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Evaluation of Drought Tolerance Indices and Yield Stability of Wheat Cultivars to Drought Stress in Different Growth Stage

Asghar Mehraban[1]*, Ahmad Tobe[1], Abdolghayoum Gholipouri[1], Ebrahim Amiri[2], Abdolali Ghafari[3], Mozffar Rostaii[4]

[1]Department of Agronomy and Plant Breeding, University of Mohaghegh Ardabili, Ardebil, Iran.
[2]Department of Agriculture, Islamic Azad University, Lahijan Branch, Lahijan, Iran.
[3]Dryland Agricultural Research Institute (DARI), AREEO, Maragheh, Iran
[4]West Azarbaijan Agricultural and Natural Resources Research and Education Center, AREEO, Urmia, Iran.

ABSTRACT

Drought and moisture stress is the most limiting factor affecting growth and productivity of crop plants.In order to study the response of ten bread wheat cultivars to drought stress, a field xperiment was conducted in 2013–2015 years at the the Agriculture and environmental research center of Ardabili, located at Moghan, Iran. The experimental design was a Split-plot xperiment based on randomized complete block design with three replications under five Drought stresses (no irrigation) regimes: rainfed (T1), the tillering stage (T2), at booting stage (T3), after anthesis (T4), full irrigation (T5) and 10 bread wheat cultivars. Combined analysis of variance revealed significant genotypic differences for Yp, STI, GMP, MP, TOL and HAM. Significant differences were also observed between drought treatments for Ys, STI, GMP, MP, TOL, HAM, SSI, YSI and DI. Nine drought tolerance indices including stress STI, SSI, TOL, HM, GMP, MP, YSI, DI) were calculated based on grain yield under drought (Ys) and irrigated (Yp) conditions. Grain yield in stress (Ys) condition was significantly and positively correlated with STI, GMP, MP and HM. Grain yield in non-stress (Yp) condition was significantly positive correlated with STI, MP, GMP, TOL, HM and SSI and significantly negative correlated with YSI and DI. Results of this study showed that the indices STI, GMP, MP and HAM can be used as the most suitable indicators for screening drought tolerant cultivars. The stability measuring of the GGE biplot polygon showed that, the performance of cultivars G3, G7 and G8 are highly variable (less stable), whereas cultivars G5, G1, G2, G10, G9 and G4 are highly stable. The cultivars G9 and G10 are more desirable than other cultivars that has both high mean yield and high stability.

Keywords: Drought stress; Bread wheat; tolerance indices; Stability; GGE biplot.

Corresponding author: Asghar Mehraban
e-mail✉ asgharmehraban @ gmail.com
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INTRODUCTION

Bread wheat (Triticum aestivum L.) is one of the most important cereal crops that has been crucial to the development of humans. Wheat, with about a 2.1 million km2 total harvested area, is the most abundant crop in the world: it is the first rain-fed crop after maize and the second irrigated crop after rice (Portmann F. T. et al. 2010). With a total production that surpassed 700 million tons (MTons) in year 2010, it is contributing to about the 20% of the total dietary calories and proteins worldwide (Lobell & Gourdji, 2012; Shiferaw B. et al., 2013). Compared to other important crops, the main wheat producing regions are characterized by 'close-to-average' yield variability (Ben-Ari & makowski, 2014). In Iran, cultivation of wheat has reached about 7.3 million hectares, with the total production of about 14.5 million tons and average productivity of about 2 tons per hectare (F.A.O., 2016). In most regions of Iran, wheat is produced under dry land and in low rainfall regions of Iran supplemental irrigation is necessary Drought is the single largest abiotic stress factor leading to reduced crop yields, so high-yielding crops even in environmentally stressful conditions are essential (Budak H. et al, 2013). This stress is one of the most important threatening factors for the production of crop plants in the arid and semi-arid regions of the world. Understanding plant responses to drought is of great importance and also a fundamental part of making crops stress tolerant (Farshadfar E. et al, 2013). Drought stress has a considerable impact on plant growth although the ranges of reductions are highly variable due to differences in the timing and intensity of the stress imposed and cultivar used (Emam Y. et al, 2010).

Notwithstanding the possible need for phenological adjustment (earliness) a higher yield potential may also translate into a higher performance under water stress (Hawkesford M. et al., 2013; Nouri A. et al., 2011). However, the potential yield and water-limited yield of wheat needs to continue increasing in order to cope with future demand for food, which is a consequence of the growing population and changes in social habits (Fischer R. A, 2007; Hawkesford M. et al., 2013). Bread wheat requires a minimum of 450-650 mm of rainfall in the growing season. Iran is located on the world's desert belt, and is considered as an arid and semiarid region. Average rainfall in the country is about 250 (mm) which is one third of average rainfall in the world. Agricultural drought is the lack of ample moisture required for normal plant growth and development to complete the life cycle (Manivannan P. et al., 2008). Plant responses to drought stress are very complex and include adaptive changes or deleterious effects. Drought affects morphology, growth, metabolism of plants and limits grain yield in most plants. The main consequences of drought in crop plants are reduced rate of cell division and expansion, leaf size, stem elongation and root proliferation, and disturbed stomatal oscillations, plant water and nutrient relations with diminished crop productivity (Li Yp. et al., 2009). To cope with such challenges, understanding the effects of drought on plants and morphological and physiological adaptations is crucial. Development of crop plants tolerant to drought stress might be a promising approach, which helps in meeting the food demands.

The susceptibility of plants to drought varies in dependence of stress degree, different accompanying stress factors, plant species, and their developmental stages (Demirevska K. et al., 2009). Water deficiency during different developmental stages can change the values of yield components (Francia E. et al., 2013; Hossain A. et al, 2012). Drought stress reduces grain yield of wheat through negative affecting the yield components i.e. number of plants per unit area, number of spikes and grains per plant or unit area and single grain weight, which are determined at different stages of plant development (Farooq M. et al., 2009; Francia E. et al., 2013; Hossain A. et al., 2012). In the other words, water deficiency in different stages of plant growth can have different effects on physiological and morphological traits. Therefore, the study aimed at determining whether the timing of the drought stress in plant development affects yield and other morphological and physiological traits in bread wheat. The current study examined the response of yield, yield components and other physiological traits to drought occurred in bread wheat plants at five different developmental stages. Drought indices which provide a measure of drought based on loss of yield under drought conditions in comparison to normal conditions have been used for screening drought tolerant genotypes (Mitra, 2001). Several selection criteria have been proposed for selecting genotypes based on their performance in stress and non-stress environments (Fischer & Maurere, 1978; Rosielle & Hamblin, 1981; Fernandez, 1992).

Fischer et al. (1998) suggested that relative drought index (RDI) is a positive index for indicating stress tolerance. Lan (1998) defined a new index of drought resistance index (DI), which was commonly accepted to identify genotypes producing high yield under both stress and non-stress conditions. Rosielle and Hamblin (1981) defined stress tolerance (TOL) as the differences in yield between the stress (Ys) and non-stress (Yp) environments and mean productivity (MP) as the average yield of genotypes under stress and non-stress conditions. The geometric mean productivity (GMP) is often used by breeders interested in relative performance, since drought stress can vary in severity in field environments over years (Fernandez, 1992). Fischer and Maurer (1978) suggested the stress susceptibility index (SSI) for measurement of yield stability that apprehended the changes in both potential and actual yields in variable environments.

Clarke et al, (1992) used SSI to evaluate drought tolerance in wheat genotypes and found year-to-year variation in SSI for genotypes and could rank their pattern. In spring wheat cultivars, Guttieri et al. (2001), using SSI, suggested that an SSI > 1 indicated above-average susceptibility to drought stress. The yield index (YI; suggested by Gavuzzi et al., 1997) and yield stability index (YSI) suggested by Bouslama and Schapaugh (1984) in order to evaluate the stability of genotypes in the both stress and non-stress conditions. Stress tolerance index (STI) was defined as a useful tool for determining high yield and stress tolerance potential of genotypes (Fernandez, 1992). To improve the efficiency of STI a modified stress tolerance index (MSTI) was suggested by Farshadfar and Sutka (2002) which corrects the STI as a weight. Moosavi et al, (2008) introduced stress susceptibility percentage index (SSPI), stress non-stress production index (SNPI) and abiotic tolerance index (ATI) for screening drought tolerant genotypes in stress and non-stress conditions. The objectives of the investigation were to (i) identify drought tolerant bread wheat genotypes at different growth stages drought stress in Moghan, Iran and (ii) study interrelationships among the drought tolerance indices.

2. MATERIALS AND METHODS

2.1. Experimental site and treatments

A field experiment was conducted through subjecting the bread wheat cultivar to five levels of moisture stress in 2013–2015 years at the experimental farm of the agriculture and environmental research center of Ardabili, located at Moghan, Iran (39° 39′ N, 48° 16′ E and 32 m above sea level). Agro-climatic characteristics of testing environments is given in table 1. The field experimental design was a split-plot experiment based on randomized complete block design with three replications under five contrasting irrigation regimes. The cultivar developed by various breeders at different research institutes/stations of Iran. The names cultivars, cods and origin of these cultivars are given in table 2. Drought stresses (no irrigation) introduced: rainfed (T1), the tillering stage (35 days after sowings) (T2), at booting stage (60 days after sowings) (T3), after anthesis (T4). At the control treatment (T5), soil moisture was maintained at the optimal level. The drought stress was maintained in the range of limited water availability and always above permanent wilting point, except for rainfed (T1).

The experimental plot consisted of six rows 6 m long with 0.2 m spacing between rows, which resulted in a plot area of 7.2 m2 and the seed rate was 300 seeds m-2 for each treatment. Based on a soil test before planting, 50 and 100 kg ha-1 of urea and P2O5 were applied, respectively. Weed control was conducted with an application of the herbicides 2-4-D at 1.0 Li. ha-1. At the end of the experiment, data on grain yield were taken from the middle four rows of each plot, leaving aside the guard rows on either side of a plot.

2.2. Calculate indices

Eight selection indices of drought tolerance including Tolerance (TOL), mean productivity (MP), geometric mean productivity (GMP), stress susceptibility index (SSI), stress tolerance index (STI), Harmonic Mean (HAM), Yield stability index (YSI) and drought resistance index (DI) were calculated based on the yield under five environments. Stress tolerance attributes were calculated by the following formula:

	Formula	
Stress Tolerance	TOL = Yp – Ys	Rosielle and Hamblin [1981]
Mean Productivity	MP = (Yp + Ys) / 2	Rosielle and Hamblin [1981]
Geometric Mean Productivity	GMP = (Yp * Ys)0.5	Fernandez [1992]
Stress Susceptibility Index	SSI = [(1 – (Ys / Yp)] / SI	Fischer and Maurer [1978]
Stress Tolerance Index	STI = (Yp * Ys) / (Ỹp) 2	Fernandez [1992]
Harmonic Mean	HAM = [2 * (Yp * Ys)] / (Yp + Ys)	Kristin *et al*., [2010]
Yield stability index	YSI = Ys / Yp	Bouslama and Schapaugh [1984]
drought resistance index	DI = Ys × (Ys/Yp)/ YS	Lan J, [1998]

Yp and Ys: Grain yield of each genotype under non-stress and stress conditions, respectively.

Ỹp and Ỹs: Mean grain yield of all genotypes under non-stress and stress conditions, respectively.

2.3. Statistical Analysis

Analysis of variance, correlation among traits, correlation among indices and grain yield in five environments and three-dimensional plots drawing, and biplot drawing were performed using SAS, SPSS and GGbiplot, respectively.

3. RESULTS AND DISCUSSION

3.1. Analysis of variance and Mean Comparison

Combined analysis of variance of the 10 bread wheat cultivars grain yield under irrigation conditions (Table 3), revealed significant genotypic differences for all measured traits except SSI, YSI and DI. Significant differences were also observed between drought treatments applied on the 10 cultivars all of the indices in five treatment conditions (Table 3). The interaction between stress treatments and cultivars was not significant for all of the indices. There were year effects for Yp, GMP and MP.

Means Comparison of grain yield and indices were carried out using Duncan's multiple rang test and showed in Tables 4 and 5. Mean seed yield under T5 (Yp) was 4407 kg/h and ranged from 3904 kg/h (G1) to 4955 kg/h (G5). While, mean seed yield under stress conditions (Ys) was 2309 kg/h and ranged from 2223 kg/h (G1) to 2399 kg/h (G5). Thus, the data indicated that mean seed yield per plant decreased under stress. To assess drought tolerance of these cultivars Ys, Yp, STI, GMP, MP, TOL, HAM, SSI, YSI and DI were calculated based on grain yield in stressed and non-stressed conditions (Table 4). Based on MP, GMP, STI and HAM indices, two cultivars G8 and G9 5were the tolerant cultivars which their high quantity is indicating tolerant genotypes (Table 5). Based on these current indices, G1 and G2 were the most susceptible cultivars.

According to SSI and TOL, G1 and G2 were the most tolerant and G9 and G8 were the most susceptible genotypes, which their low quantity is indication of tolerant genotypes. Low value of SSI and TOL indexes show the tolerance of the genotype. Therefore, the tolerant genotypes were selected based on low TOL and SSI Since genotypes, which had lower amounts of these indexes, identified as tolerant genotypes, selection genotypes according to this index leads to choosing genotypes, which had high grain yield in drought stress conditions and low yield in non-stress conditions, hence TOL and SSI cannot be able to identify tolerant genotypes (Shahryari & Mollasadeghi, 2011). Two genotypes with low/high yield may have equal SSI rate in both conditions, so selection process based on this index cause to breeders to make a mistake (Naeimi et al., 2008). G1 and G2 had the highest and G9, G10 had the lowest yield stability index (YSI). G5 and G2 displayed high DI index, while G9 and G6 showed the lowest amount. Based on all calculated drought indices, G8, G9 and G10 were susceptible to drought stress.

3.2. Correlation analysis

Correlation analysis among grain yield under all environments and drought tolerant indices were performed. Yp was significant correlated with STI, TOL, HAM and SSI and was negative correlated with YSI and DI (Table 6). Also, analysis showed that Ys was significant correlated with STI, GMP, MP and HAM. the results of Golabadi et al (2006) in durum wheat showed the positive correlation between grain yield and GMP, MP and STI indices. The highest correlation in all treatments was observed between GMP and STI (r2= 0.998**), which confirmed results of other reported studies (Ghobadi et al., 2012; Farshadfar & Elyasi, 2012).

The results indicated that except YSI and DI, all the studied drought tolerance indices were significantly correlated with grain yield in all conditions. These indices are suitable to screen drought tolerant and high yielding genotypes in stress and non-stress conditions. The STI, GMP and MP were used in different plants to screen drought tolerant high yielding genotypes in different conditions (Fernandez, 1992; Sanjari-Pireivatlou & Yazdansepas, 2008; Mohammadi et al., 2010; Karimizadeh & Mohammadi, 2011).

3.3. Yield stability at different growth stages

In a plant breeding program, potential cultivars are usually evaluated in different environments before selecting desirable ones that show stability across environments. The major objective of plant breeders in a crop breeding program is the development of cultivars or cultivars which are stable or adapted to a wide range of diversified environments. During the growth stages, plants may be exposed to drought stress. Therefore, the cultivars will be better that it to be high stability and can produce good performance in these conditions. Yield stability has been extensively studied by biometricians and various methods have been developed. The GGE biplot methodology (Yan & Kang, 2003) provides a powerful solution to study of stability. Biplot analysis is a multivariate analytical technique that graphically displays the two-way data and allows visualization of the interrelationship among environments, and the interrelationship between cultivars and environments. Biplots are useful in summarizing and approximating patterns of response that exist in the original data (Ebadi et al., 2010).

There are numerous ways to use a GGE biplot, but the polygon view of the biplot is most relevant to the mega-environments identification. For this purpose, the cultivars that are connected with straight lines so that a polygon is formed with all other cultivars contained within the polygon (Figure 1). The vertex cultivars (G2, G8, G10, G5, G1 and G4) are the best or the poorest cultivars in some or all of the environments since they had the longest distance from the origin of biplot. There are six sectors in Figure 1A. The vertex cultivar for each sector is the one that gave highest yield for environments that fall within that sector. Therefore, the first group contained T1 and T2, with cultivar G2 being the winner. Cultivar G8 gave the highest performance in T4 and T5 and cultivars G5 gave the highest performance in environment T3. Cultivars G1, G10 and G4 did not give the highest yield in any of the environments.

Other applications of the GGE biplot methodology is to visually identify the mean performance and stability of cultivars. The mean yield of the cultivars can then be approximated by nominal yields of the cultivars in that mean environments. In Figure 1B, cultivars G8, G9 and G10 had the highest mean yield and cultivars G1 AND G4 had the poorest mean yield. A cultivar is more stable if it is closer to the axis Y. Therefore, the performance of cultivars G3, G7 and G8 are highly variable (less stable), whereas cultivars G5, G1, G2, G10, G9 and G4 are highly stable. An ideal cultivar is one that has both high mean yield and high stability. Therefore, cultivars G9 and G10 are more desirable than other cultivars. For more information about the GGE-Biplot software, see the Yan and Kang (Yan & Kang, 2003).

3.4. Three dimensional plots

Three dimensional plots were drawn aimed at better identifying drought tolerant genotypes, (Fig 2, 3 and 4). In three-dimensional plots, the X-Y plane is divided into four groups including group A to group D. For distinguishing the high-yielding genotypes under two environments, the mentioned plots can be used. Three-dimensional plots (Ys, Yp and STI, GMP, MP) are presented to show the interrelationships among these three variables to separate the group A Genotypes (high yielding genotypes in both rainfed and irrigated conditions), from the other groups (groups B, C, D), and to illustrate the advantage of STI , GMP and MP indices as selection criterion for identifying high-yielding and stress tolerant genotypes. In three dimensional plots, G5, G4 and G7 were in C group. These genotypes had high yield only in rainfed environment. G6 was in B group, this genotype performs favorably only in non-stress (full irrigation) environment. G1, G2, G3 were in D group that perform poorly in both environments. Favored genotypes were G8, G9 and G10 that fall in the A group (Fig 2, 3 and 4), and from the viewpoint of STI, GMP, MP indices this genotypes had stable grain yield in two environments.

4. CONCLUSION

Selection ought to be based on the drought tolerant indices calculated from the grain yield under both conditions in case the breeder is looking for the genotypes adapted for a wide range of environments. In the research, statistical methods including correlation between grain yield and indices, biplot analysis, were identified the same genotypes as tolerant. The same pattern was pursued by the three dimensional plot; as a result, these statistical methods are advantageous in order to identify drought tolerant wheat genotypes. The findings admit that MP, GMP and STI are suggested for identification of drought tolerant.

Table 1: Agro-climatic characteristics of testing environment

Month	**Year**	**Temp(˚C)**			**Rainfall (mm)**	**Average Humidity (%)**	**Evaporation (MM)**	**Soil Condition**	
		Min	Max	Mean.					
Sep.	2013-14	15.5	30.0	22.7	19.0	68.2	165.8	Texture	Sandy-Loam-Silt
	2014-15	17.7	29.1	23.4	25.4	64.9	160.5		
Oct.	2013-14	9.7	20.6	15.15	29.7	75	67.2		
	2014-15	10.5	18.7	14.6	1.6	78.0	42	%Silt	14
Nov.	2013-14	6.3	15.7	11.1	75.0	80	21.1		
	2014-15	5.4	12.9	9.2	46.8	79.1	12.3		
Dec.	2013-14	-0.9	6.7	2.9	18.3	74	0	%Loam	57
	2014-15	2.6	10.5	6.5	5.3	81.3	0		
Jan.	2013-14	-0.6	10.7	5	7.8	70	0		
	2014-15	0.6	8.2	4.4	5.8	80.3	0	%Sandy	29
Feb.	2013-14	-0.7	9.5	4.4	89.0	74	0		
	2014-15	1.9	10.6	6.3	21.9	79.2	0		
Mar.	2013-14	4.7	15.7	20.4	51.3	70	0	Ph	7.9
	2014-15	4.4	12.7	8.5	14.9	79.8	2.6		
Apr.	2013-14	8	20.9	14.4	22.9	68	72	%N	0.01
	2014-15	7.7	19.1	13.4	11.9	71.5	86.3		
May.	2013-14	15.5	29.4	22.4	31.1	66	170	%C	0.98
	2014-15	14.0	26.7	20.3	11.6	68.2	121.5		
Jun.	2013-14	18.4	33.1	25.7	37.2	52	232.9		
	2014-15	17.5	32.6	25.0	37.2	59.6	338.3		

Table 2. Cultivars code and name of 10 bread wheat cultivars

Cultivars codes	Name
C1	Zagros
C2	Karim
C3	Kohdasht
C4	Seymareh
C5	Dehdasht
C6	Niknejad
C7	Aftab
C8	Gaboss
C9	Chmran
C10	Shirodi

Table 3. Combined analysis of drought tolerance indices and under irrigated and rainfed grain yield in 5 irrigation treatments

SOV	df	Mean square									
		Ys	Yp	STI	GMP	MP	TOL	Harm	SSI	YSI	DI
Year (Y)	1	431038 ^{ns}	1892150 *	0.027 ^{ns}	1702524 *	2902680 *	4388863 ^{ns}	976140 ^{ns}	0.017 ^{ns}	0.029 ^{ns}	0.039 ^{ns}
Replication (Y)	4	88148	181212	0.015	181019	238503	671069	1508887	0.051	0.012	0.014
Irrigation (I)	3	41296191*	0	2.159 **	18860850*	10323590*	41297127**	28238649 *	9.367 **	2.129**	2.044*
Y×I	3	1561689 **	0	0.061 **	860320 **	390364 **	1561734 **	1369304 **	0.235 **	0.065 **	0.073 *
Error (a)	12	119652	0	0.006	53836	29915	119628	80599	0.031	0.007	0.009
Cultivar (C)	9	77202 ^{ns}	774199 *	0.062 *	548098*	936688*	2601102*	310565 *	0.140 ^{ns}	0.032 ^{ns}	0.032 ^{ns}
C × Y	9	101508 ^{ns}	155685 ^{ns}	0.014 *	137209*	189565**	690424**	124094^{ns}	0.069 **	0.015 **	0.031 ^{ns}
I × C	27	83237 ^{ns}	0	0.007 ^{ns}	48580 ^{ns}	20807 ^{ns}	83246^{ns}	80304 ^{ns}	0.020 ^{ns}	0.004 ^{ns}	0.017 ^{ns}
I × C × Y	27	139351 ^{ns}	0	0.008^{ns}	79321 ^{ns}	34816 ^{ns}	139340^{ns}	126808 **	0.031 ^{ns}	0.007 ^{ns}	0.029 *
Error (b)	144	73864	145814	0.007	57773	59111	2029994	66333	0.024	0.005	0.018
CV(%)		11.77	8.66	15.89	7.65	7.24	21.48	8.74	15.79	13.85	25.17

Table 4- mean comparison of drought tolerance indices effects in studied traits, measured from irrigation treatments using duncan's method**.**

Irrigation Treatments	Ys	STI	GMP	MP	TOL	Harm	SSI	YSI	DI
T1	1608. ^{D}	0.365 ^{D}	2649. ^{D}	3007. ^{D}	2799. ^{A}	2338. ^{D}	1.329 ^{A}	0.369 ^{D}	0.3777 ^{D}
T2	1779. ^{C}	0.407 ^{C}	2782. ^{C}	3093. ^{C}	2628. ^{B}	2507. ^{C}	1.236 ^{B}	0.411 ^{C}	0.4213 ^{C}
T3	2407. ^{B}	0.547 ^{B}	3244. ^{B}	3407. ^{B}	1999. ^{C}	3091. ^{B}	0.944 ^{C}	0.552 ^{B}	0.5620 ^{B}
T4	3442. ^{A}	0.786 ^{A}	3890. ^{A}	3924. ^{A}	965. ^{D}	3856. ^{A}	0.450 ^{D}	0.787 ^{A}	0.7877 ^{A}
LSD 5%	137.6	0.03081	92.30	68.80	137.6	112.9	0.070	0.033	0.037

Drought stresses (no irrigation) introduced: rainfed (T1), the tillering stage (T2), at booting stage (T3), after anthesis (T4).

Table 5- means comparison of drought tolerance indices in bread wheat cultivars effects in studied traits, using duncan's method

Cultivars	Yp	STI	GMP	MP	TOL	Harm
C1	3904. ^{D}	0.451 ^{D}	2908. ^{E}	3064. ^{E}	1681. ^{C}	2767. ^{D}
C2	4003. ^{D}	0.479 ^{D}	2996. ^{DE}	3151. ^{DE}	1705. ^{BC}	2855. ^{CD}
C3	4240. ^{CD}	0.487 ^{D}	3036. ^{CDE}	3236. ^{CD}	2008. ^{B}	2855. ^{CD}
C4	4206. ^{CD}	0.502 ^{CD}	3060. ^{CD}	3259. ^{CD}	1894. ^{BC}	2887. ^{BCD}
C5	4366. ^{BCD}	0.542 ^{BC}	3183. ^{BC}	3382. ^{BC}	1967. ^{BC}	3005. ^{ABC}
C6	4587. ^{ABC}	0.541 ^{BC}	3178. ^{BC}	3431. ^{B}	2312. ^{A}	2955. ^{ABC}
C7	4221. ^{CD}	0.502 ^{CD}	3079. ^{CD}	3263. ^{CD}	1916. ^{BC}	2912. ^{BCD}
C8	4857. ^{A}	0.594 ^{A}	3348. ^{A}	3615. ^{A}	2484. ^{A}	3111. ^{A}
C9	4955. ^{A}	0.602 ^{A}	3361. ^{A}	3654. ^{A}	2603. ^{A}	3105. ^{A}

C10	4731. AB	0.568 AB	3262. AB	3526. AB	2410. A	3030. AB
LSD 5%	447.1	0.048	137.1	138.7	283.4	147.0

Table 6. Simple correlation coefficients matrix between drought tolerance indices and grain yield under irrigation treatments

	YS	**YP**	**STI**	**GMP**	**MP**	**TOL**	**Harm**	**SSI**	**YSI**	**DI**
YS	1									
YP	0.585	1								
STI	0.724*	0.982**	1							
GMP	0.732*	0.980**	0.998**	1						
MP	0.675*	0.993**	0.996**	0.996**	1					
TOL	0.466	0.990**	0.946**	0.943**	0.968**	1				
Harm	0.808**	0.947**	0.988**	0.992**	0.977**	0.894**	1			
SSI	0.316	0.950**	0.880**	0.872**	0.910**	0.982**	0.804**	1		
YSI	-0.318	-0.948**	-0.877**	-0.870**	-0.908**	-0.980**	-0.801**	-0.997**	1	
DI	0.091	-0.748*	-0.615	-0.606	-0.668*	-0.831**	-0.507	-0.904**	0.902**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 1. (A) mega-environment and their winning cultivars, (B) cultivars ranking based on both average yield and stability.

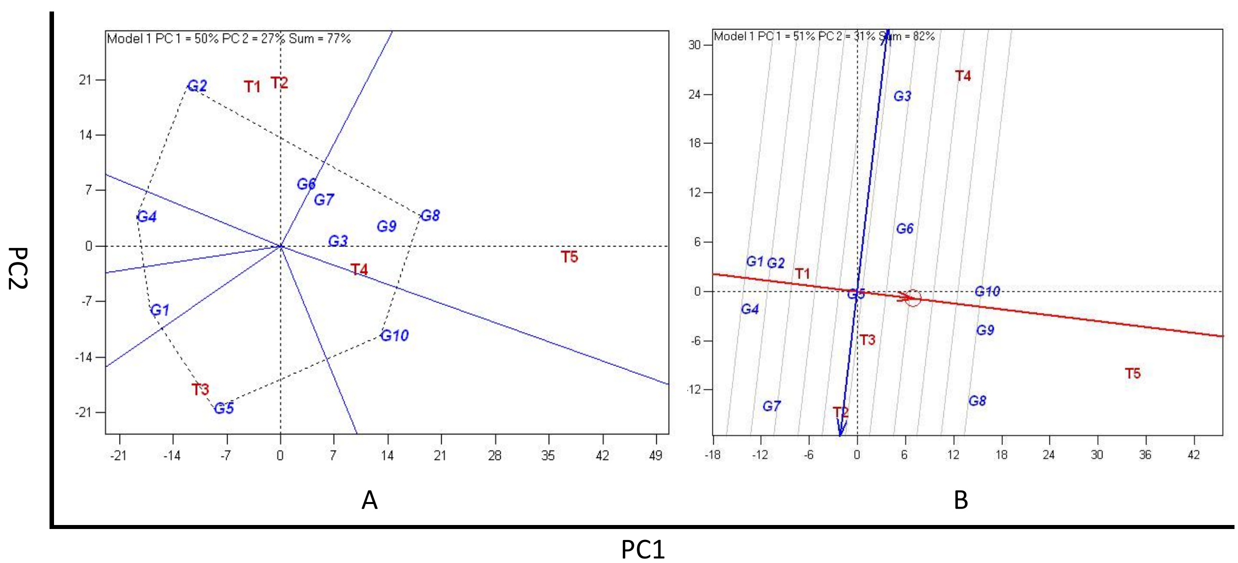


Figure 2. The 3D plot among STI, Ys and Yp.

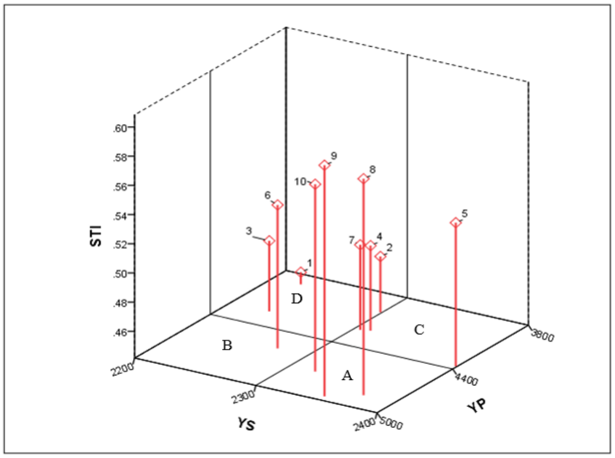


Figure 3. The 3D plot among GMP, Ys and Yp

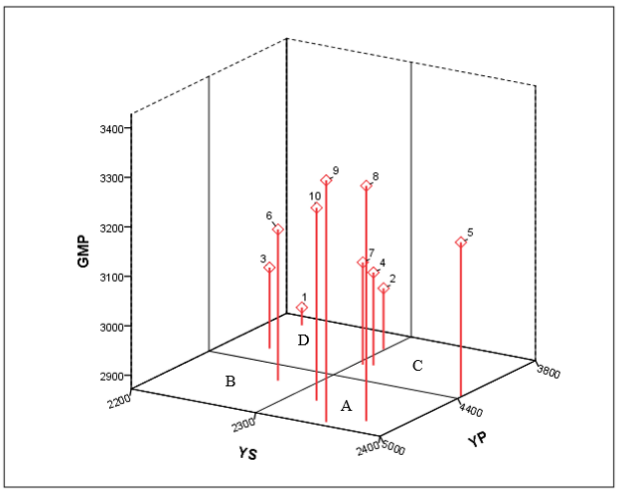
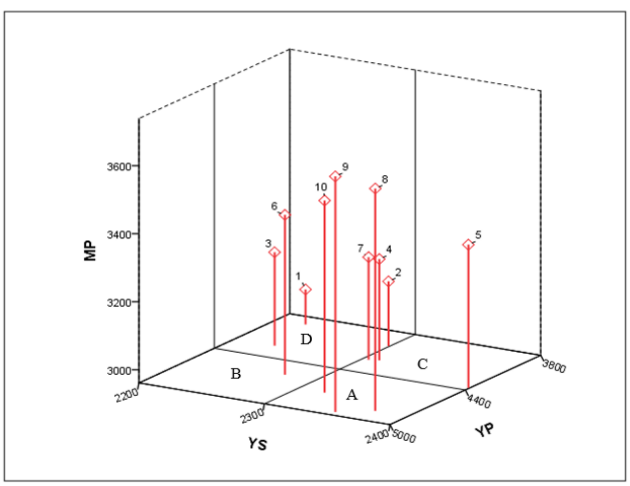


Figure 4. The 3D plot among MP, Ys and Yp



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