Journal of Dryland Agriculture
ISSN: 2476 - 8650

Shaibu et al., 2017: 3(1). p 1-9

Screening for Drought Tolerance in Maize Hybrids using Drought Indices

A. S. Shaibu[1]*, M.A. Ayo-Vaughan[2], A.A. Adnan[1] and R.O. Abdulmalik[3]

[1] *Department of Agronomy, Bayero University, Kano*

[2] *Department of Plant Breeding and Seed Technology, Federal University of Agriculture Abeokuta*

[3] *Institute for Agricultural Research, Ahmadu Bello University, Zaria*

**Corresponding author:* asshuaibu.agr@buk.edu.ng

Abstract

A study was conducted to select extra-early maize hybrids for drought tolerance and investigate the efficacy of different drought indices. The material consisted of 10 single cross hybrids which were selected from 66 single cross hybrids using IITA base index. The initial experiment was conducted at Ikenne and was laid in a randomized incomplete block design with two replicates. Data collected were subjected to analysis of variance (ANOVA) after which the best ten were selected using a base index. The selected hybrids were further subjected to estimates of SSI, STI, GMP, MP, TOL, DTE, YI, GOL, HARM, and YSI. The results revealed that most of the hybrids were tolerant to drought. However, hybrids TZdEEI 7 × TZEEI 79 and TZdEEI 7 × TZEEI 63 were found to be the most promising drought tolerant hybrids. STI, GMP, GOL, MP and YI were positively correlated to yield under drought stress conditions and were able to separate hybrids under ‘A’ group from other groups. This is an indication that the indices can be used as a measure of drought tolerance in maize.

Keywords: Maize hybrids, Extra-early, drought tolerance, drought indices.

Introduction

Maize (*Zea mays* L.) is a major staple crop, which provides calories for over 300 million people in Africa. In Nigeria, about 9.2 million tons of maize grains are produced annually on about 6 million ha of land (FAOSTAT, 2013) indicating a low output per ha (1.8 t/ha) despite the availability of improved crop management practices and improved varieties with high yield potential (>5 t/ha) (Kumwenda *et al.*, 1996).

The savannas of West and Central Africa (WCA) constitute the maize belt of the sub region. However, maize production in this agro-ecology is plagued by drought (Badu-Apraku *et al.*, 2010). Maize is a cereal with the largest annual global production at 829 M tons annually. Maize grain yields in the temperate developed world of North America and Europe average is 8.7 ton/ha vs. 3.7 t/ha in less developed tropical countries of Asia and Africa (FAOSTAT, 2012). In both production environments, drought is the most important abiotic stress constraining and destabilizing maize production.

Most of the (160 m ha) of maize grown globally is rainfed. The proportion of the crop area irrigated in the US is around 14%, in China 40% and in Egypt close to 100%, but in most other countries it is often less than 10%. Annual yield loss to drought is estimated at 15% of well-watered yield potential on a global basis, a figure that equates to 120 M tons of grain. At today’s prices this is worth around $36 billion, but the real costs are in terms of human welfare in sub-Saharan Africa where maize is a staple food for more than 300 million people. In 2011, a year of moderate food relief activity, the World Food Program purchased 410,000 tons of maize worth more than $100 M for sub-Saharan Africa (WFP, 2012).

Recurrent drought seems to have become a permanent feature under global climate change scenario especially in sub-Saharan Africa (Badu-Apraku *et al.*, 2011). In maize production, drought, on average, causes yield losses of about 15% annually in WCA (Edmeades, 2013). In marginal areas where annual rainfall is below 500 mm or where soils are sandy or shallow, drought effects on maize production may be much higher. Climatic change resulting from global warming has further increased the probability of drought, even in the so-called forest agro-ecology of WCA (Fakorede and Akinyemijiu, 2003). In view of this a study was conducted to screen some extra-early maize hybrids for their performance and level of drought tolerance.

Materials and Methods

Ten single cross hybrids selected using a base index among a set of sixty six single cross hybrids formed from diallel crosses involving 12 extra-early yellow inbred lines were used for the study. The hybrids with the checks were evaluated for their agronomic performance under induced drought stress during the dry seasons of 2013/2014 at Ikenne and under well-watered conditions at Ikenne in 2013. A 10 × 7 randomized incomplete-block design with two replications was used for each trial. The experimental units was one-row plots, each 5 m long with inter row spacing of 0.75 m and intra row spacing of. 0.40 m. Three seeds were planted and later thinned to retain two per hill about 2 weeks after emergence to give a final plant population density of about 66,666 plants ha^{-1}.

The managed drought stress was obtained using the method described by Badu-Apraku *et al.* (2012). Except for the amount of water to be applied in well-watered environments, all management practices were the same for both well-watered and drought-stress conditions. Fertilizer was applied to the well-watered and drought stress plots at the rate of 60 kg ha^{-1} each of N, P, and K at planting. An additional 60 kg ha^{-1} N was top dressed at 2 weeks after planting (WAP). The trials were kept weed free with the application of atrazine (1-chloro-3-ethylamino-5-isopropylamino-2,4,6-triazine) and gramoxone (1,1-dimethyl-4,4-bipyridinium dichloride) as pre- and post-emergence herbicides at 5 L ha^{-1} each of Primextra (Syngenta Crop Protection Canada, Inc.) and Paraquat (Shandong Dongtai Agricultural Chemistry Co., Ltd.) and subsequently by hand weeding.

Data Analysis

Yield data from the field experiment (data not shown) were subjected to drought indices estimates as follows;

1. Drought susceptibility index (DSI) was calculated by the formula given by Fischer and Maurer (1978).
   $DSI = 1 - (\frac{Ys}{Yp})/D$
   $D=\frac{\text{Mean yield of all strains under moisture stress condition}}{\text{Mean yield of all strains under irrigated condition}}$
2. Drought tolerance efficiency (DTE) was estimated by using formula given by Fischer and wood (1981).
   $DTE\ (\%) = \frac{yield\ under\ stress}{yield\ under\ non-stress} \times 100$
3. Tolerance index (TOL) = Yp−Ys (Rosielle and Hamblin, 1981)
4. Mean productivity (MP) = $\frac{Yp+Ys}{2}$ (Rosielle and Hamblin,1981)
5. Drought tolerance index (DTI) = $\frac{Yp \times Ys}{AverageYp^2}$ (Fernandez, 1992)
6. Geometric mean productivity (GMP) = $\sqrt{(Yp)(Ys)}$ (Fernandez, 1992)
7. Yield index (YI) = $\frac{Ys}{average\ Ys}$ (Gavuzzi et al., 1997; Lin et al., 1986)
8. Yield stability index = $\frac{Ys}{Yp}$ (Gavuzzi et al., 1997; Lin et al., 1986)
9. Golden mean = $\frac{Yp+Ys}{Yp-Ys}$

Where,

Ys = Grain yield of the genotype under moisture stress condition.

Yp = Grain yield of the genotypes under irrigated condition.

Results

The performances of the hybrids using different indices are presented in Table 1. According to Fernandez (1992) the best measure for selection in drought condition could be to separate genotypes which have desirable and similar yield in stress and non-tressed conditions from other groups and also, the best indices are those which have high correlation with kernel yield in both conditions. High value of STI indicated more tolerance of hybrids to drought. TZdEEI 7 × TZEEI 79 (1.07) revealed maximum tolerance to drought. GMP tends to the low value and has efficiency in selection of tolerant hybrids to drought. Based on this, TZdEEI 7 × TZEEI 79 (4070.35) and TZdEEI 13 × TZEEI 95 (2929.92) were the most tolerant and sensitive hybrids. MP index directs breeders to select in stress and non-stressed conditions. TZdEEI 7 × TZEEI 79 (4123.58) and TZdEEI 13 × TZEEI 95 (2937.56) were the most tolerant and sensitive hybrids to drought pressure. Furthermore, HARM index demonstrated the advantage of TZdEEI 7 × TZEEI 79 than others to drought tension (4017.801) and TZdEEI 13 × TZEEI 95 (2922.30) had the minimum tolerance to drought stress. More GOL indicated that yield value in drought pressure was close to yield potential and the studied hybrid had lesser damage. Based on GOL index, TZdEEI 11 × TZEEI 95 (92.89), TZdEEI 1 × TZEEI 58 (20.42), and TZdEEI 13 × TZEEI 95 (13.87) had more resistance to drought. To evaluate hybrids using TOL index, higher value of TOL indicates more changes of hybrids yield in stress and non-stressed conditions and shows the susceptibility to non-stress condition. Fernandez (1992) and Rosielli and Hamblin (1981) stated that selection based on TOL index leads to selection of genotypes which their yields in non-stress condition are low and have lower MP. Based on TOL index, TZdEEI 11 × TZEEI 95 (65.85) and TZdEEI 1 × TZEEI 79 (1934.51) were the most tolerant and non-tolerant hybrids to drought stress.

Table 5 shows the relationship between indices. A highly significant positive correlation was observed between DTI and GMP, MP, HARM and YI. Also a highly significant positive correlation was observed between Ys and GMP, MP, HARM and YI and a negative correlation was recorded between SSI and yield in drought condition (-0.24). These results are in agreement with the findings of Moradi *et al.* (2012) who reported positive correlation between DTI and GMP, MP, HARM and between Ys and GMP, MP, HARM. Correlation between drought tolerance indices and yield can be used as a suitable measure for best hybrid selection. Yahoueian *et al*. (2005) announced that GMP and DTI are paramount indices used to evaluate soybean varieties in drought pressure. Mehrabi *et al.* (2011) demonstrated that corn hybrids with high yield can be obtained based on GMP and STI indices. Jafari *et al.*, (2009) found that DTI, GMP and HARM indices which showed the highest correlation with grain yield under both optimal and stress conditions, can be used as the best indices for maize breeding programs to introduce drought tolerant hybrids. Moghaddam and Hadizadeh (2000) and Ahmadzadeh (1997) claimed that MP index is much better than SSI and TOL in selection of drought tolerant genotypes. Correlation results showed positive and significant relationship between potential yield (non-stress condition) with DTI, GMP, MP, HARM and TOL, while correlation between yield and TOL was negative in stress condition. This is also similar with the findings of Moradi *et al*. (2012) who reported a negative correlation between yield under stress and TOL. In this study, since MP, GMP, HARM and DTI had high, positive and significant correlation with yield in normal and drought pressure, they can be said to be superior indices as also reported by Moradi *et al.* (2012).

Fernandez (1992) divided the reaction of corn genotypes in stress and non-stress conditions into four groups: higher yield than average in both condition (A group), higher yield than average in non-stress condition (B group), higher yield than average in stress condition (C group) and lower yield than average in both condition (D group) and claimed that an index that can separate hybrids of A group from other is the most suitable index. The groupings of the hybrids are presented in Table 3. TZdEEI 7 × TZEEI 79 and TZdEEI 7 × TZEEI 63 are the only hybrids that fall under group A. The drought indices that were able to separate them from other groups are STI, GMP, MP and GOL. These indices are also correlated with yield under stress and can therefore be described as reliable indices to identify stress tolerant genotypes in maize.

Conclusion

In conclusion, TZdEEI 7 × TZEEI 79 and TZdEEI 7 × TZEEI 63 are the most tolerant hybrids to stress conditions and can be further evaluated across locations under drought stress for their yield stability and release for commercial cultivation. They can also be used in drought breeding program.

Acknowledgement

The authors are grateful to the Drought Tolerance Maize for Africa (DTMA) project of IITA for their financial and technical support.

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Table 1: Estimates of drought tolerance indices in ten single cross maize hybrids

PEDIGREE	Yp (kg/Ha)	Ys (Kg/Ha)	STI	TOL	GMP	MP	SSI	HARM	GOL	YI	YSI	DTE
TZdEEI 12 × TZEEI 63	3882.98	3304.57	0.83	578.41	3582.12	3593.78	1.19	3570.51	12.43	0.99	0.85	85.10
TZdEEI 13 × TZEEI 95	3149.28	2725.84	0.55	423.44	2929.92	2937.56	1.07	2922.29	13.87	0.81	0.87	86.55
TZdEEI 7 × TZEEI 79	4784.03	3463.13	1.07	1320.89	4070.35	4123.58	2.20	4017.80	6.24	1.03	0.72	72.39
TZdEEI 1 × TZEEI 58	3838.02	3479.62	0.86	358.40	3654.43	3658.82	0.75	3650.05	20.42	1.04	0.91	90.66
TZdEEI 1 × TZEEI 79	4834.07	2899.56	0.91	1934.51	3743.89	3866.82	3.19	3624.86	3.99	0.87	0.59	59.98
TZdEEI 12 × TZEEI 79	3885.01	3271.15	0.82	613.86	3564.89	3578.08	1.26	3551.75	11.66	0.98	0.84	84.19
TZdEEI 7 × TZEEI 63	4221.84	3610.59	0.98	611.24	3904.27	3916.22	1.16	3892.37	12.81	1.08	0.85	85.52
TZdEEI 1 × TZEEI 63	3774.72	3046.11	0.74	728.61	3390.89	3410.41	1.54	3371.49	9.36	0.91	0.81	80.69
TZdEEI 9 × TZdEEI 12	3896.31	3599.23	0.91	297.08	3744.82	3747.77	0.61	3741.88	25.23	1.07	0.92	92.37
TZdEEI 11 × TZEEI 95	3091.68	3025.82	0.60	65.86	3058.57	3058.75	0.17	3058.39	92.89	0.90	0.98	97.87
Mean	3935.79	3242.56										

Table 2: correlation coefficient between Yp, Ys and drought tolerance indices

	Yp	Ys	STI	TOL	GMP	MP	SSI	HARM	GOL	YI	YSI	DTE
Yp	1											
Ys	0.35541	1										
STI	0.89**	0.74494	1									
TOL	0.85**	-0.18515	0.51494	1								
GMP	0.88**	0.75*	0.999**	0.5097	1							
MP	0.92**	0.69*	0.99**	0.58542	0.99**	1						
SSI	0.81**	-0.24358	0.45909	0.99**	0.455	0.53055	1					
HARM	0.84**	0.81**	0.99**	0.42546	0.99**	0.98**	0.37141	1				
GOL	-0.61149	-0.13213	-0.50705	-0.56906	-0.51171	-0.52907	-0.64*	-0.48849	1			
YI	0.35541	1.00**	0.75*	-0.18515	0.75*	0.69*	-0.24358	0.81**	-0.13213	1		
YSI	-0.81**	0.24358	-0.45909	-0.99**	-0.455	-0.53055	-1.00**	-0.37141	0.64*	0.24358	1	
DTE	-0.81**	0.24358	-0.45909	-0.99**	-0.455	-0.53055	-1.00**E19	-0.37141	0.64*	0.24358	1.00**	1

Table 3: Grouping of hybrids based on their reaction in stress and non-stress condition into four groups as described by Fernandez (1992)

Group	Hybrids
A	TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63
B	TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63, TZdEEI 1 × TZEEI 79
C	TZdEEI 12 × TZEEI 63, TZdEEI 7 × TZEEI 79, TZdEEI 1 × TZEEI 58, TZdEEI 12 × TZEEI 79, TZdEEI 7 × TZEEI 63, TZdEEI 9 × TZdEEI 12
D	TZdEEI 11 × TZEEI 95, TZdEEI 1 × TZEEI 63, TZdEEI 13 × TZEEI 95

Table 4: selected hybrids based on different drought tolerance indices

Hybrids	Drought Index
TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63	DTI
TZdEEI 7 × TZEEI 79, TZdEEI 1 × TZEEI 79	TOL
TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63	GMP
TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63	MP
TZdEEI 7 × TZEEI 79, TZdEEI 1 × TZEEI 79	DSI
TZdEEI 7 × TZEEI 79, TZdEEI 7 × TZEEI 63	HARM
TZdEEI 7 × TZEEI 79, TZdEEI 1 × TZEEI 79	GOL
TZdEEI 7 × TZEEI 63, TZdEEI 9 × TZdEEI 12	YI
TZdEEI 1 × TZEEI 79, TZdEEI 7 × TZEEI 79	YSI
TZdEEI 1 × TZEEI 79, TZdEEI 7 × TZEEI 79	DTE