Journal of Agriculture and Ecology Research International
7(4): 1-16, 2016; Article no.JAERI.25438
ISSN: 2394-1073

SCIENCEDOMAIN *international*
www.sciencedomain.org

Influence of Deficit Irrigation at Silking Stage and Genotype on Maize (*Zea mays* L.) Agronomic and Yield Characters

A. M. M. Al-Naggar[1*], M. M. M. Atta[1], M. A. Ahmed[2] and A. S. M. Younis[2]

[1]*Department of Agronomy, Faculty of Agriculture, Cairo University, Giza, Egypt.*
[2]*Department of Field Crops Research, National Research Centre (NRC), Dokki, Giza, Egypt.*

Authors' contributions

This work was carried out in collaboration between all authors. Author AMMAN designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MMMA and MAA managed the literature searches. Author ASMY managed the experimental process and performed data analyses. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JAERI/2016/25438
Editor(s):
(1) Inz. Krzysztof Skowron, Department of Microbiology, Nicolaus Copernicus University in Torun, Collegium Medicum of L. Rydygier in Bydgoszcz, Poland.
Reviewers:
(1) C. Umeri, College of Education, Delta State, Nigeria.
(2) Nurhidayatullaili Muhd Julkapli, Universiti Malaya, Malaysia.
(3) Obert Jiri, University of Zimbabwe, Zimbabwe.
Complete Peer review History: http://sciencedomain.org/review-history/14229

Original Research Article

Received 2nd March 2016
Accepted 5th April 2016
Published 18th April 2016

ABSTRACT

Maize is considered susceptible to drought stress, when occurs at flowering stage. Thus, the development of drought tolerant maize cultivars is of important priority for plant breeders. The objectives of the present study were: (*i*) to assess the effect of maize genotype (G), irrigation (I) regime and their interaction on agronomic and yield characters and (*ii*) to identify drought tolerant and high yielding genotypes under water stress conditions. Six divergent inbred lines in drought tolerance were crossed in a diallel fashion. Inbreds (6), F_1's (15) and checks (2) were evaluated in the field for two seasons under two irrigation regimes, *i.e.* well watering (WW) and water stress (WS) *via* withholding the 4th and 5th irrigations to induce water stress at flowering stage. A split plot design in randomized complete blocks arrangement with three replications was used. Data analyzed across two seasons revealed that significant reduction in grain yield of maize (25.53%)

---

*Corresponding author: E-mail: medhatalnaggar@gmail.com;

due to water stress was accompanied with significant reductions in ears/plant (2.76%), 100-kernel weight (8.41%), rows/ear (4.23%), kernels/row (6.82%), kernels/plant (12.57%) and plant height (4.37%) and increases in days to silking (3.50%), anthesis silking interval (21.17%), barren stalks (26.18%) and leaf angle (9.41%). Interaction between genotypes and irrigation treatments was significant, indicating that selection is possible to be practiced under a specific irrigation treatment. Reduction in grain yield and its components due to water stress differed from genotype to genotype. The inbreds L20, L53 and Sk5, and the F_1 crosses L20 × L53, L53 × Sk5 and L53× Sd7 were the most drought tolerant and highest yielders under WS and the WW environments. Mean grain yield/acre (GYPA) of drought tolerant (T) was greater than sensitive (S) inbreds and crosses by 170.18 and 54.73%, respectively under water stress (WS) conditions. Under water stress, T×T crosses were generally superior in most studied characters over T×S and S×S crosses, indicating that the most tolerant cross to water stress should include two tolerant parents and assures that water stress tolerance trait is quantitative in nature.

Keywords: Corn; flowering stage; drought tolerance index; Genotype x irrigation regime interaction.

1. INTRODUCTION

The water is the most important factor which is essential for the growth of plant and ultimately enhanced the yield of crops. Water is basic requirement for plant growth and development. Without water the plant goes under drought condition and severely affects its growth stages and ultimately yield of crops is reduced. Thus, the development of tropical maize cultivars with high and stable yields under drought is an important priority for CIMMYT (International Maize and Wheat Improvement Center), as access to drought-adapted cultivars may be the only affordable alternative to many small-scale farmers [1]. Developing maize varieties that are tolerant to drought is, therefore considered critical for increasing the world's maize production [2,3] and ensuring global food security [4].

Maize is considered more susceptible than most other cereals to drought stresses at flowering, when yield losses can be severe through barrenness or reductions in kernels per ear [5]. Susceptibility of maize yield to stresses at flowering has been documented in early Corn Belt germplasm [6,7]. The studies showed that the sensitive period extended from around one week before to two weeks after 50% silking. Yield losses per day of comparable stress, before and after flowering, were around 45 and 60%, respectively, of the peak loss at silking itself [7]. Studies of more recent hybrids suggest that this period of susceptibility may have moved towards early grain filling. Grant et al. [8] reported that although yields were most severely reduced (70%) by stress coinciding with silking, yields were reduced by 40-54% from stresses occurring in the period 10 to 31 days after mid-silk, and kernel number was reduced below control for stresses occurring up to 22 days after silking. NeSmith and Ritchie [9] observed that kernel numbers per plant were reduced 8-20% when the plants were stressed in the period 18 to 31 days after silking, while weight per kernel declined by a significant 21-25%.

Recent studies have shown considerable genetic variation in the response of commercial hybrids to drought stress imposed during reproductive growth [10], and in one study, a well-known drought tolerant hybrid, P3223, displayed no additional susceptibility to stress imposed at flowering and it appeared that these responses vary considerably among hybrids [11].

Several investigators emphasized the role of maize genotypes in drought tolerance. Tolerant genotypes of maize were characterized by having shorter anthesis-silking interval (ASI) [12], more ears/plant [13,14] and greater number of kernels/ear [14,15]. The presence of genotypic differences in drought tolerance would help plant breeders in initiating successful breeding programs to improve such a complicated character. There is good evidence suggesting that hybrids maintain their advantage over open pollinated varieties in both stress and non-stress environments [16-18]. Exotic inbred lines with superior breeding values for yield and tolerance to abiotic stresses have been used as base materials to develop high-yielding and drought-tolerant hybrids [19,20]. Such germplasm can be invaluable sources of novel/favorable genes for adaptation to environmental stresses for introgression into adapted germplasm [20-22]. Thus, testing variability within available germplasm for drought adaptive traits, while evaluating drought tolerant lines and their crosses under stress and non-stress conditions can help to identify their potential for resource constrained farmers. The objectives of the present study were: (i) to assess the effect of drought at silking stage, genotype and their interaction on maize studied traits, (ii) to identify drought tolerant inbreds and F_1 hybrids and (iii) to estimate the superiority of tolerant (T) over sensitive (S) genotypes and T x T over T x S and S x S crosses.

2. MATERIALS AND METHODS

This study was carried out at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt (30° 02'N latitude and 31° 13'E longitude with an altitude of 22.50 meters above sea level), in 2012, 2013 and 2014 seasons.

2.1 Plant Material

Based on the results of previous experiments [23], six maize (*Zea mays* L.) inbred lines in the 8th selfed generation (S_8), showing clear differences in performance and general combining ability for grain yield/feddan(fed) under drought stress at flowering stage, were chosen in this study to be used as parents of diallel crosses (Table 1).

2.2 Making F_1 Diallel Crosses

In 2012 season, all possible diallel crosses (except reciprocals) were made among the six parents, so seeds of 15 direct F_1 crosses were obtained. Seeds of the 6 parents were also increased by selfing in the same season (2012) to obtain enough seeds of the inbreds in the 9th selfed generation (S_9 seed).

2.3 Evaluation of Parents, F_1's and Checks

Two field evaluation experiments were carried out in 2013 and 2014 seasons at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University. Each experiment included 15 F_1 crosses, their 6 parents and 2 check cultivars, *i.e.,* SC130 (white), obtained from the Agricultural Research Center (ARC) and SC2055 (yellow) obtained from Hi-Tech Company-Egypt. Evaluation in each season was carried out under two environments (WW and WS), *i.e.*, two water regimes, *i.e.*, well watering (WW) by giving all recommended irrigations and water stress (WS) by withholding two irrigations at and post flowering (the 4th and 5th).

A split-split plot design in randomized complete blocks (RCB) arrangement with three replications was used. Main plots were devoted to irrigation treatments (Well watering and Water stress). Sub-plots were assigned to 23 maize genotypes (6 parents, 15 F_1`s and 2 checks). Each sub-plot consisted of one ridge of 4 m long and 0.7 m width, *i.e.*, the experimental plot area was 2.8 m^2. Seeds were sown in hills at 25 cm apart, thereafter (before the 1st irrigation) were thinned to one plant/hill to achieve a plant density of 22,857 plant/acre. Each main plot was surrounded with a wide alley (1.5 m width) to avoid interference of the two water treatments. Sowing date of both environments each season was on May 5 and May 8 in 2013 and 2014 seasons, respectively.

The soil analysis of the experimental soil at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt, as an average of the two growing seasons 2013 and 2014, indicated that

Table 1. Designation, origin and most important traits of 6 inbred lines (L) used for making diallel crosses of this study

Entry designation	Origin	Institution (country)	Prolificacy	Productivity under water stress	Grain color
L20	SC 30N11	Pion. Int.Co.	Prolific	High	Yellow
L53	SC 30K8	Pion. Int.Co.	Prolific	High	White
Sk 5	Teplacinco #5	ARC-Egypt	Prolific	High	White
L18	SC 30N11	Pion. Int.Co.	Prolific	Low	Yellow
L28	Pop 59	ARC-Thailand	Non-Prolific	Low	Yellow
Sd 7	A.E.D	ARC-Egypt	Non-Prolific	Low	White

ARC = Agricultural Research Center, Pion. Int. Co. = Pioneer International Company in Egypt, SC = Single cross, W = White grains and Y = Yellow grains the soil is clay loam (4.00% coarse sand, 30.90% fine sand, 31.20% silt, and 33.90% clay), the pH (paste extract) was 7.73, the EC was 1.91 dSm^{-1}, soil bulk density was 1.2 g cm^{-3}, calcium carbonate was 3.47%, organic matter was 2.09%, the available nutrient in mg kg^{-1} are Nitrogen (34.20), Phosphorous (8.86), Potassium (242), hot water extractable B (0.49), DTPA - extractable Zn (0.52), DTPA - extractable Mn (0.75) and DTPA - extractable Fe (3.17). Meteorological variables in the 2013 and 2014 growing seasons of maize were obtained from Agro-meteorological Station at Giza, Egypt. For May, June, July and August, mean temperature was 27.87, 29.49, 28.47 and 30.33°C, maximum temperature was 35.7, 35.97, 34.93 and 37.07°C and relative humidity was 47.0, 53.0, 60.33 and 60.67%, respectively, in 2013 season. In 2014 season, mean temperature was 26.1, 28.5, 29.1 and 29.9°C, maximum temperature was 38.8, 35.2, 35.6 and 36.4°C and relative humidity was 32.8, 35.2, 35.6 and 36.4%, respectively. Precipitation was nil in all months of maize growing season for both seasons. All other agricultural practices were followed according to the recommendations of ARC, Egypt.

2.4 Data Recorded

The following grain yield traits were measured at flowering and/0r post-flowering stage. Days to 50% anthesis (DTA) (as number of days from planting to anthesis of 50% of plants per plot). Days to 50% silking (DTS) (as number of days from planting to silking of 50% of plants/plot). Anthesis-silking interval (ASI) (as number of days between 50% silking and 50% anthesis of plants per plot). Plant height (PH) (cm) (measured from ground surface to the point of flag leaf insertion for five plants per plots). Barren stalks (BS) (%) measured as percentage of plants bearing no ears relative to the total number of plants in the plot (an ear was considered fertile if it had one or more grains on the rachis). Leaf angle (LANG) (^{o}) measured as the angle between stem and blade of the leaf just above ear leaf, according to Zadoks et al. [24].

The following grain yield traits were measured at harvest. Number of ears per plant (EPP) calculated by dividing number of ears per plot on number of plants per plot. Number of rows per ear (RPE) using 10 random ears/plot at harvest. Number of kernels per row (KPR) using the same 10 random ears/plot. Number of kernels per plant (KPP) calculated as: number of ears per plant × number of rows per ear × number of kernels per row. 100-kernel weight (100-KW) (g) adjusted at 15.5% grain moisture, using shelled grains of each plot. Grain yield per plant (GYPP) (g) estimated by dividing the grain yield per plot (adjusted at 15.5% grain moisture) on number of plants/plot at harvest. Grain yield per acre (GYPA) in ton, by adjusting grain yield/plot to grain yield per acre. Drought tolerance index (DTI): Drought tolerance index (DTI) modified from equation suggested by Fageria [25] was used to classify genotypes for tolerance to water stress. The formula used is as follows: $DTI=(Y_1/AY_1) X (Y_2/AY_2)$, Where, Y_1 = grain yield mean of a genotype at non-stress. AY_1 = average yield of all genotypes at non-stress. Y_2 = grain yield mean of a genotype at stress. AY_2 = average yield of all genotypes at stress. When DTI is ≥ 1.0, it indicates that genotype is tolerant (T), If DTI is < 1, it indicates that genotype is sensitive (S).

2.5 Biometrical Analysis

Analysis of variance of the split-split plot design in RCB arrangement was performed on the basis of individual plot observation using the MIXED procedure of SAS ® [26]. Combined analysis of variance across the two seasons was also performed if the homogeneity test was non-significant. Moreover, data of each environment (WW or WS) was separately analyzed across seasons as a randomized complete block design for the purpose of determining genetic parameters using GENSTAT 10th addition windows software. Least significant differences (LSD) values were calculated to test the significance of differences between means according to Steel et al. [27].

3. RESULTS AND DISCUSSION

3.1 Analysis of Variance

Combined analysis of variance (Table 2) across years (Y) of the split plot design for the studied 23 genotypes (G) of maize showed that mean squares due to years were significant or highly significant for all studied traits, except for anthesis-silking interval (ASI), barren stalks (BS), kernels/plant (KPP), grain yield/acre (GYPA), indicating significant effect of climatic conditions on most studied traits. Mean squares due to irrigation regimes, and genotypes were significant or highly significant for all studied traits, except ASI, leaf angle (LANG), and rows/ear (RPE) for irrigation regimes, indicating that irrigation regime has a significant effect on most studied traits and that genotype has an obvious and significant effect on all studied traits. Mean squares due to G×I and G×I×Y were significant (P ≤ 0.05 or 0.01) for all studied traits, except for one trait (RPE), indicating that the rank of maize genotypes differ from irrigation regime to another, and from one year to another and the possibility of selection for improved performance under a specific water stress as proposed by Al-Naggar et al. [28-31].

Separate analysis of variance under each environment (WW or WS) (data not presented) showed that mean squares due to parents and crosses under both environments were highly significant for all studied traits, except ASI under WW, indicating the significance of differences among studied parents and among F_1 diallel crosses in the majority of cases. It is observed that variance due to genotypes was the largest contributor to the total variance in this experiment for 9 out of 12 studied traits, as measured by percentage of sum of squares to total sum of squares. For the three traits ASI, BS and EPP, error variance was the largest contributor to the total variance; the reason might be due to the large value of C.V. for these characters (20.67, 23.19 and 20.13%, respectively). Mean squares due to parents *vs.* F_1 crosses were highly significant for all studied traits under both environments, except for ASI under WW and WS, BS under WW, suggesting the presence of significant heterosis for most studied cases.

Mean squares due to the interactions parents × years (P × Y) and crosses × years (F_1 × Y) were significant or highly significant for all studied traits under both environments, except DTS under WW for F_1× Y, ASI under WW, for P x Y, BH under WW and WS for P×Y and F_1×Y, EPP under WW for P×Y, RPE under WW for P x Y and WS for F_1 x Y, KPP under WW for P x Y and WS for F_1 x Y, 100KW under WS for P x Y, GYPA under WW for P x Y and F_1 x Y. Mean squares due to parents *vs.* crosses × years were significant or highly significant in most cases (Table 4). Such interaction was expressed in both environments for DTS, BS, LANG, EPP, KPR, KPP, 100 KW and GYPA traits. This indicates that heterosis differ from season to season in these cases. It was observed that genotype is the largest contributor to total variance for all studied traits in both environments, except ASI under WW and WS, BS under WW. Among genotypes components under both environments, the largest contributor to total variance was parents vs. F_1's (heterosis) variance, followed by F_1 crosses and parents.

Table 2. Analysis of variance of split plot design for studied grain quality and yield traits of 23 maize genotypes under two irrigation regimes combined across 2013 and 2014 years

SOV	df	% Sum of squares (SS)					
		DTS	**ASI**	**PH**	**BS**	**LANG**	**EPP**
Years (Y)	1	28.98**	0.37	0.07*	0.24	1.63**	2.34**
Irrigation (I)	1	14.39**	17.31**	2.98**	10.42**	7.48**	1.81**
I×Y	1	0.32**	0.29	0.02	0.01	0.03	0.40**
Error	8	0.17	0.93	0.08	1.77	0.25	0.27
Genotypes (G)	22	44.44**	14.21**	85.43**	36.38**	65.97**	48.70**
G×Y	22	6.80**	13.14**	4.22**	10.14**	15.71**	21.26**
G×I	22	0.84**	8.74**	2.72**	9.28**	2.71**	5.79**
G×I×Y	22	1.40**	12.78**	1.70**	3.15	2.96**	11.90**
Error	176	2.67	32.23	2.79	28.62	3.25	7.53
Total SS	275	2311	99.4	235723	4542	6274	4.39
		RPE	**KPR**	**KPP**	**100-KW**	**GYPP**	**GYPA**
Years (Y)	1	0.69**	0.53**	0.14	12.57**	0.18**	0.19**
Irrigations(I)	1	6.46**	4.26**	8.89**	11.17**	11.04**	11.19**
I×Y	1	0.01	0.00	0.01	4.58**	0.01	0.00
Error	8	0.44	0.10	0.29	0.36	0.05	0.06
Genotypes(G)	22	71.64**	87.42**	79.44**	56.52**	84.26**	84.09**
G×Y	22	11.31**	4.71**	6.58**	5.69**	2.55**	2.70**
G×I	22	2.28**	0.53**	0.97**	2.65**	0.89**	0.86**
G×I×Y	22	2.38**	0.68**	0.67*	1.74**	0.31**	0.17*
Error	176	4.78	1.77	3.00	4.72	0.70	0.74
Total SS	275	402.6	13838.59	7175978	5144	1413222	28023.29

3.2 Mean Performance

3.2.1 Effect of water stress

The effects of drought at flowering stage on the means of studied traits across all genotypes across the two years are presented in Table 3. The WW environment represents the non-stressed one, while WS represents drought stressed environment. Mean grain yield/plant (GYPP) was significantly decreased due to water stress at flowering stage by 25.53%. Effects of water stress on the mean performance of grain yield/ plant were approximately in the same trend to those effects on grain yield/acre (25.91%). Consistent to these results, several investigators reported reductions due to drought stress in grain yield [30,32-35] who noted that water stress during the vegetative stage of corn production reduced grain yield by 25%, water stress during silking reduced grain yield by 50%, while water stress during grain fill reduced grain yield by 21%.The lower reduction in grain yield recorded in this study due to drought at silking stage as compared with some previous reports might be due to differences in soil properties and climate conditions prevailed during the seasons and locations of different studies.

Reductions in grain yield of maize due to water stress at flowering stage was accompanied with significant reductions in ears/plant (2.76%), 100-kernel weight (8.41%), rows/ear (4.23%), kernels/row (6.82%), kernels/plant (12.57%) and plant height (4.37%). On the contrary, withholding irrigation at flowering stage caused increases in days to silking (3.50%), anthesis silking interval (21.17%), percentage of barren stalks (26.18%) and leaf angle (9.41%). Elongation of anthesis-silking interval in this study due to water stress was in full agreement with Monneveux et al. [30] and Al-Naggar et al. [32-34,36].

3.2.2 Effect of genotype

Averages of selected traits of 6 inbred parents, 15 F_1 crosses and 2 checks under well watering (WW) and water stress (WS) across two years are presented in Table 4. In general, the F_1 hybrids were earlier than inbred lines for DTS by 2.84 day. The crosses were taller than inbreds by 56 cm for PH and had wider LANG by 2.85 degree. On the other hand, F_1 hybrids showed higher means than inbreds for KPP by 257 kernel, KPR by 12.56, 100 KW by 5.02 g, GYPP by 139.67 g, GYPF by 2.76 ton/acre, indicating that heterozygotes exhibit better (more favorable) values for most studied traits than homozygotes, which is logic and could be attributed to heterosis phenomenon.

Reduction in grain yield and its components due to water stress at flowering stage differed from genotype to genotype (Table 4). Mean grain yield/plant (GYPP) was significantly decreased due to water stress by 39.54, 28.20 and 33.57% for parents, F_1's and checks, respectively. Effects of water stress on the mean performance of grain yield/ plant were approximately in the same trend to those effects on grain yield/acre (17.58, 29.35 and 24.78%), for parents, F_1 crosses and checks, respectively. It was observed that reductions of most yield traits (KPR, KPP, 100KW and GYPP) due to water stress for inbreds were much higher than yield reductions for F_1 hybrids. This conclusion was also confirmed by Al-Naggar et al. [31,37] and El-Ganayni et al. [38], who reported that hybrids were more adapted to drought stress than inbred lines of maize. Reductions in grain yield of maize due to water stress at flowering stage was accompanied with significant reductions in ears/plant (13.14 and 13.59%), 100-kernel weight (17.46 and 11.72%), rows/ear (6.51 and 6.66%), kernels/plant (33.64 and 25.47%) and LANG (6.26 and 2.08%) for inbreds and hybrids, respectively.

Table 3. Means of studied traits under well watering (WW) and water stress (WS) conditions across two years

Trait	WW	WS	Change%	Trait	WW	WS	Change%
DTS (day)	62.77	64.97	-3.50**	**RPE**	14.53	13.92	4.23**
ASI (day)	2.36	2.86	-21.17**	**KPR**	42.85	39.93	6.82**
BS (%)	10	12.62	-26.18**	**KPP**	765.1	669	12.57**
LANG (o)	27.73	30.34	-9.41**	**100-KW (g)**	34.31	31.42	8.41**
PH (cm)	231	220.9	4.37**	**GYPP (g)**	186.26	138.7	25.53**
EPP	1.23	1.2	2.76**	**GYPA(ton)**	3.62	2.68	25.91**

*DTS = days to 50% silking, ASI = anthesis-silking interval, BS = barren stalks, LANG = leaf angle, PH = plant height, EPP = ears per plant, RPE = rows per ear, KPR = kernel per row, KPP = kernels per plant, 100-KW = 100-kernel weight, GYPP = grain yield per plant, GYPF = grain yield per feddan, * and ** indicate significance at 0.05 and 0.01 probability levels, respectively*

Table 4. Means of studied traits and percentage change (Ch%) from non-stressed (WW) to stressed environment (WS) combined across two seasons

Genotype	WW	WS		WW	WS		WW	WS	
	Mean	**Mean**	**Ch%**	**Mean**	**Mean**	**Ch%**	**Mean**	**Mean**	**Ch%**
	Day to 50 % silking (day)			**Anthesis-silking interval**			**Plant height (cm)**		
Parents	64.81	70.06	-8.1	2.69	4.69	-74.23	194.3	203.8	-4.85
Crosses	61.72	65.99	-6.92	2.2	4.02	-82.58	244.2	254.9	-4.38
Checks	64.58	68.33	-5.81	2.54	4.33	-70.49	242.1	256.2	-5.82
LSD.05	G =0.36	I =.0.164	G× I = 0.88	G =0.28	I =0.17	G× I =0.70	G =3.55	I =1.21	G× I =8.70
	Barren stalks (%)			**Leaf angle (°)**			**Ears per plant**		
Parents	9.94	14.4	-44.9	26.61	24.94	6.26	1.234	1.072	13.14
Crosses	9.97	12.14	-21.7	28.26	27.67	2.08	1.237	1.069	13.59
Checks	10.39	13.1	-26.1	27.17	27.25	-0.31	1.168	1.067	8.63
LSD.05	G = 2.30	I =1.34	G× I = 5.65				G = 0.041	I = 0.025	G× I = 0.10
	G = 0.76	I = 0.45	G× I = 1.87						
	Rows per ear			**Kernels per row**			**Kernels per plant**		
Parents	14.05	13.13	6.51	33.61	28.8	14.31	581	403	30.64
Crosses	14.62	13.64	6.66	45.81	42.21	7.86	825.1	614.9	25.47
Checks	15.33	14.43	5.86	48.39	44.61	7.82	868.2	684.9	21.11
LSD.05	G = 0.334	I = 0.132	G× I = 0.818				G = 28.49	I = 15.56	G× I = 69.80
	G = 0.81	I = 0.37	G× I = 1.99						
	100-kernel weight (g)			**Grain yield/plant (g)**			**Grain yield/acre (ton)**		
Parents	30.2	24.92	17.46	77.06	46.59	39.54	1.82	1.5	17.58
Crosses	36.04	31.82	11.72	225.1	161.62	28.2	6.2	4.38	29.35
Checks	33.67	30.68	8.87	222.59	147.87	33.57	5.77	4.34	24.78
LSD.05	G = 0.65	I = 0.49	G× I = 1.58				G = 0.11	I = 0.03	G× I = 0.27
	G = 3.80	I = 1.51	G× I = 9.32						

WW = well watering, WS = water stress, Change = 100(WW–WS)/WW, * and ** significant at 0.05 and 0.01 probability levels, respectively*

On the contrary, withholding irrigation at flowering stage caused increases in days to silking (8.10 and 6.92%), anthesis silking interval (74.23 and 82.58%) and percentage of barren stalks (44.90 and 21.70%) for inbreds and hybrids, respectively. Elongation of anthesis-silking interval in this study due to water stress was more pronounced in hybrids than inbreds.

It is observed that F_1's showed the lowest reduction due to drought in grain yield/ plant, while parental inbreds showed maximum reduction, indicating that heterozygotes are more drought tolerant than homozygotes. Superiority of heterozygotes over homozygotes in abiotic stress tolerance may be due to heterosis phenomenon and was reported by several investigators [31,38].

The F_1 crosses varied greatly in all studied traits (Table 5). The highest means for grain yield and its related characters were shown by the 4 crosses L20 × L53, L53× Sk5, L53 × Sd7 and Sk5 × L18. The F_1 cross L20 × L53 was the best cross for GYPP, GYPA, EPP, RPE, KPR, KPP and 100KW. The cross L53 × Sk5 came in the second rank and exhibited the second best means for GYPP, GYPA, EPP, KPP and 100-KW. The cross L53 × Sk5 ranked the 3rd and the cross Sk5 × L18 came in the 4th rank for GYPA. In contrast, the lowest means among all crosses for grain yield and its components were observed in the crosses L18 × L28, L53 × L18 and Sk5 x Sd7.

The best check cultivar across all studied environments was SC130 with respect of most studied traits. The best F_1´s in this study excelled significantly the best check (SC130) in GYPA by 31.77% (L20 × L53), 13.28% (L53× Sk5), 10.16% (L53 × Sd7) and 5.73% (Sk5 × L18). These crosses could be of great value for maize breeding programs and for farmers after re-testing them under more locations and years.

Table 5. Mean grain yield per plant (GYPP) and per acre (GYPP) of inbreds, F_1 crosses and checks under well watering (WW) and water stress (WS) conditions across 2013 and 2014 seasons

Genotype	WW GYPA	WS	WW GYPP	WS	Change %	DTI
				Inbreds		
L20	1.98	0.96	106.6	57.7	45.8**	1.85
L53	2.45	1.41	132.1	85.5	35.2**	3.39
Sk5	1.44	0.87	77.6	46.9	39.6**	1.09
L18	0.87	0.59	46.7	34.8	25.5**	0.49
L28	0.82	0.35	44.4	21.2	52.2**	0.28
Sd7	0.80	0.25	55.1	13.2	76.0**	0.22
				F_1 Crosses		
L20 X L53	5.15	4.49	277.4	242.7	18.8**	1.71
L20 XSK5	4.09	3.10	221.7	166.8	3.4**	1.00
L20 X L18	4.06	3.33	219.2	182.1	13.5**	0.92
L20 X L28	4.32	3.19	232.8	171.7	40.2**	1.07
L20 X Sd7	4.21	3.32	226.7	179.9	13.5**	1.02
L 53 X Sk5	4.56	3.72	245.5	203.0	16.0**	1.27
L53 X L18	3.60	2.58	197.5	138.9	23.0**	0.70
L53 X L28	4.41	3.18	237.5	171.6	31.4**	1.14
L53 X Sd7	4.48	3.58	241.0	197.3	12.6**	1.21
Sk5 X L18	4.36	3.37	234.8	183.7	23.2**	1.10
Sk5 X L28	4.14	3.27	223.2	177.2	33.8**	0.98
Sk5 X Sd7	3.83	2.74	207.2	147.7	38.1**	0.78
L18 X L28	3.16	2.30	171.1	124.0	29.9**	0.54
L18 X Sd7	3.95	2.86	213.3	154.2	19.1**	0.84
L28 X Sd7	4.20	3.19	227.6	177.2	20.2**	1.03
				Checks		
SC 130	4.27	3.05	229.8	164.2	28.5**	1.08
SC 2055	4.00	2.76	215.4	148.4	31.1**	0.92

Ch% = 100(WW– WS)/WW, DTI= drought tolerance index, * and ** significant at 0.05 and 0.01 probability levels*

3.2.3 Genotype x irrigation interaction

Mean grain yield per plant and per acre across years under the two environments (WW and WS) for each inbred, hybrid and check cultivar is presented in Table 5. In general, GYPP of the three inbreds L53, L20 and Sk5 was higher than that of the three other inbreds (L18, L28 and Sd7) under both environments (WW and WS). This means that the inbreds Sk5, L20 and Sk5 could be considered tolerant to water stress, while inbreds Sk5, L20 and Sk5 are sensitive. The highest GYPP of all inbreds was achieved under WW environment because of the optimum irrigation.

The inbred L53 showed the highest (favorable) means for GYPP and GYPA under both environments. The inbred L20 was the second highest for grain yield, while inbred SK5 came in the third rank. On the contrary, the inbred Sd7 exhibited the lowest means for GYPP and GYPA under both environments. The rank of inbreds under WW for GYPP and GYPA was similar to that under WS environment, indicating less effect of interaction between inbreds and irrigation regime on these traits. For the inbred lines L20, L28 and L53, the percent reduction in GYPP due to water stress relative to non stress (WW) was smaller than the inbreds L18, Sk5 and Sd7, which could be attributed to the higher potential yield of the first group of lines than the second one, under good environmental conditions. The first group of lines exhibited drought tolerance index (DTI) greater than one, while the second group (L18, Sk5 and Sd7) showed DTI < 1, indicating that the inbreds L20, L28 and L53 are tolerant to water stress, while the inbreds L18, Sk5 and Sd7 are sensitive. The most tolerant inbred is L53 (DTI=3.39) followed by L20 and Sk5, while the most sensitive inbred is Sd7 (DTI=0.22) (Table 5).

The highest GYPP in this experiment (277.4 g) was obtained from the cross L20 × L53 under well watered environment (WW) followed by the crosses L53 x Sk5 (245.5 g), L53 × Sd7 (241.0 g) under the same environmental conditions. These crosses could therefore be considered responsive to this good environment. The same crosses were also the highest yielders under water stress with the same order; these crosses were also considered tolerant to water stress. The DTI of these crosses were the highest among F_1's (1.71, 1.27 and 1.21, respectively). It is clear that such tolerant inbreds (L53, Sk5 and L20) might be considered as source of tolerance and responsiveness in these crosses.

Some F_1 crosses showed significant superiority in GYPP over the best check in this experiment (SC130), namely the crosses L20 × L53, L53 × Sd7, Sk5 x L18 and L28 x Sd7 under both environments. Under water stress conditions, L20 x L53, L53× Sk5, L53 × Sd7, Sk5 x L18, L20 x L18, L20 x Sd7 and Sk5 x L28 showed significant superiority in grain yield over the best check in this experiment (SC130) by 47.8, 23.6, 20.2,11.9, 10.9, 9.6 and 7.9%, respectively.

Comparing to the non-stressed environment (WW), all 15 F_1 crosses under WS environment showed a decrease in their GYPP ranging from 3.4% (L20 x Sk5) to 40.2% (L20 x L28). The highest GYPA under both environments (WW and WS) was shown by the cross L20 x L53 followed by L53 x Sk5 and L53 × Sd7. The highest crosses in GYPA under WS environment were L20 x L53 (4.49 ton/acre), L53 × Sk5(3.72 ton/acre), L53× Sd7 (3.58 ton/acre). It is worthy to note that these three crosses are the most tolerant ones to water stress (DTI=1.71, 1.27 and 1.21, respectively) and the highest responsive ones to well watering.

3.3 Superiority of Drought Tolerant (T) Over Sensitive (S) Genotypes

Based on drought tolerance index (DTI), the drought tolerant inbreds were L20, L53 and Sk5, while the drought sensitive inbreds were L18, L28 and Sd7. The F_1 crosses L20 × L53, L53 × Sk5 and L53× Sd7 were considered the most tolerant to drought, while the crosses L18 × L28, L53 × L18 and Sk5× Sd7were considered as the most drought sensitive crosses (Table 5). Data averaged for each of the two groups (T and S) for inbreds and hybrids differing in tolerance to drought stress indicated that GYPA of drought tolerant (T) was greater than that of the sensitive (S) inbreds and crosses by 170.18 and 54.73%, respectively under water stress conditions (WS) (Table 6).

Superiority of drought tolerant (T) over sensitive (S) inbreds in GYPA under drought was associated with superiority in most studied traits, namely GYPP (174.80%), EPP (1.59%), RPE (15.50%), KPR (28.86%) KPP (41.36%), 100-KW (19.28%), BS (-12.00%), ASI (-7.21%), DTS (-0.58%), and LANG (-17.50%). Superiority of T over S crosses in GYPF under drought was due to their superiority in GYPP (56.62%), EPP (26.93%), RPE (19.39%), KPR (20.70%) KPP (39.93%), 100-KW (21.04%), BS (-58.08%), ASI (-4.81%), DTS (-3.80%) and LANG (-27.11%). CIMMYT breeders found that maize grain yield under drought was closely related to some secondary traits such as more ears per plant, *i.e.* less barrenness, short ASI and late leaf senescence, *i.e*. stay grain [39-42]. These results are in consistency with those reported by Al-Naggar et al. [28-30,32,33].

Reduction in barren stalks and shortening in ASI of tolerant as compared to sensitive inbreds and hybrids in the present study are desirable and may be considered as important contributors to drought tolerance. Similar conclusions were reported by Vasal et al. [17], Al-Naggar et al. [23,34], Edmeades et al. [42], Buren et al. [43], Dow et al. [44] and Beck et al. [45].

3.4 Differential Response of T×T, T×S and S×S Crosses

Mean performance of traits were averaged across three groups of F_1 crosses, *i.e.,* T×T, T×S and S×S groups based on grain yield per plant of their parental lines under water stress and non-stress conditions, *i.e.,* parental tolerance to water stress and presented in Table 7. Number of crosses was 3, 9 and 3 for the T×T, T×S and S×S groups, respectively. In general, T×T crosses had favorable (higher) values for grain yield and its attributes and lower (favorable) values for DTS, ASI, PH, BS and LANG than S×S and T×S crosses under water stress.

Table 6. Superiority (%) of the three most tolerant (T) over the three most sensitive (S) inbreds and crosses for studied characters under the stressed environment (WS) combined across 2013 and 2014 seasons

Trait	Inbreds			Crosses		
	T	S	% Superiority	T	S	% Superiority
DTS (day)	66.97	67.36	-0.58**	62.72	65.20	-3.80**
ASI (day)	2.86	3.08	-7.21*	2.86	3.01	-4.81
PH (cm)	178.44	172.89	3.21**	227.67	249.94	-8.91**
BS (%)	11.02	12.52	-12.00*	7.60	18.14	-58.08**
LANG (°)	24.89	30.17	-17.50**	26.44	36.28	-27.11**
EPP	1.16	1.14	1.59**	1.38	1.09	26.93**
RPE	14.25	12.34	15.50**	15.30	12.81	19.39**
KPR	34.04	26.41	28.86**	47.15	39.06	20.70**
KPP	542.90	384.06	41.36**	857.27	612.63	39.93**
100-KW (g)	30.81	25.83	19.28**	35.41	29.25	21.04**
GYPP (g)	63.39	23.07	174.80**	214.34	136.86	56.62**
GYPF (ard)	1.13	0.42	170.18**	4.13	2.67	54.73**

% Superiority = 100 × [(T – S)/S]

Table 7. Trait differences averaged across 2013 and 2014 seasons for T×T, T×S and S×S groups of F_1 crosses for water stress under two irrigation regimes

Trait	Well watering (WW)			Water stress (WS)		
	T×T	T×S	S×S	T×T	T×S	S×S
DTS (day)	60.78	61.69	62.72	63.00	63.89	65.06
ASI (day)	2.11	2.20	2.28	2.89	2.73	3.03
PH (cm)	227.78	245.28	257.17	229.44	238.11	246.06
BS (%)	8.36	9.84	11.99	8.91	12.99	16.23
LANG (°)	24.39	28.52	31.33	27.39	31.85	35.00
EPP	1.36	1.22	1.16	1.36	1.20	1.12
RPE	15.74	14.59	13.58	15.05	13.94	13.26
KPR	49.68	45.30	43.46	46.54	42.85	40.63
KPP	918.58	818.10	752.37	844.13	727.02	643.91
100-KW (g)	38.14	35.92	34.30	34.54	32.46	30.65
GYPP (g)	248.19	224.43	204.01	204.17	172.25	151.80
GYPA (ton)	4.83	4.36	3.96	3.96	3.33	2.92

T = tolerant, S = sensitive

Water stress T×T crosses were generally superior in most studied characters over other groups of crosses; where S×S crosses were the most inferior (Table 7) under water stress conditions. This indicates that the tolerant cross to water stress should include two tolerant parents and assures that water stress tolerance trait is quantitative in nature, so the tolerant cross accumulates additive genes of water stress tolerance from both parents. Superiority of water stress T×T crosses over S×S and T×S crosses was expressed also under well watering and was more pronounced under water stress conditions, indicating that these T×T crosses are tolerant to water stress and responsive to well watering conditions.

Under water stress, grain yield per acre of water stress T×T (3.96 ton) was greater than that of S×S (2.92 ton) and T×S (3.33 ton) by 35.44 and 14.03% and respectively (Table 8). Superiority of water stress T×T and T×S over S×S crosses in GYPA under water stress conditions was due to their superiority in GYPP by 34.50 and 13.47%, EPP by 21.43 and 7.14%, RPE by 13.50 and 5.13%, KPR by 14.55 and 5.46%, KPP by 31.09 and 12.91%, 100-KW by 12.69 and 5.91%, respectively (Table 8).

Moreover, the water stress T×T and T×S crosses were earlier in DTS by 3.70 and 1.80%, of shorter ASI by 4.62 and 9.90%, shorter PH by 6.75 and 3.23%, and lower BS by 45.10 and 19.96% than S×S, respectively under water stress conditions.

The superiority of water stress tolerant maize crosses over the sensitive ones was attributed by CIMMYT researchers to their synchronization between anthesis and silking, prolificacy or less barrenness [39-42]. Results of the present study are in agreement with those reported by CIMMYT breeders.

3.5 Grouping Genotypes Based on WS Efficiency and Responsiveness to WW

According to efficiency under water stress and responsiveness to well watering, studied inbreds and crosses were classified into four groups, *i.e.,* water stress efficient and responsive to well water, water stress efficient and non-responsive, water stress non-efficient and responsive and water stress non-efficient and non-responsive based on GYPF trait. The inbreds No.2 (L53), No.1 (L20) and No.3 (Sk5) were classified as water efficient and responsive, while inbreds No.4 (L18), No.5 (L28) and No.6 (Sd7) were classified as water non-efficient and non-responsive (Fig. 1). The F_1 crosses No. 1 (L20 × L53), No. 6 (L 53 × Sk5), No. 9 (L53 × Sd7), No. 10 (Sk5 × L18) and No.5 (L20 × Sd7) had the highest GYPF under high-D and Low-D, *i.e.*; they could be considered as the most water stress efficient and the most responsive genotypes in this study (Fig. 2). On the contrary, the F_1 crosses No.13 (L18 × L28), No.7 (L53 × L18), No.12 (Sk5 × Sd7), No.14 (L18 × Sd7) and No.2 (L20 ×Sk5) had the lowest GYPF under both WW and WS and therefore could be considered inefficient and non-responsive (Fig. 2). The crosses No.3 (L20 × L18) and No.15 (L28 × Sd7) occupied the group of water efficient and non-responsive (high GYPF under WS but low GYPF under WW). The crosses No.4 (L20 × L28), No.8 (L53 × L28) and No.11 (Sk5 × L28) had low GYPF under WW and under WS, i.e. water

Table 8. Superiority (%) of T × T and T × S over S × S crosses for studied traits under two irrigation regimes across two seasons (2013 and 2014)

Trait	Well watering (WW)		Water stress (WS)	
	T×T	T×S	T×T	T×S
DTS	-3.09**	-1.64	-3.17**	-1.80*
ASI	-7.46	-3.51	-4.62	-9.9
PH	-11.43**	-4.62**	-6.75**	-3.23
BS	-30.28*	-17.93	-45.10**	-19.96
LANG	-22.15**	-8.97**	-21.74**	-9.00**
EPP	17.24**	5.17	21.43**	7.14
RPE	15.91**	7.44*	13.50**	5.13
KPR	14.31**	4.23*	14.55**	5.46*
KPP	22.09**	8.74	31.09**	12.91
100-KW	11.20**	4.72	12.69**	5.91*
GYPP	21.66**	10.01**	34.50**	13.47**
GYPA	21.96**	10.22**	35.44**	14.03**

% Superiority = 100 × [(T×T) or (T×S) –(S×S)/(S×S)], T = tolerant, S = sensitive

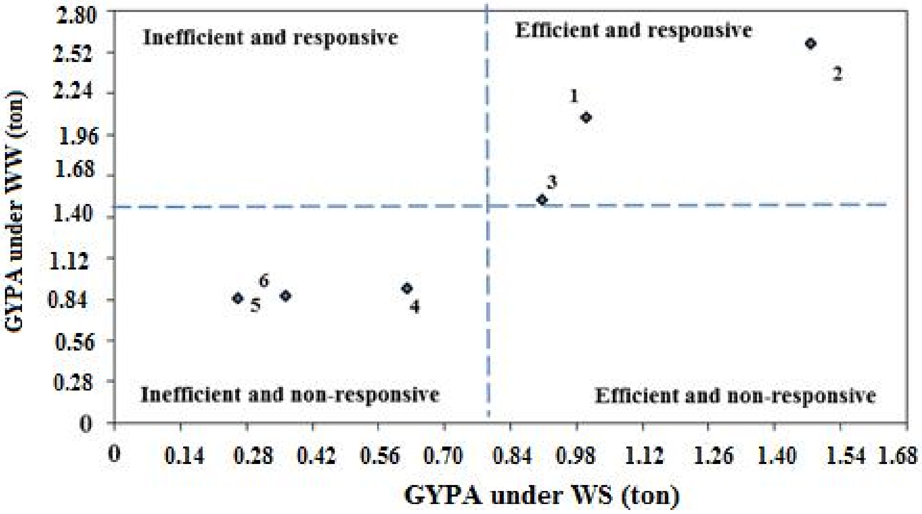

Fig. 1. Relationships between GYPA of 6 parental inbreds under well watering (WW) and water stress (WS) combined across 2013 and 2014 seasons. Broken lines represent mean of GYPA. 1=L20, 2=L53, 3= Sk5, 4=L18, 5=L28 and =Sd7

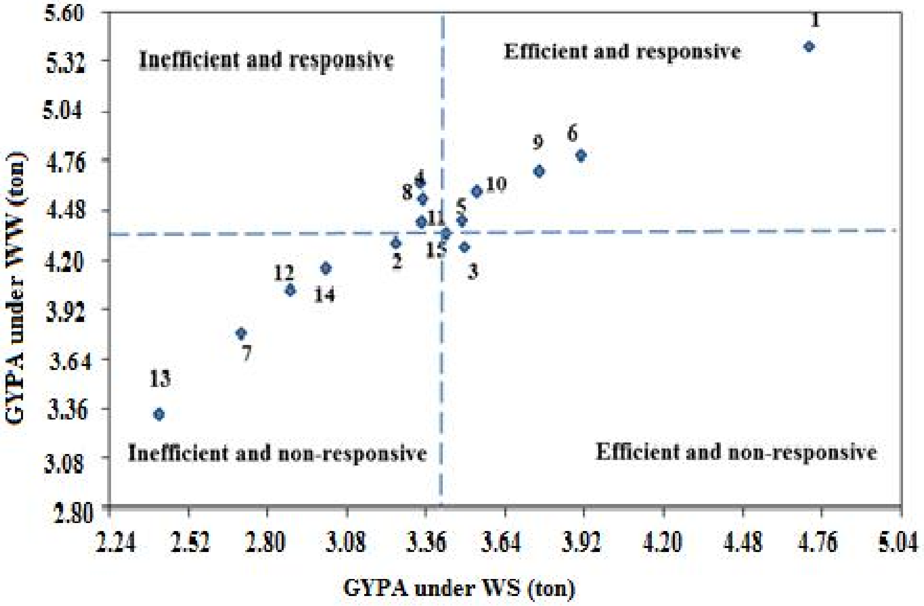

Fig. 2. Relationships between GYPA of 15 F_1 maize hybrids under well watering (WW) and water stress (WS) combined across 2013 and 2014 seasons. Broken lines represent mean GYPA of all F_1's. 1= L20 X L53, 2= L20 XSK5, 3= L20 X L18, 4= L20 X L28, 5= L20 X Sd7, 6= L 53 X Sk5, 7= L53 X L18, 8= L53 X L28, 9= L53 X Sd7, 10= Sk5 X L18, 11= Sk5 X L28, 12= Sk5 X Sd7, 13= L18 X L28, 14=L18 X Sd7, 15= L28 X Sd7

stress inefficient and responsive. According to Fageria and Baligar [46-48] genotypes (progenies) belonging to the 1st group "effecint and responsive" (above all) and 2nd group "efficient and non-responsive" (to a lesser extent) appear to be the most desirable materials for breeding programs that deal with adaptation to water stress.

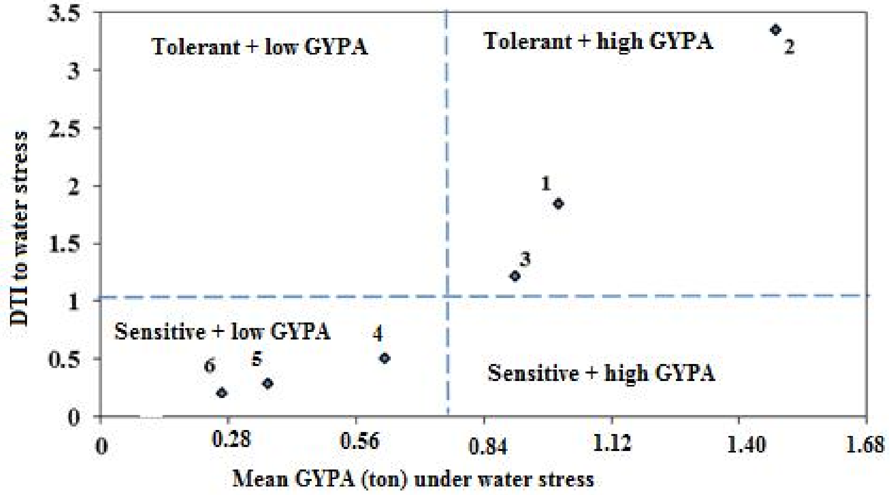

Fig. 3. Relationships between drought tolerance index and means of GYPA of inbreds under water stress (WS), combined across two seasons. Broken lines represent means of all inbreds. 1=L20, 2=L53, 3= Sk5, 4=L18, 5=L28 and =Sd7

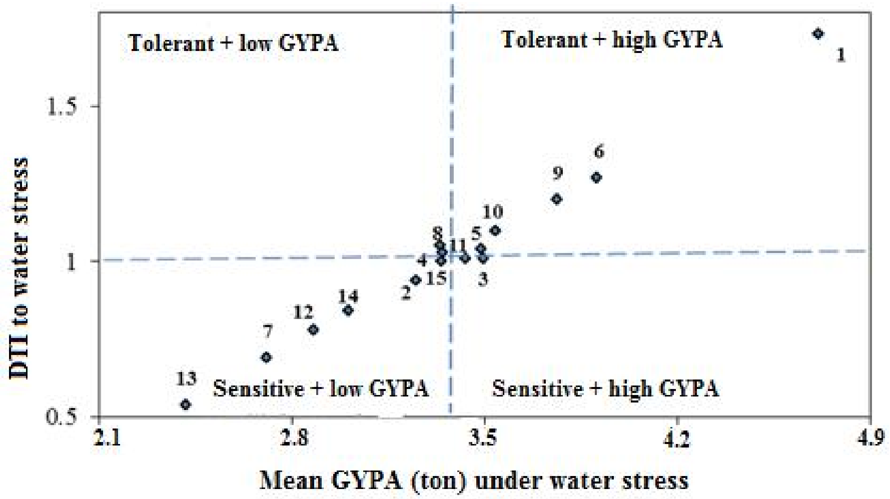

Fig. 4. Relationships between drought tolerance index and means of GYPA of F_1's under water stress (WS), combined across two seasons. Broken lines represent means of all F_1's. 1= L20 X L53, 2= L20 XSK5, 3= L20 X L18, 4= L20 X L28, 5= L20 X Sd7, 6= L 53 X Sk5, 7= L53 X L18, 8= L53 X L28, 9= L53 X Sd7, 10= Sk5 X L18, 11= Sk5 X L28, 12= Sk5 X Sd7, 13= L18 X L28, 14=L18 X Sd7, 15= L28 X Sd7

3.6 Grouping Genotypes Based on Drought Tolerance and High Yield under WS

Mean grain per acre across years of studied genotypes under water stress (WS), was plotted against same trait of the same genotypes under WW (Figs. 3 and 4), which made it possible to distinguish between four groups, namely tolerant high- yielding, tolerant low-yielding, sensitive high-yielding and sensitive low-yielding under WW according to Sattelmacher et al. [49], Worku et al. [50] and Al-Naggar et al. [51].

The inbreds No.2 (L53), No.1 (L20) and No.3 (Sk5) were classified as drought tolerant and high yielding, while inbreds No.4, No.5 and No.6 were classified as water stress sensitive and low yielding (Fig. 3). The F_1 crosses No. 1 (L20 × L53), No. 6 (L 53 × Sk5), No. 9 (L53 × Sd7), No.

10 (Sk5 × L18) and No.5 (L20 × Sd7) had high DTI and high yielding, *i.e.*; they could be considered as the most water stress tolerant and the most responsive genotypes to water stress in this study (Fig. 4). On the contrary, the F_1 crosses No.13 (L18 × L28), No.7 (L53 × L18), No.12 (Sk5 × Sd7), No.14 (L18 × Sd7) No.2 (L20 ×Sk5) and No.15 (L28 × Sd7) had the lowest GYPA under WS and therefore could be considered sensitive and low yielding (Fig. 4). The crosses No.3 (L20 × L18) and No.11 (Sk5 × L28) occupied the group of water stress tolerance and non-responsive (low GYPA) under WS. The crosses No.4 (L20 × L28) and No.8 (L53 × L28) had low DTI and high yielding under WS, *i.e.* water stress sensitive and responsive to water stress.

Summarizing the above-mentioned classifications, it is apparent that the inbreds L53, L20 Sk5 and the F_1 crosses (L20 × L53), (L 53 × Sk5), (L53 × Sd7) and (Sk5 × L18) occupied the first group (best one) in both classifications; they are the most efficient, most drought tolerant, the highest yielder under the stressed and the non-stressed environments. On the contrary, the three inbreds L18, L28 and Sd7 and the crosses (L18 × L28), (L53 × L18), (Sk5 × Sd7), (L18 × Sd7) and (L20 ×Sk5) occupied the fourth group in all classification; they are the most inefficient , most sensitive to water stress, non-responsive to the good environment and low yielders under the stressed environment.

4. CONCLUSION

Analysis of variance across two seasons revealed that mean squares due to G×I and G×I×Y were significant ($P \leq 0.05$ or 0.01) for all studied traits, except for one trait (RPE), indicating that the rank of maize genotypes differs from irrigation regime to another, and from one year to another and the possibility of selection for improved performance under a specific water stress environment. The lower reduction in grain yield recorded in this study due to drought at silking stage than that reported by previous investigators might be due to differences in soil properties and climate conditions prevailed during the seasons and locations of different studies. Reductions of most studied yield traits due to water stress for inbreds were much higher than those for F_1 hybrids indicated that hybrids were more adapted to drought stress than inbred lines of maize. Superiority of tolerant (T) over sensitive (S) inbreds and crosses in grain yield under drought was due to higher values of ears/plant, rows/ear, kernels/row, kernels/plant, 100 kernel weight and lower values of barren stalks, anthesis-silking interval, days to silking and leaf angle. Water stress T×T crosses were generally superior in most studied characters over T×S and S×S crosses; where S×S crosses were the most inferior under water stress conditions, indicating that the most tolerant cross to water stress should include two tolerant parents and assures that water stress tolerance trait is quantitative in nature, so the tolerant cross accumulates additive genes of water stress tolerance from both parents. The inbreds L20, L53 and Sk5, and the F_1 crosses L20 × L53, L53 × Sk5 and L53× Sd7 were the most drought tolerant and highest yielders under WS and the WW environments; these genotypes could be offered to future plant breeding programs.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Monneveux P, Sanchez C, Beck D, Edmeades GO. Drought tolerance improvement in tropical maize source populations: Evidence of progress. Crop Sci. 2006;46(1):180-191.
2. Campos H, Cooper M, Habben JE, Edmeades GO, Schussler JR. Improving drought tolerance in maize: A view from industry. Field Crops Res. 2004;90:19-34.
3. Xiong L, Wang RG, Mao G, Koczan JM. Identification of drought tolerance determinants by genetic analysis of root response to drought stress and abscisic acid. Plant Physiol. 2006;142:1065–1074.
4. Mir RR, Zaman-Allah M, Sreenivasulvu N, Trethowan R, Varshney RK. Intregrated genomics, physiology, and breeding approaches for improving drought tolerance in crops. Theor. Appl. Genet. 2012;125:625–645.
5. Bolanos J, Edmeades GO. The importance of the anthesis-silking interval in breeding for drought tolerance in tropical maize. Field Crops Res. 1996;48:65–80.
6. Claassen MM, Shaw RH. Water deficit effect on corn. 1-Vegetative components. Agron. J. 1970;62:649-652.
7. Shaw RH. Water use and requirements of maize - A re- view. In: Agrometeorology of the Maize (corn) Crop. World Met. Organization Publication 480. 1977;119-134.

8. Grant RF, Jakson BS, Kiniry JR, Arkin GF. Water deficit timing effects on yield components in maize. Agron. J. 1989; 81(1):61-65.
9. NeSmith DS, Ritchie JT. Short- and long-term responses of corn to a pre-anthesis soil water deficit. Agron. J. 1992;84:107-113.
10. O'Neill PM, Shanahan JF, Schepers JS, Caldwell B. Agronomic responses of corn hybrids from different eras to deficit and adequate levels of water and nitrogen. Agron. J. 2004;96(6):1660-1667.
11. Bruce WB, Edmeades GO, Barker TC. Molecular and physiological approaches to maize improvement for drought tolerance. J. Exp. Bot. 2002;53:13-25.
12. Bolanos J, Edmeades GO. Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield, biomass, and radiation utiliz-ation. Field Crops Research. 1993;31:233–252.
13. Edmeades GO, Lafitte HR. Defoliation and plant density effects on maize selected for reduced plant height. Agron. J. 1993;85: 850-857.
14. Ribaut JM, Jiang C, Gonzatez-de-Leon GD, Edmeades GO, Hoisington DA. Identification of quantitative trait loci under drought conditions in tropical maize. II Yield components and marker-assisted selection strategies. Theor. Appl. Genet. 1997;94:887-896.
15. Hall AJ, Viella F, Trapani N, Chimenti C. The effects of water stress and genotype on the dynamics of pollen shedding and silking in maize. Field Crop Res. 1982;5: 349-363.
16. Dass S, Dang YP, Dhawan AK, Singh NN, Kumar S. Morho- physiological basis for breeding drought and low-N tolerant maize genotypes in India. In Edmeades GO, Bänziger M, Mickelson HR, Pena-Valdiva CB, (Eds.). Developing drought and low n-tolerant maize. Proceedings of a Symposium, March 25-29, 1996, CIMMYT, El Batan, Mexico. Mexico, D.F.: CIMMYT. 1997;106-111.
17. Vasal SK, Cordova H, Beck DL, Edmeades GO. Choices among breeding procedures and strategies for developing stress tolerant maize germplasm. Proceedings of a Symposium, March 25-29, CIMMYT, El Batan, Mexico. 1997;336-347.
18. Duvick DN. Commercial strategies for exploitation of heterosis. In: "The Genetics and Exploitation of Heterosis in Crops" (Eds. Coors JG, Pandey S). ASA, CSSA, and SSSA. Madison, Wisconsin, USA. 1999;19-29.
19. Hallauer AR, Miranda JB. Quantitative genetics in maize breeding, 2nd. Iowa State University Press. Ames. IA. USA; 1988.
20. Dhliwayo T, Pixley K, Menkir A, Warburton M. Combining ability, genetic distances, and heterosis among elite CIMMYT and IITA tropical maize inbred lines. Crop Sci. 2009;49:1201–1210.
21. Kim SK, Efron Y, Khadr F, Fajemisin JM, Lee M. Registration of 16 maize-streak virus resistant tropical maize parental inbred lines. Crop Sci. 1987;2:824–825.
22. Eberhart SA, Salhuana W, Sevilla R, Taba S. Principles of tropical maize breeding. Maydica. 1995;40:339–355.
23. Al-Naggar AMM, Atta MM, Hassan HTO. Variability and predicted gain from selection for grain oil content and yield in two maize populations. Egyptian Journal of Plant Breeding. 2011;15(1):1-12.
24. Zadoks JC, Chang TT, Konzak CF. Decimal code for the growth states of cereals. Eucarp. Bull. 1974;7:42-52.
25. Fageria NK. Maximizing crop yields. Dekker. New York. 1992;423.
26. Littell RC, Milliken GA, Stroup WW, Wolfinger RD. SAS System for Mixed Models. SAS Inst., cary, NC. 1996;300.
27. Steel RGD, Torrie GH, Dickey DA. Principles and procedures of statistics: A biometrical approach. 3rd ed. McGraw-Hill, New York, USA. 1997;450.
28. Al-Naggar AM, Radwan MS, Atta MMM. Analysis of diallel crosses among maize populations differing in drought tolerance. Egypt. J. Plant Breed. 2002;6(1):179–198.
29. Al-Naggar AM, Mahmoud AAK, Atta MMM, Gouhar AMA. Intra-population improvement of maize earliness and drought tolerance. Egypt. J. Plant Breed. 2008; 12(1):213-243.
30. Al-Naggar AMM, Shabana R, Mahmoud Mahmoud AA, Abdel El-Azeem MEM, Shaboon SAM. Recurrent selection for drought tolerance improves maize productivity under low-N conditions. Egyptian Journal of Plant R Breeding. 2009;13(AA): 53-70.
31. Al-Naggar AMM, Atta MMM, Ahmed MA, Younis ASM. Grain protein, oil and starch contents and yields of maize (*Zea mays* L.) as affected by deficit irrigation, genotype and their interaction. International Journal of Plant & Soil Science. 2016;10(1):1-21.

32. Al- Naggar AMM, Shabana R, Sadek SE, Shaboon SAM. S_1 recurrent selection for drought tolerance in maize. Egypt. J. Plant Breed. 2004;8:201-225.
33. Al-Naggar AM, El-Murshedy WA, Atta MMM. Genotypic variation in drought tolerance among fourteen Egyptian maize cultivars. Egypt. J. of Appl. Sci. 2008; 23(2B):527-542.
34. Al-Naggar AMM, Soliman SM, Hashimi MN. Tolerance to drought at flowering stage of 28 maize hybrids and populations. Egyptian Journal of Plant Breeding. 2011;15(1):67-87.
35. Denmead OT, Shaw RH. The effect of soil moisture stress at different stages of growth on the development and yield of corn. Agron. J. 1960;52:272-274.
36. Monneveux P, Zaidi PH, Sanchez C. Population density and low nitrogen affects yield-associated traits in tropical maize. Crop Sci. 2005;45:535-545.
37. Al-Naggar AM, El- Ganayni AA, El-Sherbeiny HY, El-Sayed MY. Direct and indirect selection under some drought stress environments in corn (*Zea mays* L.). J. Agric. Sci. Mansoura Univ. 2000;25(1): 699–712.
38. El-Ganayni AA, Al-Naggar AM, El-Sherbeiny HY, El-Sayed MY. Genotypic differences among 18 maize populations in drought tolerance at different growth stages. J. Agric. Sci. Mansoura Univ. 2000;25(2):713–727.
39. Lafitte HR, Edmeades GO. Improvement for tolerance to low soil nitrogen in tropical in maize. I. Selection criteria. Field Crops Research. 1994;39:1-14.
40. Lafitte HR, Edmeades GO. Improvement for tolerance to low soil nitrogen in tropical maize. II. Grain yield, biomass production, and N accumulation. Field Crops Research. 1994;39:15-25.
41. Banziger M, Lafitte HR. Efficiency of secondary traits for improving maize for low-nitrogen target environments. Crop Sci. 1997;37:1110-1117.
42. Edmeades GO, Bolanos J, Chapman SC, Lafitte HR, Banziger M. Selection improves drought tolerance in tropical maize populations. I. Gains in biomass, grain yield and harvest index. Crop Sci. 1999;39: 1306–1315.
43. Buren LL, Mock JJ, Anedrson IC. Morphological and physiological traits in maize associated with tolerance to high plant density. Crop Sci. 1974;14:426-429.
44. Dow EW, Daynard TB, Muldoon JF, Major DJ, Thurtell GW. Resistance to drought and density stress in Canadian and European maize (*Zea mays* L.) hybrids. Can. J. Plant Sci. 1984;64:575-583.
45. Beck DL, Betran J, Bnaziger M, Willcox M, Edmeades GO. From landrace to hybrid: Strategies for the use of source populations and lines in the development of drought tolerant cultivars. Proceedings of a Symposium, March 25-29, CIMMYT, El Batan, Mexico. 1997;369-382.
46. Fageria NK, Baligar VC. Screening crop genotypes for mineral stresses. In: Adaptation of plants to soil stress, (Eds. Maranville J, Baligar W, VC, Duncan RR, Yohe JM), Nebraska-Lincoln Press, Inc, United states, NE. 1994;152–159.
47. Fageria NK, Baligar VC. Phosphorous—Use efficiency by corn genotypes. J. Plant Nutr. 1997;20:1267–1277.
48. Fageria NK, Baligar VC. Integrated plant nutrient management for sustainable crop production— An Over. Inter. J. Trop. Agri. 1997;15:7–18.
49. Sattelmacher B, Horst WJ, Becker HC. Factors that contribute to genetic variation for nutrient efficiency of crop plants. Z. Pflanzen, Bodenk. 1994;157:215–224.
50. Worku M, Banziger M, Erley GSA, Alpha DF, Diallo O, Horst WJ. Nitrogen uptake and utilization in contrasting nitrogen efficient tropical maize hybrids. Crop Sci. 2007;69:519-528.
51. Al-Naggar AMM, Shabana RA, Atta MMM, Al-Khalil TH. Maize response to elevated plant density combined with lowered N-fertilizer rate is genotype-dependent. The Crop Journal. 2015;3(2):96-109.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/14229