations for studies traits under well watering (WW) and drought stress (DS) conditions (Data are combined across seasons).

Parameter	WW	DS	WW	DS	WW	DS
	DTA		BS		RPE	
Highest	SC30N11	SC30N11	SC30D80	SC30k8	AED	Comp21
	SC30k9	Tep5	TWCMajed	TWC310	Pop59	SC155
	Tep5	TWC329	Cairo1	PopLocal	Pop45	Pop59
	TWCMajed	SC30k9	PopLocal	Tep5	TWC329	AED
Lowest	PopLocal	PopLocal	SCAgeeb	SC128	TWC323	TWCMajed
	Pop59	Pop59	Tep5	SC10	SC101	TWC323
	SC101	SC128	SC155	DTP1	SC30N11	SC3062
	SC128	SC101	SC10	TWC323	SC30D80	TWC324
	DTS		LR		100KW	
Highest	SC30N11	Tep5	TWC329	SC30N11	SC101	SC30k9
	Tep5	SC30N11	Cairo1	AED	SC128	TWCMajed
	TWCMajed	SC30k9	Comp21	TWC323	SCAgeeb	TWC314
	SC30k9	TWC329	TWC324	TWC329	SC10	SC128
Lowest	PopLocal	PopLocal	TWC321	SC3062	PopLocal	PopLocal
	Pop59	Pop59	TWC310	TWCMajed	SC124	SC124
	SC101	SC128	SC30k8	SC128	SC30D80	Tep5
	SC30D80	SC155	SC30D80	Cairo1	TWC352	SC30K8
	ASI		LS		KPP	
Highest	Comp21	TWC314	Comp21	TWC321	SC162	SC155
	TWC314	TWC310	Pop45	TWC352	SC30 N11	SC 3062
	Pop59	SCAgeeb	TWC329	PopLocal	SC128	SC128
	AED	Pop59	TWC324	Comp21	TWC321	SC101
Lowest	SC30D80	SC30D80	DTP1	TWCMajed	Tep5	Tep5
	TWC324	SC3062	SC162	Tep5	PopLocal	TWC329
	SC3062	DTP1	SC10	SC30N11	Pop59	TWC324
	PopLocal	SC155	SC128	SC30k9	SCAgeeb	SC30k9
	PH		EPP		GYPP	
Highest	Cairo1	Cairo1	SC30N11	SC3062	SC30k8	SC124
	SC30N11	SC30N11	SC162	SC155	SC128	SC128
	TWC324	TWC314	SC128	SC128	TWC321	SCAgeeb
	TWC329	SC10	SC3062	SC101	SC10	SC3062
Lowest	PopLocal	Pop59	Pop59	TWC329	Tep5	Tep5
	Pop59	PopLocal	Tep5	Tep5	Pop59	DTP1
	DTP1	SC3062	PopLocal	SC124	AED	Cairo1
	SC124	SC30D80	Pop45	TWC324	TWC352	AED
	EH		KPR		GYPF	
Highest	Cairo1	SC30N11	SC101	SC10	SC101	SC128
	TWC324	Cairo1	TWC310	SC162	SC124	SC124
	TWC329	AED	SC124	SC101	SCAgeeb	SC30D80
	Comp21	Tep5	AED	Cairo1	SC128	SC101
Lowest	SC101	Pop59	SCAgeeb	SC30N11	Pop59	AED
	SC30k8	PopLocal	SC30N11	SC30D80	Comp21	Cairo1
	Pop59	SC30k8	TWC352	TWCMajed	Tep5	DTP1
	DTP1	SC101	Cairo1	SC30k9	AED	Tep5

Hybrids vs populations

Partitioning genotype degrees of freedom into its components, i.e., single (SC) and 3-way (TWC) crosses and populations (Pop) for GYPP and GYPF (Table 4) showed that mean squares due to SC's were highly significant across seasons, indicating presence of significant differences among single crosses for grain yield traits. Mean squares due to SC x year and TWC x year interactions were significant and highly significant for both yield traits, indicating that SC's and TWC's perform differently from year to year.

Table 4. Partitioning genotype (G) degrees of freedom into single (SC) and 3-way (TWC) hybrids (H) and populations (Pop) and their interaction under drought stress (DS) conditions (Data are combined across years)

SOV	df	Mean squares	
		GYPP	GYPF
Genotypes (G)	27	1165.44**	26.23**
Hybrids (H)	19	665.01**	14.96**
Single cross (SC)	11	854.04**	19.23**
3-way cross (TWC)	7	367.78	8.27
SC vs TWC	1	666.20*	14.94*
Popultions (Pop)	7	137.38	3.10
Pop vs H	1	17870.22**	402.17**
G × Y	27	5312.67**	13.68**
H × Y	19	13181.35**	16.27**
SC × Y	11	46762.26**	19.59**
TWC × Y	7	9545.33*	12.75*
SC vs TWC × Y	1	1942.13	4.38*
Pop × Y	7	1272.02	6.77
Pop vs H × Y	1	304.52	12.79**

Mean squares due to orthogonal comparisons, i.e. SC vs TWC and H vs Pop were significant for both traits, indicating that the group of single crosses differs significantly from the group of 3-way crosses and group of hybrids differs significantly from the group of populations.

Comparing maize genotypes for drought tolerance, based on narrow- vs medium vs broad base genetic background (Table 5), indicated on average, that under drought, narrow-genetic base genotypes (single crosses) showed the highest means for GYPP and GYPF. Medium genetic base genotypes (3-way crosses) came in the second rank after single crosses, while broad base genotypes (populations) exhibited the lowest means for grain yields that express tolerance to drought. This indicates that, on average the single crosses were the highest tolerant to drought, the 3-way crosses

Table 5. Comparison of drought tolerance among single and three-way crosses and populations for grain yield/plant (GYPP) and grain yield/feddan (GYPF), in the two seasons and combined across them.

Genotypes	2009 season		2010 season		Combined	
	GYPP (g)	GYPF (ard)	GYPP (g)	GYPF (ard)	GYPP (g)	GYPF (ard)
			Well Watering			
Single crosses	132.08	19.50	124.67	18.70	128.38	19.10
Three-way crosses	117.99	16.07	116.34	17.45	117.17	16.76
Populations	87.70	13.00	81.47	12.22	84.59	12.61
			Drought Stress			
Single crosses	63.92	10.84	97.15	14.57	80.54	12.71
Three-way crosses	49.20	10.51	89.75	13.46	69.48	11.99
Populations	41.71	7.90	67.29	10.09	54.50	9.00
			Reduction %			
Single crosses	51.61	44.41	22.07	22.09	37.26	33.46
Three-way crosses	58.30	34.60	22.86	22.87	40.70	28.46
Populations	52.44	39.23	17.41	17.43	35.57	28.63

Reduction % = 100(Well watering – Drought stress)/Well watering

were of medium tolerance and the open-pollinated populations were of lowest tolerance, for both and across years (Table 5). This might be attributed to the high productivity of the newly developed single cross hybrids under drought conditions as compared to 3-way crosses and populations. These results are in agreement with those reported under low-nitrogen conditions by Akinotoye *et al* (1999) and Worku *et al* (2007).

On the contrary, average reduction due to drought stress was at minimum (favorable) for the set of studied populations expressed in GYPP (Table 6). Maximum reduction due to water stress was shown by the group of 3-way crosses for GYPP. Average reduction because of water deficit for the group of single crosses was of medium magnitude for GYPP and maximum for GYPF. Thus, the group of single cross hybrids could be considered the most tolerant genotypes, since they showed the highest absolute estimates under drought for the most important traits expressing drought tolerance and medium reduction in GYPP due to drought conditions. In contrast, the group of populations could be considered the most sensitive genotypes in the present study, because of their inferiority in absolute estimates of GYPP and GYPF. The lowest reductions due to water – deficit exhibited by populations may be attributed to the lowest absolute means under well watering, i.e. to their low potential performance.

Superiority of tolerant over sensitive genotypes

To describe the differences between drought tolerant (T) and sensitive (S) genotypes, data of studied characters were averaged for the two groups of genotypes differing in their tolerance (Table 6). The four highest tolerant genotypes (T) to drought were SC 128, SC 124, SC Ageeb and SC 3062, while the four most sensitive (S) ones were Tep-5, DTP-1, AED and Cairo-1 in both and across the two studied years.

Table 6. Average performance of selected characters averaged over the four highest and four lowest genotypes in grain yield and superiority (%) of tolerant (T) over sensitive (S) genotypes under drought stress conditions combined across seasons.

Characteristic	Tolerant (T)	Sensitive (S)	Superiority %
No. of genotypes	4	4	
DTA (day)	67.04	71.21	-5.85
DTS (day)	73.00	77.21	-5.45
ASI (day)	5.92	6.00	-1.38
PH (cm)	207.71	222.50	-6.65
EH (cm)	94.58	111.25	-14.98
BS (%)	9.33	11.31	-17.57
LR	4.58	5.75	-20.25
LS	4.62	4.71	-1.78
EPP (No)	0.80	0.64	24.71
100KW (g)	28.54	27.47	3.89
KPP (No)	377.82	300.38	25.78
GYPP (g)	99.38	45.53	118.30

Grain yield of tolerant (T) genotypes was greater than that of the sensitive (S) ones by 118.30% across years. Superiority of T over S genotypes under water stress in grain yield was due to superiority in the three yield components; i.e. number of kernels/plant (25.78%), number of ears/plant (24.71%) and 100 kernel weight (3.89%). Superiority of T over S under drought in number of kernels was more than six fold greater than such superiority in kernel weight.

In contrast, significant lower values (desirable) exhibited in T than in S by about 20.25% for leaf rolling, 17.57% for barren stalks, 14.98% for ear height, 6.65% for plant height, 5.85% for days to anthesis, 5.45% for days to silking, 1.78% for leaf senescence and 1.38% for anthesis silking interval, indicating that T genotypes were earlier, shorter, of less leaf rolling and senescence and less barrenness than S genotypes.

Trait interrelationships

Under drought conditions across the two years, grain yield/plant had significant and highly significant positive associations with kernels/plant, 100KW, kernels/row, ears/plant, plant height and rows/ear (Table 7), but the magnitude of such correlations was small (>0.39). On the contrary, grain yield/plant showed a highly significant negative correlation coefficient with anthesis-silking interval, barren stalks, leaf rolling and leaf senescence, all are drought adaptive traits. This indicates that maize plant, to produce high grain yield under drought stress should be characterized by short ASI, low barrenness, low leaf rolling and low leaf senescence.

Table 7. Simple correlation coefficients between grain yield/plant and other studied traits under well-watered and drought-stress conditions in 2009 and 2010 seasons and their combined

Trait	Well watering			Drought stress		
	2009	2010	Combined	2009	2010	Combined
DTA	-0.37**	-0.05	-0.19**	-0.16	0.04	0.18**
DTS	-0.32**	-0.12	-0.22**	-0.27*	-0.01	-0.05
ASI	0.04	-0.17	-0.03	-0.19	-0.08	-0.32**
PH	0.11	0.10	0.10	0.13	0.18	0.28**
EH	0.09	-0.16	0.01	0.15	0.03	-0.09
BS	-0.05	-0.16	-0.10	-0.10	-0.15	-0.25**
LR	-0.02	-0.29**	-0.17*	-0.10	-0.02	-0.29**
LSE	0.05	0.02	0.04	-0.01	0.03	-0.28**
EPP	0.01	0.13	0.05	0.13	0.17	0.32**
KPR	-0.04	-0.22*	-0.08	0.11	0.16	0.32**
RPE	0.03	-0.04	0.00	0.08	-0.13	0.13*
100 KW	0.32**	0.41**	0.33**	-0.09	0.16	0.33**
KPP	0.50**	0.32**	0.42**	0.32**	0.07	0.39**
GYPF	1.00**	1.00**	1.00**	1.00**	1.00**	1.00**

An increased ASI (or asynchrony) has usually been associated with reduction in grain yield (Classen and Shaw 1970, Moss and Downey 1971, Edmeades *et al* 1993, Bolanos and Edmeades 1996 and Al-Naggar *et al* 2004 and 2008). Under well watering, grain yield had significantly positive correlations with KPP and 100KW and significant negative correlations with LR, DTA and DTS. Under both drought stress and non-stress conditions, GYPP had a very strong positive correlation coefficient (r=1.00) with GYPF (Table 7).

Identifying genotypes based on water efficiency and responsiveness

Mean grain yield/plant combined across years of studied genotypes under drought stress at flowering stage was plotted against mean grain yield of the same genotypes under well irrigation (Fig.1), which made it possible to distinguish between water efficient and inefficient genotypes on the basis of above-average and below-average grain yield under drought stress, respectively and responsive and non-responsive genotypes on the basis of above-average and below-average grain yield under well watering respectively (Sattelmacher *et al* 1994). Similarly, means of EPP, KPP, ASI and LS under water stress were plotted against means of the same traits for the same genotypes under well watering (Figures 1 2, 3, 4 and 5, respectively).

Studied genotypes were classified into four groups, i.e. water efficient and responsive, water efficient and non-responsive, water non-efficient and responsive and water non-efficient and non-responsive based on GYPP, EPP, KPP, ASI and LS traits, taking into consideration that the high values of GYPP, EPP and KPP and low values of ASI and LS are favorable.

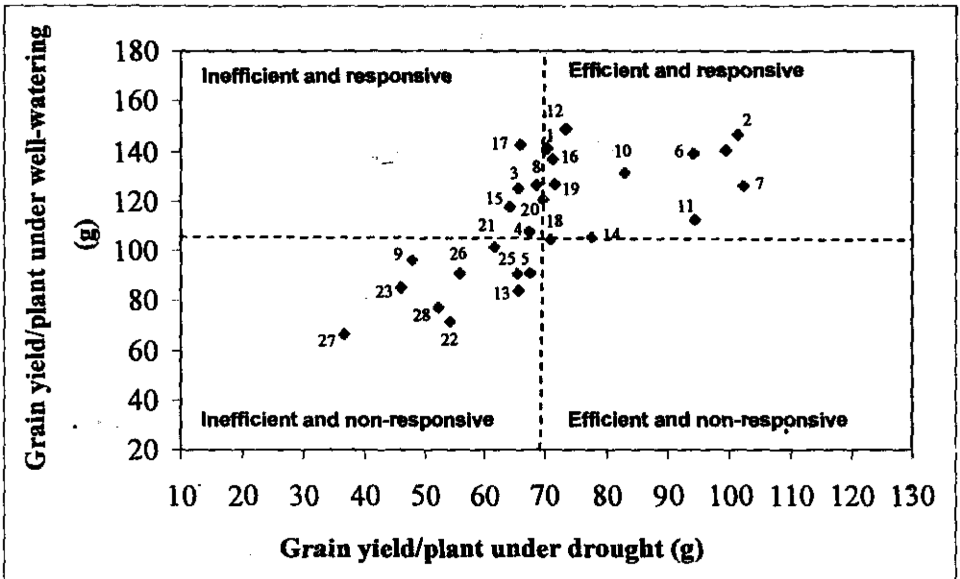

Figure 1. Relationships between grain yields of 28 maize hybrids and populations under well-watering and drought combined across seasons. Broken lines represent mean grain yield.

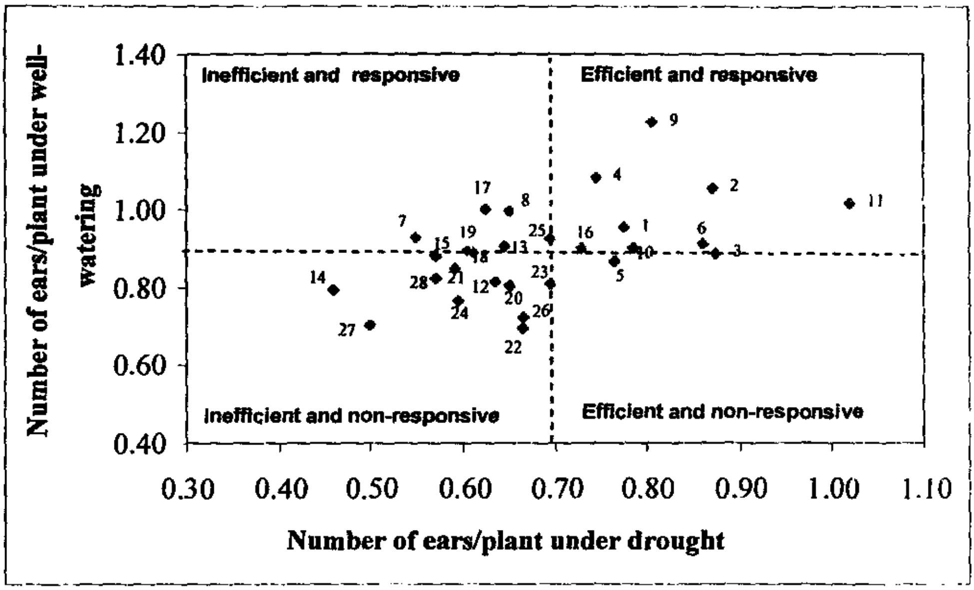

Figure 2. Relationships between number of ears/plant of 28 maize hybrids and populations under well-watering and drought combined across seasons. Broken lines represent mean number of ears/plant.

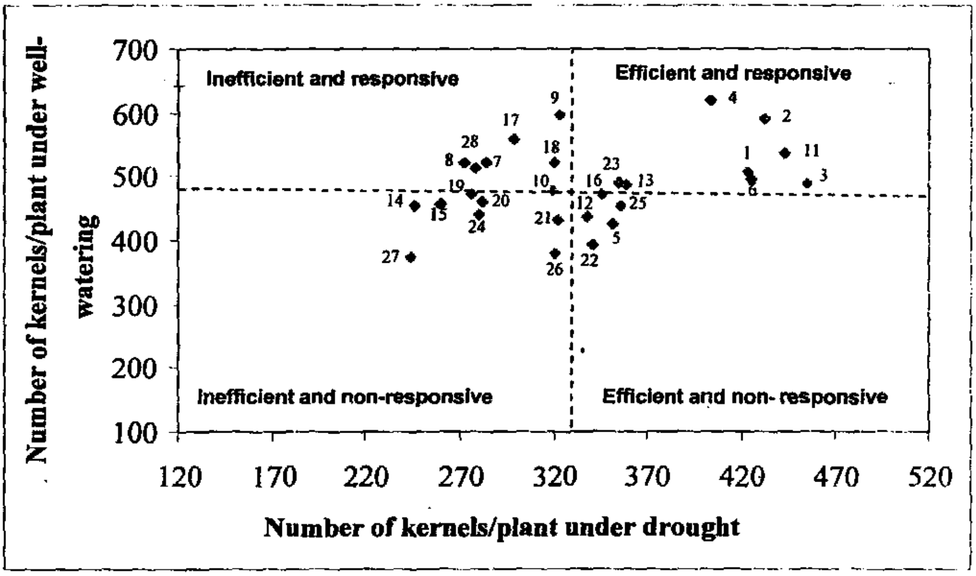

Figure 3. Relationships between number of kernels/plant of 28 maize hybrids and populations under well-watering and drought combined across seasons. Broken lines represent mean number of kernels/plant yield.

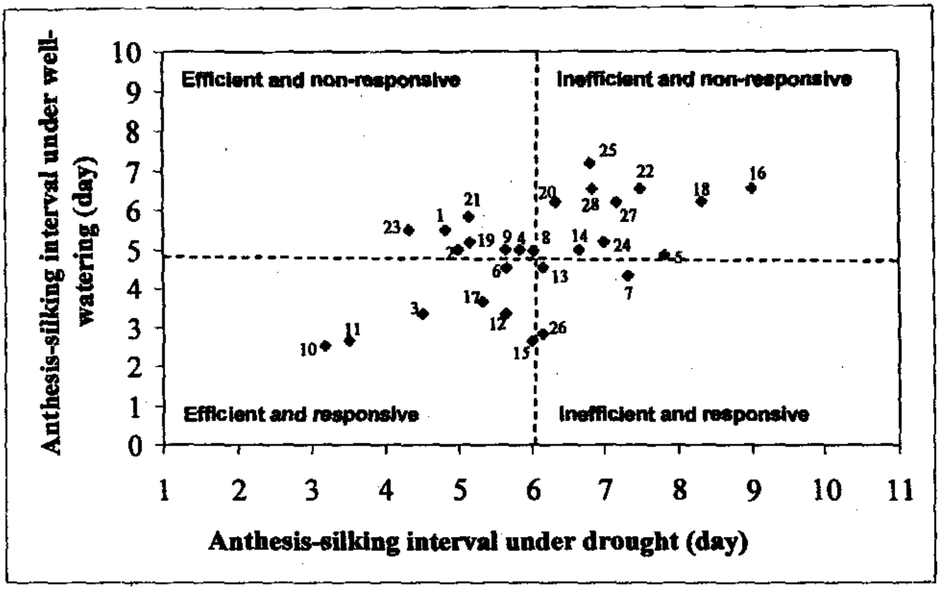

Figure 4. Relationships between anthesis-silking interval of 28 maize hybrids and populations under well-watering and drought combined across seasons. Broken lines represent mean anthesis-silking interval.

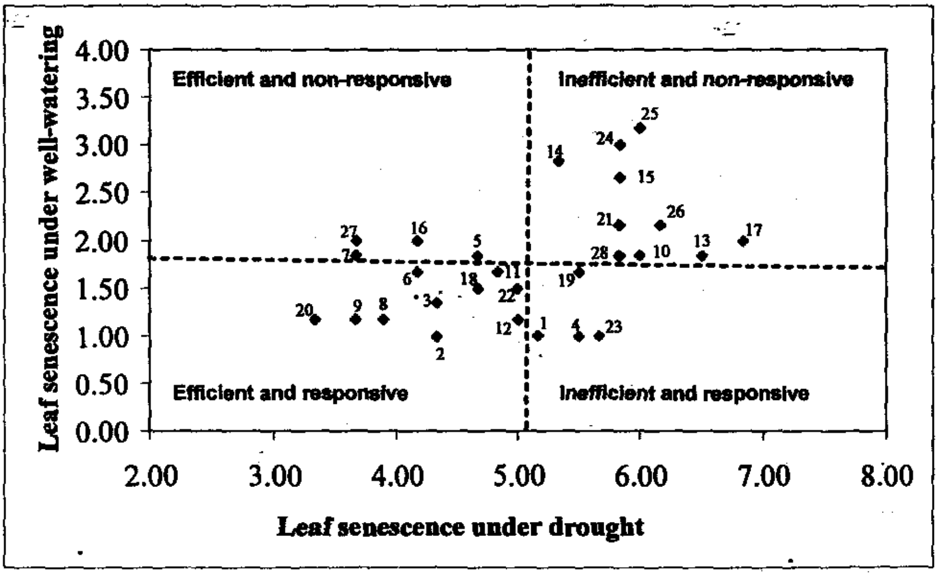

Figure 5. Relationships between leaf senescence of 28 maize hybrids and populations under well-watering and drought combined across seasons. Broken lines represent mean leaf senescence.

Genotype 2 (SC 128) had the highest yield at well watering and highest yield at drought stress, i.e. it could be considered as the most water efficient and the most responsive genotype in this study (Fig. 1). Genotypes 5 (SC Ageeb), 6 (SC 101) and 7 (SC 124) came in the second rank after SC 128 followed by genotypes 10 (SC 30D80), 11 (SC 3062), 12 (SC 30K08) and 1 (SC 10) and could also be considered water efficient and responsive genotypes. On the contrary, most studied populations were the lowest yield genotypes under both drought stress and non-stress conditions and therefore, could be considered water inefficient and non-responsive (Fig. 1). Genotypes 17 (TWC 321), 3 (SC 155) and 15 (TWC 324) are considered inefficient and responsive with respect of GYPP.

The efficient and responsive genotypes classified based on grain yield, viz. 2 (SC 128), 6 (SC 101) and 11 (SC 3062) were also efficient and responsive based on ears/plant, kernels/plant, ASI and leaf senescence as illustrated in Figs. (2, 3, 4 and 5, respectively). The genotype 10 (SC 30D80) was amongst the efficient and responsive ones for ASI (Fig. 4). The genotype 12 (SC 30K08) is efficient and responsive for ASI (Fig. 4) and leaf senescence (Fig. 5). The efficient and responsive genotype 1 (SC 10) based on GYPP was also efficient and responsive based on EPP (Fig. 2) and KPP (Fig. 3).

It is worthy to note that the inefficient and non-responsive genotypes for GYPP were of high number of ears/plant (Fig. 2) and low leaf senescence (Fig. 5) under drought stress and non-stress conditions for genotype 9 (SC 30N11) and of high number of kernels/plant (Fig. 3) under both environments for genotype 23 (DTP-1).

It could be concluded from this study that the superiority of maize genotypes under drought conditions could be a result of superiority in a combination of EPP and KPP (grain yield traits) and ASI and LS (drought adaptive traits) (SC 128, SC 101, and SC 3062) or a result of superiority in only one component, i.e. either grain yield traits (SC 10) or only drought adaptive traits (SC 30D80 and SC 30K08). The present study suggested that further investigation should be conducted to determine the underlying plant mechanisms contributing to the water efficient selected hybrids of maize.

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تحمل الجفاف فى مرحلة التزهير لعدد ٢٨ هجين وعشيرة من الذرة الشامية

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تم تقييم ثمانية وعشرون هجينا وعشيرة مفتوحة التلقيح من الذرة الشامية فى الحقل التجريبى لمحطة البحوث الزراعية بكلية الزراعة جامعة القاهرة بالجيزة فى موسمى ٢٠٠٩ و ٢٠١٠. كانت اهداف الدراسة هى لختبار الاختلافات فى تحمل الجفاف فى مرحلة التزهير بين ثلاث مجاميع من الذرة تختلف فى قاعدتها الوراثية: الاولى ضيقة القاعدة (هجن فرديه) والثانيه متوسطة القاعدة (هجن ثلاثية) والثالثة عريضة القاعدة (عشائر مفتوحة التلقيح) وتحديد التراكيب الوراثية ذات الكفاءة العالية لاستخدام ماء الرى الشحيح والاستجابه لوفرته. اشارت النتائج المجمعه عبر الموسمين ان الاجهاد المائى تسبب فى نقص معنوى لصفات محصول الحبوب للنبات وللفدان وعدد كيزان النبات وعدد حبوب النبات ووزن الـ١٠٠ حبه وزيادة معنوية فى الفترة من نثر القاح حتى خروج الحريرة ونسبة النباتات الذكر والتفاف الاوراق وشيخوخه الاوراق. وصل اعلى نقص فى صفة محصول حبوب النبات (حوالى ٣٨%) ولكن أعلى زيا دة وصلت فى صفة التفاف الاوراق (حوالى٣١١ %) كنتيجة للإجهاد المائى. اظهرت التراكيب الوراثيه ضيقة القاعدة (الهجن الفردية) اعلى المتوسطات بالنسبة لمحصول حبوب النبات والفدان. اتت التراكيب الوراثيه متوسطة القاعدة(الهجن الثلاثيه) وعريضة القاعدة (العشائر) فى المركزين الثانى والثالث ، على التوالى بالنسبه لنفس الصفات التى تعبر عن تحمل الجفاف. كان تفوق التراكيب الوراثيه المتحملة على الصلابة تحت ظروف الجفاف فى محصول حبوب النبات (١١٨.٣%) و يمكن ارجاع ذلك الى تفوقها فى كل مكونات المحصول - وهى عدد حبوب النبات (٢٥.٧٨ %)، عدد كيزان النبات (٢٤.٧١%) ووزن الـ ١٠٠ حبه (٣.٨٩%) وكذلك فى الصفات التأقلمية لتحمل الجفاف أى لقيم منخفضة فى صفات السيقان الذكر التفاف الاوراق شيخوخه الاوراق الفتره من نثر اللقاح حتى خروج الحريرة وارتفاع النبت والكوز اعتبرت الهجن

الفرديه ١٢٨ ، عجيب ، ١٠١ ، ١٢٤ متبوعه بـ 30D80، 3062 ، 30K08 ثم هـ ف ١٠ بأنها ذات كفاءة عاليه لاستخدام الماء وذات استجابه عاليه بينما كانت العشائر مفتوحه التلقيح الاقل كفاءة والاقل استجابه. ويمكن ارجاع تفوق الهجن الفرديه ١٢٨، ١٠١، 3062 فى محصول حبوب النبات الى لتفوقها فى عدد كيزان النبات ، عدد حبوب النبات ، قصر الفترة بين نثر اللقاح وخروج الحريرة ونقص شيخوخه الاوراق . بينما التفوق فى المحصول للهجن الفردية 30D80، 30K08 يرجع لنقص قيم الفترة بين نثر اللقاح وخروج الحريرة . وشيخوخة الاوراق والتفوق للهجين الفردى ١٠ فى المحصول يرجع لتفوقه فى عدد كيزان النبات وعدد حبوب النبات. وقد اوصت الدراسه بضروره اجراء دراسات مستقبليه لتحديد الميكانيكيات النباتيه التى تسهم فى هجن الذره ذات الكفاءه العاليه فى استخدام الماء.

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