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Drought Stress Indices in Some Silage Maize Cultivars

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***Abstract*—**Several yield-based stress indices have been developed that may be more applicable to work on drought tolerance. In this study, we investigate possibility of using stress susceptibility index (SSI), tolerance index (TOL), yield stability index (YSI), yield index (YI), stress tolerance index (STI), geometric mean productivity (GMP), harmonic mean (HARM), mean productivity (MP) to identify genotypic performance of some maize cultivars under normal and stressed condition. The results indicate that it was possible to identify superior genotypes for drought tolerance based on their stress indices and generally SSI indices which showed the lowest negative correlation with dry matter yield can be used as the best index for maize breeding programs to introduce drought tolerant hybrids. It was found that SC 647 showed the best behavior under drought stress condition based on TOL and SSI. A higher STI, GMP, and HARM values were attained for ko_6. It can be suggested that ko_6 should be cultivated in moderate stressful environment of Iran.

***Keywords*—**Index, productivity, stress, susceptibility tolerance, yield.

I. Introduction

DROUGHT is a meteorological term and is commonly defined as a period without significant rainfall. Generally drought stress occurs when the available water in the soil is reduced and atmospheric conditions cause continuous loss of water by transpiration or evaporation. Drought stress tolerance is seen in almost all plants but its extent varies from species to species and even within species. Water deficit and salt stresses are global issues to ensure survival of agricultural crops and sustainable food production [25]. Conventional plant breeding attempts have changed over to use physiologic selection criteria since they are time consuming and rely on present genetic variability [38]. Tolerance to abiotic stresses is very complex, due to the intricate of interaction between stress factors and various molecular, biochemic and physiological phenomena affecting plant growth and development [29]. Iran, with mostly arid and semi arid climatic condition, is facing an extreme water shortage. Lack of adequate water in this country has more visible recently. Its annual renewable water availability is now less than 2000 cubic meters per capita and this country is about to face water stress [22]. Rapid population increase is the most important factor of per capita renewable water decrease in our country during the last 80 years. The per capita renewable water resources (PCRWR) of Iran were decreased from 13,000 cubic meters in 1925 to about 1900 cubic meters in 2005. From the total of 8 million ha of irrigated lands in Iran; 7.6 million ha (95%) are under surface irrigation and 0.4 million ha (5%) under the pressurized irrigation. The agricultural sector plays a vital role in the national economy and food products of Iran. About 27 percent of GNP and 23 percent of Iran labor power are related to this sector. Although equal land areas are allocated for the irrigated and rain-fed farms, the irrigated farming is the basic factor of food production because of the improper location and periodical precipitation, that is, about 89 percent of the total agricultural products in the last 5 years have been produced from the irrigated cultivation. Therefore, the solution to get rid of water scarcity in Iran is to concentrate on the integrated water and land management, emphasizing on the agricultural water management. One of these solutions is cultivation activities improvement and change in crop pattern (approach to crops with less water consumption, crops with higher yield and income) [14]. Due to long-term trends in global climate change and the development of maize production in drought prone regions, the expansion of drought-tolerant maize varieties is of high importance, particularly for maize producers in developing nations where plant breeding improvements are more easily adopted than high-input agronomic practices. Drought causes interruptions in reproductive development, often leading to ovary abortion and thus, causing yield losses. Drought is estimated to cause average annual yield losses in maize of about 17% in the tropics [12]. Across the globe today, maize (*Zea mays* L.) is a direct staple food for millions of individuals and, through indirect consumption as a feed crop, is an essential component to global food security. It is exacerbated by any stress that reduces canopy photosynthesis and the flux of assimilates to the developing ear so that it falls below a threshold level necessary to sustain grain formation and growth [13] and [35]. The reduction in photosynthesis can be due to a decrease in radiation interception, associated with reduced leaf expansion, leaf rolling [4] and foliar senescence [37], and to a reduction in C fixation per unit leaf area because of stomatal closure or a decline in carboxylation capacity [6]. Different crops are used as silage in the world. References [31], [36] mentioned that silage corn is a popular forage crop that is used for ruminant animals because of high yield, digestibility, palatability, storage ability and etc. The annual production of forage crops (except alfalfa and clover) in Iran in 2008 production year was about 9411 t. The harvested area was almost 280000 ha with the average yield of 36 ($ton.ha^{-1}$). In all provinces Tehran ranks first in forage crop production (except alfalfa and clover) with share of 25% [1]. Significant yield losses due to water stress are present in both temperate and tropical environments of other continents that also provide maize for

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local and global consumption [7]. Thus, the development and adoption of drought-tolerant varieties is seen as a long-term solution to many of the problems plaguing drought-prone maize production regions around the globe [23]. Substantial increases in yield could be possible if irrigation water was applied at the most appropriate time to prevent excessive drought stress. With the increase in the cost of energy required to pump and move water to desired locations, coupled with the decrease of available water for irrigation, it is essential to attain the maximum benefit from each unit quantity of water used for irrigation. Plant drought stress detection is thus of great importance. Classification of plants according to their performance in stressful and stress free environments to four groups was done: genotypes with similar good performance in both environments (Group A); genotypes with good performance only in non-stress environments (Group B) or stressful environments (Group C); and genotypes with weak performance in both environments (Group D) [16]. It was found that STI was more useful in order to select favorable corn cultivars under stressful and stress-free conditions [27]. It was showed that based on GMP and STI indices, corn hybrids with high yield in both stress and non-stress environments can be selected [21]. Yield under irrigated conditions could not be considered a reflection of its yield under drought condition and that yield under irrigated conditions should not be used as a selection criterion to improve yield under drought [2]. Therefore, yield in low and high yielding environments should be considered as two separate traits that are not necessarily maximized by identical sets of alleles [15]. Consequently, plant breeding strategies should be different when targeting stress and non-stress environments [8], [9]. It seems these indices are reliable indices being able to identify high-yielding, drought tolerant genotypes under both environmental conditions [33]. it was reported that GM, STI, and SSI can be used to evaluate the genotypic performance under stress and low-stress conditions [18], [32]. It was found that heat tolerance indices, STI and GM, although correlated, were found to be effective stress indices for the selection of genotypes with good yield potential under stress and low-stress conditions [28]. High yield potential under drought stress is the target of crop breeding. In many cases, high yield potential can contribute to yield in moderate stress environment [3]. The objective of this study was to determine to improve corn yield and stability in stressful environments, there is a necessity to identify selection indices able to distinguish high yielding corn cultivars in these situations. Thus, our purpose was evaluation of efficiency and profitability of different selection indices in identification of cultivars which are compatible with stressful and optimal conditions, to achieve cultivars that can tolerate long irrigation intervals or likely no irrigation at sensitive growth stages.

II. Method and Material

Field assessments were conducted on a sandy loam at researching farm of Islamic Azad University (IAU), Arak branch that was about center of Iran (34°42`N, 49°29`E). The soil was well drained with a PH of 7.8. Plots were fertilized with 200 kg ha^{-1} of di–ammonium phosphate (21-53-0). Although, plots were broadcasted with 150 kg ha^{-1} of urea [$(NH4)_2$ CO] (46-0-0) at 7-9 leaf stage. A split plot layout within randomized complete block design with three replications was used. Main plots were one of three irrigation regime in three levels Normal Relative water content (RWC about 90%), mild stress (RWC about 60-70%), and serve stress (RWC about 40%). Subplots were cultivars (KO_6, SC700, SC704 and SC647). The relative water content (*RWC*) was estimated from the equation given [10].

$$RWC = \left[\left(FW - DW/(TW - DW)\right)\right] \times 100 \qquad (1)$$

where *FW* is the fresh weight of the three lively fully expended leaves, *TW* is the weight at full turgid, measured after floating the leaves for 24 h in distilled water at room temperature and *DW* is the weight estimated after drying the leaves at 70℃ until a constant weight is achieved. Drought tolerance indices were calculated using the following equations (Table I) [5], [16], [17], [19], [20], [30], [33].

TABLE I
DIFFERENT STRESS INDICES

Equation Number	Stress Index	Equation
(2)	stress susceptibility index (SSI)	$\left[1-\left(\frac{Ys}{Yp}\right)\right]/\left[1-\left(\frac{\widetilde{Ys}}{\widetilde{Yp}}\right)\right]$
(3)	tolerance index (TOL)	$Y_p - Y_s$
(4)	yield stability index (YSI)	Ys/Yp
(5)	yield index (YI)	$Ys/\widetilde{Ys}$
(6)	Stress tolerance index (STI)	$(Yp \times Ys)/(\widetilde{Yp})^2$
(7)	geometric mean productivity(GMP)	$(Yp \times Ys)^{1/2}$
(8)	harmonic mean (HARM)	$2(Yp \times Ys)/(Yp + Ys)$
(9)	mean productivity (MP)	$(Yp + Ys)/2$

y_s yield of variety under stress, y_p yield of variety under irrigated condition, $\tilde{y}_s$ mean yields of all varieties under stress and $\tilde{y}_p$ mean yield of all cultivars under non-stress conditions.

All cultivars were planted in 75cm row width. Maize seeds were over – planted and thinned after emergence to achieve final plant density about 130000 (plant.ha^{-1}). Each subplot consisted of five 6-m rows. Destructive harvests were taken from each subplots at forage physiologic maturity (approximately when the grain was at 65% milk line), with 40-50% seed moisture. Harvests were confined to the center of second rows, with 3.75 m^2 harvested per row. Harvest area was buffered from row ends by 0.5 m^2. The forage samples from each plots were oven-dried at 70℃ in air drier for 48-h to determine forage dry matter DM. In each stage, RWC was determined as irrigation interval increased. All data were analyzed with analysis of variance (ANOVA) in SPSS statistical software package and Microsoft Excel 2003. The mixed linear model was used to calculate the appropriate error terms for statistical tests associated with the split plot design. When ANOVA identified treatment effects, Duncan's multiple range test (DMRT) was used to identify which treatments differed at 5% significance level. Effects were considered significant in all statistical calculations if P-Value<0.05 [34].

III. Results

Results of ANOVA showed that significant differences among hybrids for all of traits in different condition ($p<0.05$), which demonstrated existence of high variety among cultivar considered for drought tolerance. Among all cultivars, KO_6 had highest and SC 647 produced highest yield in optimal and stressful conditions, respectively (Table II). It was reported that the highest DM yield of maize was observed in normal condition (RWC about 95%) and drought stress reduced DM yield significantly [11].

TABLE II (A)
Mean Squares from Analysis of Variance of Effect of Water Deficit Treatment on Maize Dry Matter Yield (DM),Stress Tolerance Index (STI), Tolerance Index (TOL), Harmonic Mean (HM)

Source Of Variation	DM ($Kgha^{-1}$)	STI	TOL	HARM
irrigation regime				
non- stressed	28200 a	0.0 c	0.0 c	0.0 c
mild stress	18870 b	0.68 b	9250 b	22492.9 a
severe stress	14150 c	2.04 a	14050 a	198833.2 a
hybrids				
KO_6	25020 a	0.57 a	71.7 a	16888.2 a
SC700	20110 c	0.38 c	65.4 b	14898.6 a
SC704	21490 b	0.41 b	65.8 b	14439.4 a
SC647	15000 d	0.34 d	65.3 b	10208.7 b

TABLE II (B)
Mean Squares from Analysis of Variance of Effect of Water Deficit Treatment on Yield Index (YI), Yield Stability Index (YSI), Yield Stability Index (YSI), Mean Productivity (MP), Geometric Mean Productivity (GMP), Stress Index Susceptibility (SSI)

Source Of Variation	YI	YSI	MP	GMP	SSI
irrigation regime					
non- stressed	0.0b	0.0 c	0.0 b	0.0 b	0.0b
mild stress	0.996a	0.68 a	23533.3 a	23029.9 a	0.9559a
severe stress	0.999a	0.51 b	21175 a	19938.4 b	0.9722a
hybrids					
KO_6	0.81 a	0.395 a	18222.2 a	17536.3 a	0.6383ab
SC700	0.64 b	0.387 a	14777.7 b	14116.6 b	0.6802ab
SC704	0.67 b	0.359 a	15911.1 b	15154.6 b	0.748a
SC647	0.51 c	0.45 a	10700 c	10483.4 c	0.505b

Drought resistance indices were determined to recognize the tolerance cultivar.SC 647 was as tolerant hybrid based on TOL which its low quantity indicates tolerant hybrids (Table II (A)). It seems TOL had succeed in choosing hybrids with high yield under stress, but failed to select genotypes with proper yield under both condition [30]. Higher SSI is expressive of more sensitive cultivar in front of stressful environment. Thus, Using SSI index SC 704 was as sensitive one (Table II (B)). It seems if a given hybrid has high yields under both stress and normal conditions, though there is much variation in its yields between these two situations, it would not be detected as tolerant by SSI (e.g., KO_6). This finding was in agreement with the results of other experiment [24]. A higher STI, GMP, and HARM value is indicative of more drought stress tolerant [16]. In view of that, our findings showed that KO_6 was identified as superlative and SC 700 and SC647 were the weakest hybrids in response to drought stress (Table II). Based on GMP and HARM indices, KO_6 was classified as group A [16]. SC 647 and SC 700 are the most vulnerable hybrids, located in group D (Table II). There were high and significant correlations between GMP, SSI, MP, YI and HARM. Therefore, the results showed that different indices will produce similar results (Table IV). Thus, as it was stated, it seems these indices are reliable indices being able to identify high-yielding, drought tolerant genotypes under both environmental conditions [33]. Analogous results were described [32]. In this evaluation of water deficit tolerance indices, STI and MP, although correlated ($r = 0.67^{**}$), were found to be effective stress indices for the selection of genotypes with good yield potential under stress and low-stress conditions (Table III). However, there was significant negative correlation between dry forage maize yield and SSI ($r = 0.72^{**}$) under drought conditions, indicating that SSI might be a very useful selection criterion for drought-tolerance breeding in maize.

TABLE III
CORRELATION BETWEEN DIFFERENT INDICES AND DRY MATTER YIELD OF SILAGE MAIZE CULTIVARS

	STI	YI	MP	GMP	HARM	SSI	YSI	TOL	DM
STI	1								
YI	.75**	1							
MP	.71**	.98**	1						
GMP	.69**	.98**	.99**	1					
HARM	.67**	.98**	.97**	.97**	1				
SSI	.72**	.93**	.94**	.93**	.92**	1			
YSI	.46**	.89**	.86**	.88**	.89**	.84**	1		
TOL	.89**	.84**	.86**	.84**	.79**	.88**	.58**	1	
DM	-.57**	-.64**	-.60	-.59**	-.59**	-.72**	-.67**	-.61**	1

TABLE IV
SELECTED HYBRIDS BASED ON DIFFERENT DROUGHT TOLERANCE INDICES

Selected Cultivar	Different Indices
SC 647, SC 700	Selected on TOL
SC 647	Selected based on SSI
KO_6	Selected based on MP
KO_6	Selected based on GMP
KO_6	Selected based on STI
KO_6	Selected based on HARM

IV. DISCUSSION

In this experiment, drought stress effects on yield of maize cultivars extremely were appeared. It seems if a given hybrid has high yields under both stress and normal conditions, but there is much variation in its yields between these two situations**,** it would not be detected as tolerant by SSI. In brief, it seems HARM, STI and GMP indices have a similar ability to separate drought sensitive and tolerant genotypes. Thus, they can use to discover genotypes which have low water supplies and/or suffer fewer yield diminution by water deficiency during their growth stage, to be suggest to cultivate in regions with restricted water resources with the purpose of improve cultivated area and production efficiency. It become visible that KO_6 hybrid can be cultivated in moderate stressful environment of Iran. Plant breeders are mainly interested in lines that combine drought tolerance with high yield, which might suggest wide adaptation possibilities. It seems that lack of success probably results from a combination of following factors: Lack of efforts through multidisciplinary approach to understand the integrated plant responses to drought and complex genetic control of different mechanisms of drought resistance. Repeatable and precise screening techniques are not identified. Knowledge is incomplete about reliable attributes as indices of drought resistance, selection criteria and influence of environment on drought-related traits. As a final suggestion, any effort for genetic improvement in drought resistance utilizing the existing genetic variability requires an efficient screening technique, which should be rapid and capable of evaluating plant performance at the critical developmental stages and screening a large population using only a small sample of plant material. The importance of developing a reliable screening technique for drought resistance has been realized very early. The different techniques such as using infrared thermometry for screening efficient water uptake as a non-contacting technique can be recommended, as suggested by [26].As loss of yield is the main concern for the crop plant from agricultural point of outlook, plant breeders highlight on yield performance under moisture stress condition [22]. A drought index which provides a measure of drought based on loss of yield under drought-condition in comparison to moist condition has been used for screening drought-resistant genotype. An artificially created water-stress environment is used to provide the opportunity in selecting superior genotype out of a large population. Visual scoring or measurement for maturity, leaf rolling, leaf length, angle, root morphology and other morphological characters of direct relevance to drought resistance are also taken into consideration. The threshold values of each indicator in drought stress detection should be determined. These threshold values were consistent with the results found in the literature. The advantages and disadvantages of each indicator were discussed, and situations that were more appropriate for application of each indicator were discussed and recommended.

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