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Evaluation of tropical maize hybrids under drought stress

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Abstract

The performances of plants and seedlings of 14 tropical-adapted, registered maize hybrids were evaluated under drought stress to assess genotype suitability for off-season planting and to identify parental materials for developing drought tolerant hybrids from locally adapted germplasm. Field evaluation was done at a rain forest location (Ikenne, Ogun State, Nigeria) on irrigated plots under well-watered and water-deficit conditions during the dry period of 2002/2003 cropping season. Data was collected on total biomass and grain yield. Drought stress tolerance index (DSTI) and harvest index (HI) were estimated from total biomass and grain yield data. Hybrids 2016-1 and 2016-6 had highest total biomass and grain yield under water deficit conditions as well as DSTI values above 0.9. Other hybrids with satisfactory performance in terms of biomass and grain yields under drought stress had DSTI values approximating 0.6 and above. From the seedling evaluation, correlation analysis of number of rolled seedling leaves with field stress tolerance indices was significant. Based on number of rolled leaves, hybrid 2016-6 had the least value, ranking it the most tolerant, but based on multiple seedling traits including seedling height, total seedling biomass, leaf chlorophyll content and leaf stay green ability (SGA), hybrids 9033-26, 0103-11 and 9022-13 were high performers. All hybrids with satisfactory seedling performance also had DSTI values from the field evaluation that were approximately or above 0.6. The results emphasized the usefulness of DSTI as a useful index for determining drought stress and suggest that maize hybrids with DSTI values around 0.6 from field trials have potentials for satisfactory productivity under drought stress.

Key words: Maize, tropical hybrids, germplasm evaluation, seed production, controlled drought, biomass yields, grain yields, drought stress tolerance.

Introduction

The production of adequate food in the tropics is being challenged by declining availability of water resources and fertility of arable land [3]. Moreover, climate change elicits drought stress-induced reductions in crop productivity particularly in marginal soils [11, 18]. In maize, drought stress has various effects on development at various stages of the crop cycle. Drought stress at seedling and flowering stages of maize has been estimated to cause annual grain yield losses of up to 13% in the tropics [7]. Biomass production generally decreases with decreasing water availability, and plants primarily respond to shortage of water at any developmental phase by stomata closure which triggers other reactions that culminate in reducing carbon exchange rates and thus assimilate production. Stress experienced by maize crops during growth has cumulative effects, which are ultimately expressed as a reduction in final biomass production below the unstressed potential [14]. In maize, reduction in the flush of assimilates to the developing ear in event of drought stress during flowering and grain filling results in infertility and failed grain filling causes significant reduction in kernel number [17]. The identification and development of drought tolerant maize genotypes capable of satisfactory productivity under sub-optimal water availability are therefore of major interests in maize improvement [2-4].

Genetic tolerance of maize plants to drought stress can fill up to 30% of the gap between potential and realized biomass yields under water stress in marginal areas like the tropical agro-ecosystems [9]. The long-term goal of evaluating genotypes for drought tolerance is to develop crop germplasm that are productive despite drought stress, and these genotypes can be used to achieve multiple productions during the cropping year. However, on yearly basis production of hybrid seed is normally done during the dry seasons because dry production environments are required for low equilibrium seed moisture content and enhanced seed quality. Therefore, evaluation of drought adaptation in hybrids is an important step towards stabilizing maize production because it helps to identify inbred parent materials that are suitable for creating drought tolerant populations. This study was therefore set up to evaluate drought tolerance among registered tropical maize hybrid germplasm from the International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria.

Materials and Methods

Fourteen Savannah-adapted hybrid maize genotypes registered and released by IITA, Ibadan, were evaluated in this study. They were categorized as old and new maize hybrids depending on the year of release, varieties released before year 2000 were categorized as old hybrids (Table 1). The parental inbred lines used to produce the hybrid varieties are also shown in Table 1. Most of the old hybrids are single cross hybrids among the adapted inbred maize population of IITA while the new hybrids are 3-way crosses or top crosses of commercial hybrids.

The field evaluation was carried out during the dry season of January, 2003 to April, 2003 and the seedling screening was done in April, 2003-July, 2003. The field evaluation was conducted at IITA's experimental farm, Ikenne, Southwestern Nigeria ($6^{\circ}53^{1}$N, $3^{\circ}42^{1}$E, altitude 60 m). The field experiment was planted in two blocks that received different irrigation treatments. Two seeds were planted per hill and later thinned to one per hill to give a density of 53,333 plants/ha. Nitrogen fertilizer was applied at the rate of N 90 kg/ha and phosphorus and potassium were applied as triple super-phosphate and muriate of potash at the rate of 60 kg/ha of each nutrient. Sprinkler irrigation was used to supply water every week to all blocks from planting to the end of the 4th week, irrigation was thereafter discontinued in the blocks with the water deficit treatment. Irrigation continued on the well-watered plots until physiological maturity. The genotypes were planted in a randomized complete block design replicated 3 times. Blocks consisted of six rows, 3 m long, with 0.75 m spacing between rows and 0.25 m between plants. Sampling was done on plants within an area of 4 m^2 on total of 20 plants in the center of each plot. Assessment of biomass yield was done at harvest period on eight plants from the four central rows of each plot cut and separated into stems, leaves and ears. The plant materials were chopped and oven-dried at 80°C to constant weight. Grain yield of the plants was also measured as grain weight of sampled plants. Harvest index was calculated as proportion of grain weight from total plant biomass. Drought stress tolerance index was calculated based on grain yield data under well-watered and water deficit conditions using an inverse equation of drought stress susceptibility index of Fisher and Maurer [10] according to Porch [15]: $DSTI = (Yp \times Ys)/Xp^2$, where *Yp* is the grain yield of genotype under non-stress condition, *Ys* is the genotype mean under stressed condition and *Xp* is the mean yield of all genotypes under non-stress condition.

Seedling screening was carried out under screenhouse conditions at the IITA, Ibadan station, on seeds of 6 genotypes selected based on DSTI values sown in wooden boxes. Temperature in the screenhouse ranged between 25 and 35°C and RH 45 to 60% during the experiment. Each wooden box was 130 cm x 63 cm x 25 cm in dimension. They were lined with polythene sheets and filled with top soil to a depth of about 20 cm. Sowing was done 10 cm apart in straight rows in the wooden boxes with a distance of 5 cm within the rows. Two seeds were sown in each row and later thinned to one plant per stand. The experiment was laid out in a completely randomized design with 3 replicates. The boxes were then watered at two days interval until emergence after which the seedlings were subjected to two different moisture treatment regimes (3 weeks stress and watered control). After 3 weeks, data was collected on plant biomass, plant height, leaf chlorophyll content, number of fully expanded leaves, stay-green ability (SGA) under stress which was rated by visual observation of leaf greenness from scales 1-5; where 1 is a condition of total greenness of the plant and 5 represents extreme discoloration. Leaf chlorophyll content was evaluated with the use of a Chlorophyll Meter.

Table 1. List of 14 maize hybrids tested under watered and water–deficit conditions.

Variety	Description	Pedigree	Year released	
OBA SUPER 1	Semi-dent	1368 x 9071	1980	(old)
8321-21	Semi-dent	1393 x 9071	1983	(old)
OBA SUPER 2	Semi-dent	4001 x KU1414SR	1984	(old)
8522-2	Semi-dent	4001 x 7268	1984	(old)
8321-21	Semi-dent	4001 x 7268	1985	(old)
8644-31	Semi-dent	KU1414SR x 9450	1986	(old)
8644-32	Semi-dent	8425-8STR x KU1414SR	1986	(old)
9033-26	Dent	8321 x 1368	1990	(old)
9031-29	Dent	AK9443 x 9071	1990	(old)
9022-13	Dent	1368STR x 9030STR	1990	(old)
2016-1	Dent	1368 x 9071 x Bg-3-1-B	2000	(new)
2016-6	Dent	9071 x Agseeds-361-1-B	2000	(new)
0103-11	Dent	1368 x 9071 x Bg-1-2-B	2001	(new)
0103-4	Dent	1368 x 9071 x Bg-6-1	2001	(new)

Statistical analyses were carried out using the general linear model (GLM) procedure of SAS (version 6.12) [16]. Post-hoc tests were conducted on mean values of drought parameters for mean comparison among genotypes and drought stress treatments. Correlation analysis was carried out on the seedling stress tolerance measurements and field stress tolerance indices (DSTI and HI) of stressed plants using the Pearson statistics.

Results

Mean precipitation throughout the experiment ranged from 1.6 to 1.9 mm within the first 2 months and there were no rains in the last 2 months of the field trial. Average temperatures ranged from 23 to 36°C and relative humidity from 55 to 80% during the field experiments (Table 2).

Table 3 shows the total biomass, grain yield and estimated indices of performance of various tropical maize hybrids under well-watered and water deficit conditions. For almost all hybrids, the mean of total biomass of plants on the well-watered plots was greater than total biomass of plants on the water deficit plots by over 100%. Grain yield of well-watered plants were also approximately 62% higher than in water deficit plots for most of the hybrids, ranging from 4202 to 5439 g/ha in well-watered plots and 2056 to 3849 g/ha in water deficit plots. Genotypes with high values of grain yield under well-watered conditions did not necessarily exhibit high grain yield values under water deficit conditions, for instance, the highest grain yield at harvest under well-watered condition (5439 g/ha) was recorded for genotype 8425-8STR, while 2016-6 had the highest grain yield (3849 g/ha) under water deficit conditions. Total biomass ranged from 140 to 168 g on well-watered plots while total biomass ranged from 60 to 79 g on water deficit plots. Also, total plant biomass under water deficit condition was highest in hybrid 2016-6. The differences in HI of the hybrids on well-watered and water deficit plots were not significant. Estimates of DSTI of the evaluated genotypes ranged from 0.46 to 0.94, hybrids 2016-1 and 2016-6 had DSTI values that were above 0.9; hybrids 8425-8STR, 9022-13 and 9033-26 had DSTI values above 0.6; hybrids 8644-32, Oba Super1, 01034-4, 0103-11 had DSTI values between 0.5 and 0.6 while hybrids 8321-21, 864431, Oba Super2 and 9031-29 had DSTI values below 0.5. The six genotypes selected for seedlings evaluation in the screenhouse were randomly drawn from these various DSTI value ranges

Table 2. Weather data of the experimental site during the field trial on drought tolerance of registered tropical maize hybrids at Ikenne, Nigeria.

Month	Week	Total rainfall (mm)	Temperature (°C) Minimum	Maximum	Mean	Relative Humidity (%)
Jan	1	0.00	23.43	32.71	28.07	80.00
	2	6.40	22.43	32.29	27.86	84.00
	3	0.00	23.29	33.57	28.43	78.00
	4	0.00	22.00	33.57	27.79	75.00
mean		1.60	22.79	33.39	28.04	79.25
February	5	0.00	22.71	32.14	27.93	79.00
	6	7.60	23.85	33.43	28.64	78.00
	7	0.00	24.29	33.43	28.85	80.00
	8	0.00	24.29	34.57	29.43	79.00
mean		1.90	23.79	33.64	28.71	79.00
March	9	0.00	20.29	34.14	27.21	55.00
	10	0.00	19.29	35.57	27.43	57.00
	11	0.00	24.00	35.71	29.86	54.00
	12	0.00	25.00	36.14	30.57	54.00
mean		0.00	22.15	35.39	28.77	55.00
April	13	0.00	37.00	24.15	30.57	73.00
	14	0.00	24.71	37.71	31.21	74.00
	15	0.00	24.42	36.43	30.43	73.00
	16	0.00	24.57	35.71	30.14	71.00
mean		0.00	36.71	24.46	30.59	72.75

Source: Department of Meteorological Service, Institute of Agricultural Research and Training, Ikenne sub-station, Ogun State.

except those with values below 0.5. It was noted that the genotypes with DSTI values below 0.5 were the older hybrids, all new hybrids had DSTI values above 0.5.

A significant negative correlation was observed between number of rolled seedling leaves under water deficit condition and the two field drought stress indices (HI and DSTI) (Table 4). A highly negative but insignificant correlation was also observed between number of wilted plants and DSTI. Correlation between all other seedling variables and drought stress was insignificant (Table 4).

Plant height, chlorophyll content of leaves, expanded leaves and total biomass of each genotype were consistently higher in watered seedlings than the seedling under 3 week of drought stress and *vice versa* for number of rolled leaves, wilted plants and SGA (Table 5). Number of rolled leaves after 3 weeks of drought stress was least in seedlings of hybrid 2016-6, though differences in comparison with other genotypes were not significant. There were significant differences in seedling height, leave chlorophyll content, total biomass and number of wilted plants in seedlings treated with 3 weeks of moisture stress (Table 5). Leaf chlorophyll content of hybrids 8425-8STR and 9022-13 was significantly greater than in other hybrids, but hybrid 8425-8STR exhibited significantly lowest value of total biomass and the highest number of wilted seedlings (Table 5). SGA was not significantly different among genotypes under drought stress condition. Based on multiple seedling traits including seedling height, total seedling biomass and leaf chlorophyll content, hybrids 9033-26, 0103-11 and 9022-13 exhibited higher values than other hybrids under drought stress. It is interesting to note that hybrids 2016-6, 9033- 26, 0103-11 and 9022-13 had DSTI value around 0.6.

Discussion

The responses of the plants under well watered and water deficit conditions with respect to reduced biomass and grain yields in stressed plant of all the maize genotypes were expected, since all possible mechanisms involved in adaptation of crop plants to drought stress often results in loss of biomass yields [2]. Earliness and tolerance are important mechanisms of plant adaptation to drought both of which brings about reductions in biomass productivity; the former by reducing light absorbed by plants and the latter by inducing stomatal closure leading to reduced CO_2 assimilation and photosynthetic efficiency [20]. Drought tolerant cultivars are thus the genotypes that can be characterized with enhanced productivity despite drought stress [2]. The results of this study suggests that drought tolerant cultivars are not necessarily the cultivars with high biomass productivity and harvest index under well-watered conditions, contradicting the conclusions of Duvick [6] that performance of hybrids under optimal

Table 3. Total plant biomass, grain yields, harvest index (HI) and drought stress tolerance index (DSTI) of fourteen maize genotypes at harvest under well-watered and water deficit conditions.

Variety	Well watered plots Total biomass (g/plant)	Grain yield (g/ha)	Harvest Index	Water-deficit plots Total biomass (g/plant)	Grain yield (g/ha)	Harvest index	Drought stress tolerance index
8321-21	168.26a	4718b	0.965a	73.35a	2138e	0.9660	0.464d
8425-8 STR	161.83a	5439a	0.971a	63.82c	2618b	0.976a	0.655b
8522-2	168.32a	5096a	0.968^a	60.09c	2851b	0.979a	0.668b
8644-31	145.90b	4353b	0.967a	53.93d	2431d	0.978a	0.486d
8644-32	159.43a	4527b	0.965a	62.12c	2736c	0.977a	0.569c
Oba Super 1	163.88a	5028a	0.968a	68.38b	2551b	0.973a	0.589c
Oba Super 2	160.23a	4395b	0.965a	71.42a	2056e	0.966a	0.415d
9022-13	159.93a	4124b	0.962a	74.01a	3211a	0.977a	0.609bc
9031-29	133.34c	4202b	0.969a	64.96b	2409c	0.973a	0.465d
9033-26	140.46b	4223	0.967a	77.04a	3561a	0.978a	0.691b
2016-1	168.43a	5283a	0.969a	74.77a	3822a	0.981a	0.928a
2016-6	146.17b	5323a	0.973a	79.09a	3849a	0.979a	0.942a
0103-4	133.74c	4326b	0.970a	69.15b	3012a	0.977a	0.599c
0103-11	166.01a	4257b	0.962a	78.22a	2971a	0.974a	0.581c
Mean	155.0	4664	0.967	67.88	2873	0.975	0.6188

Means within columns that are similar are not significantly different at P=0.05 by the DMRT.

Table 4. Correlations among seedling variables and estimated indices of drought tolerance among six tropical maize hybrids.

	Plant height (cm)	Number of expanded leaves	Number of rolled leaves	Leaf chlorophyll	Number of wilted plants	Total plant biomass (g)	Stay green ability (SGA)
HI	-0.12	0.00	-0.92**	0.14	-0.16	-0.09	0.53
DSTI	-0.22	0.00	-0.82*	-0.11	-0.77	-0.22	0.25

*Significant at P=0.05; **Significant at P=0.01.

Table 5. Seedling evaluation of tropical maize hybrids under well-watered (control) and water stressed (3 weeks of drought) conditions.

	Plant Height (cm)	Number of expanded leaves	Number of rolled leaves	Leaf chlorophyll	Number of wilted plants	Total plant biomass (g)	Stay green ability (SGA)
Control							
9033-26	39.4	7.3	0.0	37.5	0.0	7.8	1.0
0103-11	42.2	8.3	0.3	37.8	0.0	9.5	2.0
8644-32	38.6	8.4	0.0	35.4	0.0	7.5	1.3
2016-6	42.2	8.7	0.0	35.5	0.0	8.6	1.3
9022-13	39.3	8.3	0.3	36.6	0.0	7.7	1.3
8425-8STR	38.8	7.7	0.0	36.7	0.0	8.1	1.3
Means	40.08	8.17	0.10	36.58	0.00	8.12	1.37
L.S.D (df = 17)	2.013	0.621	0.186	1.199	-	1.133	0.402
3 weeks drought							
9033-26	27.3	0.0	3.0	15.5	3.0.	1.2	2.0
0103-11	27.2	0.0	3.3	13.9	2.3	1.2	2.0
8644-32	26.1	0.0	3.0	14.8	3.0	1.1	2.3
2016-6	25.2	0.0	2.7	14.9	2.7	1.1	2.0
9022-13	25.4	0.0	3.0	17.5	3.0	1.2	2.3
8425-8STR	23.4	0.0	3.0	17.5	8.7	1.0	2.0
Means	25.77	0.00	3.00	15.68	3.78	1.13	2.15
L.S.D. (df = 17)	1.755	-	2.294	1.808	2.927	0.099	0.586

moisture conditions could predict performance under drought conditions. Our results rather suggests that to develop drought stress tolerant hybrids, considerable effort should be on evaluating parental populations for drought stress under sub optimal water regimes rather than extrapolate performance of genotypes under optimal moisture conditions in agreement with Betran *et al.* [4].

Yield-based indices that quantify the responses of crop plants to environmental stresses help to assess drought tolerance among genotypes thus providing a means of identifying potential sources of genes for improvement of drought tolerance and crop production. The usefulness of secondary traits for improving selection efficiency in maize populations under low nitrogen stress conditions was demonstrated [1]. Results from this trial showed that there were no significant differences in HI among genotypes under well-watered and drought conditions, but there were significant differences in DSTI, thus DSTI discriminated the various genotypes more effectively and made it possible to identify superior genotypes under moisture stress conditions. In previous studies, Porch [15] reported correlations of a heat tolerance index calculated in a similar way as the DSTI with yield-related traits in common bean, confirming the efficacy of stress tolerant indices for selection of genotypes. Based on DSTI estimates, results of this study identified hybrids with values around 0.6 as drought tolerant genotypes for off-season production and as possible parents for developing drought stress tolerant hybrids for this environment, since stress tolerance in source populations increases the probability of deriving stress-tolerant hybrids [8]. It was also concluded by Betran *et al.* [4] that tropical maize inbred lines identified as drought stress tolerant combined well with other inbreds and are stable across various test environments indicating that identifying and incorporating drought tolerance to parental lines has potentials to enhance hybrid performance under drought.

The seedling screening trial of this study showed that under drought stress seedling leaf chlorophyll content and number of wilted plants are the leaf traits that varied significantly among the genotypes. Leaf chlorophyll content is a trait that can differentiate genotype responses under stress, because drought stress affects the photo-oxidation of chlorophyll molecules at the cellular level resulting in free high energy electrons and loss photosynthetic capacity in leaves [2]. Besides, leaf chlorophyll content and duration are desirable traits to breed for when attempting to improve drought tolerance in maize germplasm since a delayed rate of leaf senescence increases the duration of photosynthetic activities and translocation of more assimilates to the silks during grain filling, ultimately resulting in grain yield increase [5]. Results from seedling responses to drought-stress in this study agree with this assertion; significant reductions of chlorophyll content of leaves in drought stressed seedlings in comparison with unstressed seedlings resulted in significant reduction in total biomass of the genotypes. Reductions in leaf chlorophyll content under drought stress is an important adaptation mechanism for plants to regulate elevated leaf temperature induced by drought and thus improve water use efficiency [21]. Consequently, desirable performers based on leaf and seedling biomass traits during seedling screening under water deficit conditions can be used as source populations in breeding programmes to increase the frequency of favourable genes for water use efficiency under drought [3].

Conclusions

Evaluating maize genotypes for drought stress is an essential step towards stabilizing yields under drought as well as for crop and seed production during dry season planting. The evaluation also helps to identify potential parental populations for breeding purposes. From this study, secondary trait such as DSTI under stress conditions was a useful tool for rapid selection of maize genotypes for tolerance to drought stress. From the genotype comparison that was done based on DSTI values, the hybrids with the highest DSTI values were 2016-6 and 2016-1, which also had the highest values of total biomass and grain yields under induced drought stress. Based on seedling parameters, also hybrids 2016-6, 9033-26, 0103-11 and 9022-13 were optimal performers under drought stress. The study also showed that genotypes that demonstrated desirable seedling drought tolerance traits also had high DSTI values (>0.6). The pedigrees of these hybrids are therefore recommended for further examination in breeding adapted drought tolerance populations and for regular hybrid seed multiplication under the prevailing environments.

It was noted that most of the high performance genotypes under drought stress are newer hybrids, most of which are top crosses of older single cross hybrids. Generally, maize hybrids released after year 2000 performed better than older genotypes with respect to DSTI. The same trend was observed for biomass weight, grain yield and seedling traits during drought stress. Poor performance of older hybrids could be due to the effect of hybrid breakdown or genetic contamination over years. With continuous reconstitution of drought tolerance alleles by further hybridization, there are prospects of improving hybrid parental populations for drought tolerance among the registered tropical hybrid population in the IITA maize germplasm.

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References

[1] Bänziger, M. and Lafitte, H.R. 1997. Breeding tropical maize for low N environments: II. The values of secondary traits for improving selection gains under low N. Crop Science **37**:1110-1117.

[2] Bänziger, M., Edmeades, G.O., Beck, D. and Bellon, M. 2000. Breeding for Drought and Nitrogen Stress Tolerance in Maize: From Theory to Practice. CIMMYT, Mexico, D.F., pp. 68.

[3] Beck, D., Betran, F.J., Bänziger, M., Willcox, M. and Edmeades, G.O. 1997. From landrace to hybrid: Strategies for the use of source population and lines in the development of drought-tolerant cultivars. In Edmeades, G.O., Bänziger, M., Mickelson, H. R. and Pena-Valdivia, C.B. (eds). Developing Drought and Low N-Tolerant maize. Proceedings of a Symposium CIMMYT, El Batan, Mexico, pp. 369-382.

[4] Betran, F.J., Beck, D., Bänziger, M. and Edmeades, G.O. 2003. Genetic analysis of inbred and hybrid grain yield under stress and nonstress environments in tropical maize. Crop Sci. **43**:807-817.

[5] Bolanos, J. and Edmeades, G.O. 1993. Eight cycles of selection for drought tolerance in lowland tropical maize. I. Responses in grain yield business and radiation utilization. Field Crops Research **31**:233-252.

[6] Duvick, D.N. 1984. Genetic contribution to yield gain of US hybrid maize, 1930 to 1980. In Fehr, W.R. (ed.). Genetic Contributions to Yield Gains of Fire Major Crop Plants. CSSA, Special Publications 7, Madison, WI, pp. 15-47.

[7] Edmeades, G.O., Bolanos, J., Hernadez, M. and Bellon, M. 1993. Causes for skill delay in lowland tropical maize population. Crop Science **33**:1029-1035.

[8] Edmeades, G.O., Bänziger, M., Cortes, C. and Ortega, C. 1997. From stress tolerant populations to hybrids: The role of source germplasm. In Edmeades, G. O. *et al.* (eds). Drought- and Low N-Tolerant Maize. Proceedings of a Symposium, CIMMYT, El Batan, pp. 263-273.

[9] Edmeades, G.O., Bänziger, M., Schussler, J.R. and Campos, H. 2004. Improving abiotic stress tolerance in maize: A random or planned process? In Proceedings of the Arnel R. Hallauer International Symposium on Plant Breeding, Mexico City, 17–22 August 2003, Iowa State University Press.

[10] Fisher, R. A. and Maurer, R. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. **29**:897-912.

[11] Hillel, D. and Rosenzweig, C. 2002. Desertification in relation to climate variability and change. Adv. Agron. **77**:1–38.

[12] Kramer, P.J. 1980. Drought stress and the origin of adaptations. In Turner, N.C. and Kramer, P.J. (eds). Adaptation of Plants to Water and High Temperature Stress. John Wiley Interscience, New York, pp. 7-20.

[13] NeSmith, D.S. and Ritchie, J.T. 1992. Effects of soil water difficult during tassel emergence on development and yield components of maize (*Zea mays* L.). Field Crops Res. **28**:251-156.

[14] Novero, R.P., O'Toole, J.C., Cyrus, R.T. and Garrity, D.P. 1985. Leaf water potential, crop growth response and microclimate of dry land rice under line source sprinkler irrigation. Agricult. and Forest Meteorol. **35**:71-82.

[15] Porch, T.G. 2006. Application of stress indices for heat tolerance screening of common bean. Journal of Agron. & Crop Sci. **192**:390-394.

[16] SAS Institute 1997. SAS/STAT Software: Changes and Enhancement through release 6.12. Cary, NC.

[17] Schussler, J.R. and Westgate, M.E. 1995. Assimilate flux determines kernel set at low water potential in maize. Crop Sci. **35**:1074-1080.

[18] Thomas, F., Lohmann, G., Kuhnert, H., Lorenz, S.J., Scholz, D., Paetzold, J., Al-Rousan, S.A. and Al-Moghrabi, S. 2004. Increased seasonality in Middle East temperatures during the last interglacial period. Nat. **429**:164-168.

[19] Westgate, M.E. 1997. Physiology of flowering in maize: Identifying avenues to improve kernel set during drought. In Edmeades, G.O., Bänziger, M., Mickelson, H.R. and Pena-Valdivia, C.B. (eds). Developing Drought and Low N – Tolerant Maize. Proceedings of Symposium, CIMMYT, El Batan, Mexico, pp. 136-141.

[20] Yin, Y.F., Zhang, C.L. and Yao, F.X. 1995. The relationship between photosynthetic rate and stomata resistance and conductance in different winter wheat cultivars. Acta Agron. Sinica **21**:561-567.

[21] Zaharieva, M., Gaulin, E., Havaux, M., Acevedo, E. and Monneveux, P. 2001. Drought and heat response in wild wheat relative *Aegilops geniculata* Roth: Potential interest for wheat improvement. Crop Sci. **41**:1321-1329.