Original Research Article

Evaluating the Productivity of some Barely Genotypes under Deficient Water Application in Clayey Soils

ABSTRACT

A-field experiment was conducted to evaluate twenty barely genotypes according to their productivity and drought stress tolerance, water use efficiency (WUE) and water productivity (WP) under application of full irrigation (FI, rainfall + irrigation) and water stress (WS, sowing irrigation only + rainfall). The results showed that the values applied irrigation water were 3430 and 1995m^3/ha under WSunder FI, which were lower by 42%,compared toFI amount, average over the two seasons. The interaction between barley genotypesand irrigation revealed that plant height of line-7, spike length and number of grains/spike of line-6, number of spikes/m^2 of Giza133, and grain and biological yields of line-5 were the least affected by WS, compared with their values under FI. The highest values of WUE under WS were found for line-6 and line-11, which also attained the highest WPLine-8 and line-13 had the highest value of mean productivity, geometric mean productivity and stress tolerance indices. Furthermore, line-7 had the highest value of stress susceptibility index. Thus, based on WUE, WP and drought tolerance indices, it could be concluded that line-6, line-7, line-8, line-11and line-13 have the ability to withstand water stress and could be selected for breeding programs.

Key word:*Full irrigation, water stress, water use efficiency, water productivity, drought tolerance indices*

1. INTRODUCTION

Barley (Hordeumvulgare L.)ranked fourth in importantin cereal after wheat, rice and maize. In Egypt barely is one of the most important crops used in animal feed as well as by human for its nutritional value against degenerative diseases including diabetes, obesity, and colon inflammation. This is due to its rich dietary fibers, i.e., β-glucan composition, high source of phosphorus and potassium (Kumari& Kotecha [24]). It is also a good source of starch, minerals, vitamins, and protein (Farag et al. [12]).

Barely is considered as a resilient crop characterized by having tolerance to drought (Sánchez-Díaz et al. [34]) due to a more extensive root systems and its early development that permits drought escape (Kooyers [23]).Nevertheless,drought stress could have negative effects on barely, which is dependent on the exposed growth stage. Early drought could reduce seed germination, and seedling emergence (Srivastava [39]),as well as seedling growth (Hameed et al. [18]). Whereas, drought stress occurs during flowering reduces pollination and grain filling (Ceccarelli et al. [8]), which negatively affects two important components of barely grain yield, namely the number of grain per spike and grain weight (Sallam et al. [33]) and consequently it negatively affect final yield of barley (Al Ajlouniet al. [2]).

Plant breeding programs in Egypt have been successful in producing new barley cultivars having a high degree of drought tolerance under both mild and severe stress conditions. This suggests better description of crop biodiversity in order to understand their response to drought, as well as identify the physiological mechanisms that contribute in increasing itsproductivity(Almeselmaniet al. [5]).Zargar et al. [48]) reported that, study the effect of genotype and the interaction between genotype and environment are important in selection of stable genotypes.Istanbuliet al. [20]) reported that drought significantly affected most of the studied morpho-physiological traits resulting in strong

decreases in yield and the studied traits. In addition to genotypes with the most spikes, the highest 1000-grain weight, and biological yields achieved higher grain yields under water stress conditions.
Several drought tolerance indices have been studied to differentiate between low and high yielding cultivars under stress conditions, namely mean productivity, geometric mean productivity, stress tolerance indexandstress susceptibility index. Rosielle& Hamblin [32]) defined mean productivity as the average stress yield and non-stress yield. Karamiet al. [21]) and[Nazari &Pakniyat27])reported that mean productivity index, and geometric mean product index were the most suitable indices in define drought tolerance.Ramirez & Kelly [31]) indicated that geometric mean productivity is interested in the relative performance under various conditionsof drought stresses, where its severity can vary under field environment over years. Furthermore,Rosielle& Hamblin [32]) defined stress tolerance index as the differences in yield between the stress (Ys) and non-stress (Yp) environments. Stress tolerance index can be used to identify genotypes that produce high yield under both stress and non-stress conditions(Fernandez, [13]).Sio-Semardeh et al. [36]) indicated that stress tolerance index was more effective in identifying high yielding cultivars in both drought-stressed and irrigated cultivars.Another drought stress index was proposed by Fischer & Maurer [14]), namely stress susceptibility index (SSI) of the cultivar. Whereas, Guttieri et al. [17])usedanother droughtindex, namely stress susceptibility index (SSI), where it was suggested that higher value SSI than1.0 indicating above-average susceptibility and lower SSI value than 1.0 indicated below-average susceptibility to drought stress.
It follows, that the objectives of current work were a field assessmentof twenty barely genotypes under full irrigation and water stress to determine high-yielding genotypes under stress, with higher water use efficiency and water productivity.

2. MATERIALS & METHODS

A field experiment was carried out at Sakha Agricultural Research Station, Agricultural Research Center, KafrEl-Sheikh Governorate (Lat. 31° 06' 25.20" N, Long. 30° 56' 26.99" E, elevation above sea level 17 m),Egypt during 2018/19 and 2019/20 growing seasons.For each season, the tested entries were evaluated in two separate irrigation treatments using flood irrigation method. The first treatment included the normal irrigation (three times after planting irrigation), while the second one included planting irrigation only (water stress) in addition to the amount of rainfed. Average monthly weather data at the experimental site during the two growing seasons were obtained from https://power.larc.nasa.gov/data-access-viewer/.The values of metrological data in 2018/19 and 2019/20 are presented in Table (1). Furthermore, the valuesofmonthly reference evapotranspiration (ETo) was calculated using Penman-Monteith equation, as presented in the United Nations FAO organization by Allenet al. [4])(Table 1). This equation exists in The Basic Irrigation Scheduling model(BISm)(Snyderet al. [39]).

Table 1.Monthly means of weather data and ETo in 2018/19 and 2019/20 growing seasons in the experimental site.

Month	SR	Tmax	Tmin	WS	Tdew	RH	Rainfall	ETo
2018/19								
Dec	9.27	19.5	13.9	2.92	9.29	75.6	22.6	2.6
Jan	11.78	18.9	12.3	3.18	3.96	67.8	34.9	2.9
Feb	14.59	19.7	14.3	2.74	6.13	72.6	15.3	3.1
March	19.11	21.7	17.6	3.08	7.26	72.2	17.3	4.3
April	22.30	25.1	21.3	3.19	8.21	64.9	3.90	5.7
2019/20								
Dec	10.22	21.4	13.4	3.16	9.04	86.4	27.9	3.0
Jan	10.49	18.4	11.8	3.09	7.99	74.7	38.4	2.3
Feb	13.59	20.4	12.7	2.65	8.27	70.6	14.3	2.7
March	18.52	22.6	15.6	3.14	8.96	67.5	30.8	4.1
April	23.74	26.0	18.9	2.84	10.52	62.6	0	5.2

SR = solar radiation (MJ/m^2/day), Tmax, Tminand Tdew= maximum and minimum and dew point temperatures (°C), respectively, WS = wind speed (m/s), RH= relative humidity (%), rainfall=sum of rainfall (mm/month), ETo = reference evapotranspiration (mm/day).

Disturbed and undisturbed soil samples were collected from the top 60 cm of soil surface at 15 cm interval. Soil samples were analyzed to determine main chemical and physical soil properties. Chemical analysis was done according to Pageet al. [28]).The obtained values are presented in Table 2. According to Natural Resources Conservation Service (NRCS), Oregon State University, USA, the soil at the experimental site can be classified as saline soil where (EC > 4 dS/m, SAR < 13, ESP < 15% and soil pH < 8.5) (Hornecket al. [19]).

Table 2: Chemical soil properties of the experimental site before cultivation.

Soil depth (cm)	pH	EC dS/m	Soil SAR	Soil ESP (%)	Soluble cations (meq L^{-1})				Soluble anions (meq L^{-1})		
					Na^+	Ca^{++}	Mg^{++}	K^+	HCO_3	Cl^-	SO_4
0-15	7.93	4.89	10.92	12.93	33.30	7.80	10.80	0.90	4.50	25.00	23.30
15-30	8.21	5.26	11.32	13.37	35.80	8.40	11.60	0.90	5.00	26.60	25.00
30-45	8.20	5.35	11.41	13.47	36.43	8.75	11.80	1.00	4.83	27.27	25.49
45-60	8.46	5.91	12.00	14.12	40.20	9.50	13.00	1.20	5.50	30.20	28.10
Mean	-	5.35	11.41	13.47	36.43	8.61	11.80	1.00	4.96	27.27	25.47

*Note that: EC = ∑Cations * 10 = ∑Anions * 10*

Particle size distribution was determined according to Piper [29]), and soil moisture constants in the experimental site were determined according to Stackman [41]) and bulk density was calculated according to (Blak&Hartage, [6]) (Table 3).

Table 3.Soil physical properties and soil moisture constants of the experimental site before cultivation.

Soil depth (cm)	Particle size distribution (%)			Texture	Field capacity (%)	Wilting point (%)	Available water (%)	Bulk density (mg/m^3)
	Sand	Silt	Clay					
0-15	16.3	33.2	50.5	Clayey	42.80	22.86	19.94	1.18
15-30	14.4	33.9	51.7	Clayey	39.29	21.30	17.99	1.27
30-45	12.8	34.3	52.9	Clayey	38.00	20.21	17.79	1.32
45-60	13.5	34.8	51.7	Clayey	38.00	20.21	17.79	1.32

2.1. Plant materials and the experimental design

In randomized complete block design with three replicates, twenty barley genotypes were grown under two water application treatments (full irrigationand water stress). The planting date was December 10th in both growing seasons. Each genotype was sown in six rows of 3.5 m in length, and 20 cm among rows. The pedigree of the twenty barley genotypes is presented in Table (4).

Table 4.Name and pedigree of the studied twenty barely genotypes.

No	Genotypes	Pedigree
1	Giza 123	Giza117/FAO 86
2	Giza 133	Carbo/Gustoe
3	Line-1	Giza 121//ENCINO/TOCTE
4	Line-2	Giza 121//ENCINO/TOCTE
5	Line-3	Giza 121/7/Alanda/5/Aths/4/Pro/TolI//Cer*2/TolI/3/5106/6/ AwBlack/Aths// Arar/3/9Cr279-07/Roho
6	Line-4	Giza 123/4/Acsad 1180 /3/ Mari / Aths *2 // M-Att-73-337-1
7	Line-5	Giza 125//ENCINO/TOCTE
8	Line-6	Giza 126/6/Lignee527/NK1272//JLB70-63/5/ BKFMaguelone1604/3/Apro// Sv.02109/ Mari/4/Giza119
9	Line-7	C .C 89/4/Acsad 1180 /3/ Mari / Aths *2 // M-Att-73-337-1
10	Line-8	Rihane-03//Lignee527NK1272/5/Arizona5908/Aths//Avt/attiki /3/s.t/ Barley/4/Aths/ Lignee640/6/Giza 126
11	Line-9	Rihane-03//Lignee527NK1272/5/Arizona5908/Aths//Avt/ attiki/3/ s.t/ Barley/4/Aths/ Lignee 640/6/Alanda//Lignee 527/ Arar /5/Ager // Api / CM67/3/Cel/WI2269//Ore/4/Hamra-01
12	Line-10	Lignee527/NK1272/6/Cita'S'/4/Apm/Rl//Manker/3/Maswi/Bon/5/Copal'S'+Aths/Lignee 686 /5/Apm/RL/4/Api/EB489-8-2-15-4//por/ U.Sask1766/3/Cel/CI

13	Line-11	Giza 121/4/Arar//Hr/Nopal/3/Alanda -01/Alanda-01
14	Line-12	M64 - 76 / Bon // Jo / York /3/ M5/Galt // As 46 /4/Hj 34 - 80 / Astrix /5/ NK 1272/7/ Alanda/5/ Aths/4/Pro/TolI//Cer*2 /TolI/3/ 5106/6/Baca'S'/3/AC253 //CI08887/CI05761
15	Line-13	Giza 2000/4/CalMr/3/Alanda//Lignee527/Arar
16	Line-14	ACSAD 1182/4/ Arr/ ESP // Alger/ Ceres 362-1-1/3/ WI /5/Alanda/Hamra//Alanda-01
17	Line-15	Giza 126/4/Acsad 1180 /3/ Mari / Aths *2 // M-Att-73-337-1
18	Line-16	U.Sask.1766/Api//Cel/3/Weeah/4/Giza121/Pue
19	Line-17	Panniy/Salmas/5/Baca"s"/3/AC253//CI08887/CI05761/4/JLB70-01
20	Line-18	CABUYA/ESMERALDA

The effect of two irrigation treatments on the barley genotypes were studied, namely full irrigation (FI), where 120% ETo was timely applied with the total of five irrigation events and water stress treatment (WS), where plants were exposed only to rainfall throughout the growing season except for application of sowing irrigation. Seven agro-morphological parameters for barley were measured: plant height (cm),spike length (SL) (cm), number of grain/spike (No.G/spk), number of spike/m^2 (No.spk/m^2),1000-grain weight (g), grain yield (ton/ha), and biological yield (ton/ha).Harvest was done on April 30th in both growing seasons.

2.2. Water relations

2.2.1. Amount of applied irrigation water

The depth of applied irrigation water (AIW) to the experimental plots was calculated according to the following equation:

$$AIW = \frac{120\%\ EToXI}{Ea}$$

Where: AIW = depth of applied irrigation water (mm),ETo=reference evapotranspiration (mm/day), I = irrigation interval (days), Ea = application efficiency (fraction) = 0.6 for surface system at the site.

2.2.2. Effective rainfall (Re)

The depth of effective rainfall during growing season was calculated according the relation suggested by the U.S. Bureau of Reclamation (Smith [38]) giving as follows:

$$\begin{aligned} Peff &= Ptot(125 - 0.2\,Ptot)/125 \quad for\ Ptot < 250\,mm,\ and \\ Peff &= 125 + 0.1\,Ptot \quad for\ Ptot > 250\,mm \end{aligned}$$

Where:

Peff = effective rainfall (mm), andPtot = total rainfall (mm).

2.2.3. Water consumptive use (WCU)

Crop water use was estimated by the method of soil moisture depletion according to Majumdar [25]) as follows:

$$WCU = \sum_{i=1}^{i=4} \frac{\theta 2 - \theta 1}{100} \times Bdxd$$

Where: WCU= water consumptive use or crop evapotranspiration (mm), i= number of soil layer,θ2 = soil moisture content after irrigation, (%, by mass), θ1 = soil moisture content just before irrigation (%, by mass),Bd= soil bulk density (g/cm^3), d= depth of soil layer (mm).

2.2.4. Water use efficiency (WUE)

Water use efficiency for each barley genotype was calculated according to Stanhill [42])as:

$$WUE = \frac{Barleyyield\ (kg/ha)}{WCU\ (m3/ha)}$$

2.2.5. Crop water productivity (WP)

WP is defined as crop yield per unit of applied irrigation water, which determines the efficient use of applied irrigation water and is given as follows **(**Zhang [49]):

$$WP = \frac{Barleyyield\ (kg/ha)}{Appliedirrigationwater\ (m3/ha)}$$

2.2.6. Drought tolerance indices

To assess the tolerance of the studied barely genotypes to water stress, five drought tolerance indices were calculated using the following equations presented in Table (5).

Table5.**Stress tolerance indices used for the evaluation of barley genotypes to watertolerance.**

No.	Stress tolerance indices	Equation	Reference
1	Mean productivity	$MP = (Ys+Yp)/2$	Bouslama&chapaugh [7]
2	Geometric mea productivity	$GMP = \sqrt{Ys} \times Yp$	Sio-Se Mardeh et al. [36]
3	Tolerance index	$TOL = Yp - Ys$	Rosielle& Hamblin [32]
4	Stress tolerance index	$STI = Yp \times Ys/\bar{Y}p^2$	Fernandez [13]
5	Stress susceptibility index	$SSI = (1 - Ys/Yp)/(1 - \bar{Y}s/\bar{Y}p)$	Fischer & Maurer [14]

Where: Ys and Yp are the yields of genotypes under stress and non-stress conditions, respectively, $\bar{Y}s$ *and* $\bar{Y}p$ *are the mean yields of all genotypes under stress and non-stress conditions, respectively.*

2.3. Statistical analysis

The combined data of measured morphological characteristics from the two seasons were analyzed by the randomized complete block design with three replicates. All data were statistically analyzed by analysis of variance (ANOVA) published by Gomez & Gomez[15]). Means of the treatments were compared by the least significant difference (LSD) at 5% level of significance as developed by Waller & Duncan [44]). Combined analysis across the two irrigation treatments in the two seasons was performed when the assumption of errors homogeneity cannot be rejected according to Cochran [9]).

3. RESULTS & DISCUSSIONS

3.1. Applied irrigation water

The results in Table (6) indicated that the values of applied irrigation water under full irrigation were 3364 and 3495 m^3/ha in the first and second season, respectively and it were 1902 and 2087 m^3/ha for water stress treatments in the first and second season, respectively. Furthermore, the applied irrigation amount under full irrigation was higher by 44 and 40% than the applied water under water stress treatment, which provide highly stressful environment for barley genotypes to test their ability to withstand water deficiency. The results also showed thatfor water stress treatmentwaslower inthe second season, compared to the first season, due to differences in weather elements between the two seasons.

Table 6. **Applied irrigation amounts (m^3/ha) under full irrigation and water stress treatments to barely genotypes in the two growing seasons.**

Irrigation	Full irrigation (m^3/ha)		Water stress (m^3/ha)		
	First season	Second season	Irrigation + rainfall	First season	Second season
Sowing irrigation	962	973	Sowing irrigation	962	973
1st Irrigation	488	459	Rainfall (December)	226	279

2nd Irrigation	471	438	Rainfall (January)	349	384
3rd Irrigation	502	512	Rainfall (February)	153	143
Total amount of rainfall	940	1114	Rainfall (March)	173	308
-	-	-	Rainfall (April)	39	0
Total	3364	3495	Total	1902	2087

3.2. Analysis of variance

Combined analysis of variance for the studied traits ispresented in Table (7). Significant effects of seasons(S), irrigation treatments (T) and genotypes (G) ($p < 0.05$ or 0.01) were observed for all the studied traits.The mean square of irrigation treatments explained most of the total variations for all performance in 2018/19 and 2019/20 growing seasons. Mean squares due to seasons, irrigation treatmentsand genotypesinteraction were significant for all characters, except the interaction between S and T for plant height and number of spike/m^2, interaction between T and G for plant height, spike length and number of grains/spike, and interaction between S, T and G for plant height, spike length, number of grains/spike and 1000-grain weight.This suggests the importance of the evaluation of genotypes under low amount of irrigation in order to identify the best genetic makeup under low irrigation amount. Similar results were obtained by Tawfelis [43]).

Significant variations were detected due to interactions between genotypes and irrigation treatments for all performances. The variations due to genotypeswere higher than those of interactions between genotypes and irrigation treatments. The significance of genotypes variances for all performances under all conditions reflects the presence of sufficient genetic variability between these genotypes and provides the basis for genetic gain (Rajaram et al. [30]). Moreover, the significance of the interactions is a result of the different abilities of genotypes to adjust their performances to the low applied irrigation amounts and seasons, suggesting the importance of genotypes evaluation under different irrigation treatments to identify its tolerance to low application of water.

Table 7.**Analysis of variance for the studied traits under irrigation treatmentsfor the studied genotypes.**

SOV	df	Plant height(cm)	Spike length (cm)	No of grains/spike	No. of spikes/m^2	1000-grain weight (g)	Grain yeild (ton/ha)	Biological yeild (ton/ha)
Season (S)	1	1220.95**	9.16**	329.77**	8807.61**	65.29**	5.29**	101.75**
Treatments (T)	1	11818.87**	59.23**	2132.44**	183465.49**	187.63**	25.88**	262.56**
S x T	1	15.91	1.29**	46.42**	154.18	2.38**	0.4**	4.8**
Reps/S/T = Error (a)	8	21.23	0.06	1.16	102.75	0.10	0.01	0.08
Genotypes (G)	19	544.72**	12.9**	464.54**	31774.36**	27.67**	3.84**	37.7**
S x G	19	41.89*	0.44*	15.91*	426.7**	1.7**	0.15**	2.2**
T x G	19	26.99	0.26	9.39	2309.47**	3.87**	0.22**	3.38**
S x T x G	19	17.99	0.2	7.26	357.79*	0.59	0.08**	1.17**
Pooled error b	152	24.52	0.26	9.47	190.16	0.41	0.04	0.23
CV%		4.57	6.27	5.05	3.21	1.26	3.73	3.01

3.3. The effect of the interaction between seasons, irrigation treatmentsandgenotypes

Due to insignificant values for the S x T x G interactionfor plant height, spike length, number of grains/spike and 1000 grain weight (table 7) the results will be discussed as S x G interaction for these traits. Results in Table (8) showed that,the highest values were obtained for plant height from line 12 at first and second season (115.5 and 117.91cm, respectively),for spike length from line 8 in the first season and line 13 in the second season (9.15 and 10.0 cm, respectively),for number of grains/spike from line 8 in the first season and line 13 in the second season (66.90 and 71.99grain, respectively) and for 1000 grain weightfrom line 14 in the first season and line 6 in the second season (53.07 and 53.59g, respectively).

Table 8.**Mean performance of plant height, spike length,number of grains/spike and 1000 grain weightas affected by interactions among seasons and genotypes.**

Genotypes	Plant height (cm)		Spike length (cm)		No of grains/ spike		1000 grain weight (g)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Giza 123	99.50	106.60	7.77	8.12	58.60	60.72	49.43	50.51
Giza 133	88.50	92.15	6.15	6.36	48.90	50.17	51.00	51.34
Line-1	112.83	113.43	7.98	8.84	59.90	65.06	51.01	51.68
Line-2	105.83	109.80	7.78	8.29	58.70	61.73	50.56	50.76
Line-3	105.83	110.40	8.55	8.61	63.30	63.63	49.90	51.30
Line-4	111.67	115.56	7.82	8.55	58.90	63.29	48.03	49.52
Line-5	110.00	114.41	7.93	9.16	59.60	66.94	52.29	52.94
Line-6	108.17	116.54	9.02	8.68	66.10	64.09	53.01	53.59
Line-7	100.00	107.87	6.28	6.45	49.70	50.72	50.52	51.52
Line-8	109.83	115.41	9.15	9.31	66.90	67.86	50.94	52.40
Line-9	116.00	116.45	9.00	9.09	66.00	66.53	49.48	50.74
Line-10	92.00	96.62	6.70	7.01	52.20	54.04	45.91	48.46
Line-11	104.83	121.50	9.07	9.36	66.42	68.15	51.53	51.47
Line-12	115.50	117.91	8.48	8.62	62.90	63.73	49.55	51.10
Line-13	111.17	113.70	8.95	10.00	65.70	71.99	51.51	52.30
Line-14	102.67	108.76	5.78	6.68	46.70	52.07	53.07	53.43
Line-15	107.33	109.45	7.12	7.22	54.70	55.35	49.10	50.33
Line-16	109.50	110.18	9.02	9.20	66.10	67.22	47.17	49.99
Line-17	104.83	104.98	8.63	9.01	63.80	66.04	50.57	51.94
Line-18	105.83	110.36	7.98	8.43	59.90	62.58	51.36	51.45
Mean	106.09	110.60	7.96	8.35	59.75	62.10	50.30	51.34
LSD0.05	5.35	6.01	0.60	0.58	3.62	3.46	0.81	0.65
LSD0.05 S x G	5.68		0.59		3.54		0.73	

With respect to number of spikes/m^2, Table(9) indicated that,under full irrigation,the highest values were found for line-6, namely 566.00 and 573.96 in first and second season,respectively. While the lowest values were found for line-7, namely 364.00 and 372.76, in first and second season respectively. The highest values under water stress treatment were found for line-11, i.e. 517.33 and 526.85 in first and second season, respectively. While the lowest values were found for line-7, i.e.302.67 and 310.41 in the first and second season, respectively.

With respect to grain yield, Table (9) indicated that, under full irrigation, the highest values were found for line-6 and line-13, namely 6.51 and 6.85 ton/ha in first and second season, respectively. While the lowest values were found for line-2, namely 4.53 and 4.73 ton/ha, in first and second season, respectively. The highest values under water stress treatment were found for line-6, i.e. 5.79 and 6.42 ton/ha in the first and second season, respectively. While, the lowest values were found for line-7 and line-2, i.e.3.87 and 4.25 ton/ha in the first and second season, respectively.

Table 9.**Mean performance of number of spikes/m^2, grain and biological yield as affected by interactions among seasons, irrigation treatments and genotypes.**

Genotypes	No. of spikes/m2				Grain yield (ton/ha)				Biological yield (ton/ha)			
	2018/2019		2019/2020		2018/2019		2019/2020		2018/2019		2019/2020	
	FI	WS	FI	WS	FI	WS	FI	WS	FI	WS	FI	WS
Giza 123	412.67	384.00	423.63	390.39	4.84	4.35	4.99	4.73	14.31	12.75	15.42	15.04
Giza 133	428.00	410.00	427.15	420.00	5.10	4.46	5.36	4.86	15.70	13.54	15.95	14.19
Line-1	478.33	428.00	484.21	437.84	5.63	4.35	5.96	4.98	18.63	12.75	19.66	15.71
Line-2	421.33	398.00	437.97	400.21	4.53	4.10	4.73	4.25	13.79	13.33	16.24	14.12
Line-3	529.33	482.00	528.81	476.29	6.25	5.44	6.85	5.55	18.54	15.88	19.70	17.80
Line-4	377.33	362.67	394.81	364.96	4.75	3.96	4.76	4.39	13.94	11.33	14.66	13.65
Line-5	426.33	364.00	474.88	374.92	5.36	4.85	5.53	5.50	16.06	14.42	17.18	16.48
Line-6	566.00	480.00	573.96	494.73	6.51	5.79	6.71	6.42	19.88	18.38	21.22	19.90
Line-7	346.00	302.67	372.76	310.41	4.78	3.87	5.39	5.06	13.73	11.08	15.39	13.99

Line-8	411.33	362.67	413.35	366.88	4.72	4.04	5.04	4.54	13.67	11.83	14.87	13.94
Line-9	388.00	351.33	391.28	374.83	4.75	4.54	5.04	4.53	15.56	14.25	14.71	13.93
Line-10	492.00	354.67	508.19	447.43	5.08	4.67	5.36	4.79	15.73	14.42	16.87	16.02
Line-11	548.00	517.33	551.55	526.85	6.41	5.72	6.60	6.24	19.35	18.04	20.48	18.46
Line-12	482.00	445.33	494.25	452.22	5.53	4.94	5.40	4.76	16.75	14.58	17.76	13.97
Line-13	476.67	372.00	477.93	386.49	6.09	4.68	6.09	5.24	17.56	13.17	17.33	16.17
Line-14	442.00	332.00	454.25	355.43	5.28	4.75	5.35	4.73	15.73	13.50	17.21	14.07
Line-15	422.00	361.33	433.32	372.17	4.64	4.08	5.03	4.73	13.90	12.17	16.50	16.14
Line-16	470.00	411.33	474.27	426.16	5.98	4.72	6.18	5.43	19.15	14.75	19.41	15.61
Line-17	466.67	416.00	474.27	420.21	5.90	4.87	5.89	5.14	17.56	14.00	18.61	16.92
Line-18	465.33	376.00	468.75	387.28	5.58	4.77	5.78	4.64	16.55	14.42	17.31	14.18
Mean	452.47	395.57	462.98	409.29	5.39	4.65	5.60	5.03	16.30	13.93	17.32	15.51
LSD0.05	29.52	16.49	26.08	15.96	0.32	0.23	0.32	0.38	0.91	0.83	0.53	0.83
LSD0.05 S x T x G	22.25				0.31				0.77			

FI= full irrigation, WS= water stress.

The results inTable (9) also illustrate that, under full irrigation, the highest values of biological yield were found for line-6, namely 19.88 and 21.22 ton/hain the first and second season, respectively. While, the lowest values were found for line-8 and line-4, namely 13.67 and 14.66 ton/ha,in the first and second season, respectively.The highest values under water stress treatment were found forline-6, namely18.38 and 19.90 ton/ha, in the first and second season, respectively. Whereas, the lowest values were found for line-7 and line-4, i.e.11.08 and 13.65 ton/ha,inthe first and second season, respectively.

Yan & Kang [46]) showed that, both genotype effect and the interaction of genotype and environment must be examined simultaneously. Zargaret al. [48]) reported that, study the effect of genotype and the interaction between genotype and environment are important in selection of stable genotypes. Ali &Mansorr [3]) found that water stress caused a reduction in plant height, biological yield and grain yield components. Katerji [22])found that drought stress reduced the grain yield by 37% and straw yield by 18%. Istanbuli et al. [20]) reported that drought significantly affected most of the studied morpho-physiological traits resulting in strong decreases in yield and the studied traits. In addition to genotypes with the most spikes, the highest 1000-grain weight, and biological yields achieved higher grain yields under water stress conditions.

3.4. Barley genotypes and water relations

3.4.1. Water productivity and water use efficiency

Crop water productivity is a quantitative term used to define the relationship between crop produced and the amount of water involved in crop production(Zhang [49]).FAO[11])reported thatquantification of crop water productivity help in studying the impact of irrigation scheduling decisions, with regard to water management.The results in Table (10)showed that application of water stress treatment attained the highest water productivity values in both growing seasons due to lower barley yield by 14 and 10% average over all the genotypes in the first and second season, respectively under water stress treatment and lower amount of irrigation water by 44 and 40% in the first and second season, respectively.Similar result was observed by Goswami&Sarkar [16]), who stated thatlower water productivity exited under application of higher levels of irrigation amounts. Furthermore, the results also showed that the highest values of water productivity under water stress treatment were found forline-6 and line-11, where its values were3.04and 3.01kg/m^{3}in the first season, and were 3.08 and 2.99 kg/m^3 in the second season, respectively.

Table (10) also showed that application of water stress treatment resulted in higher values water use efficiency than its values under full irrigation. Five genotypes attained higher water use efficiency values than the rest of the studied genotypes, namely Giza133, line-3, line-5, line-6, and line-11, where the values were > 4.0 kg/m^{3}in the first season and were > 5.0 kg/m^3 in the second season.

Table 10.Water Productivity and water use efficiency of barley genotypes under full irrigation and water stress treatmentsin the two growing seasons.

Genotypes	Water productivity (kg/m^3)				Water use efficiency (kg/m^3)			
	First	Second	First	Second	First	Second	First	Second

	season	season	season	season	season	season	season	season
	Full irrigation		Low irrigation		Full irrigation		Low irrigation	
Giza 123	1.44	1.43	2.29	2.27	2.16	2.33	3.95	4.94
Giza 133	1.52	1.53	2.34	2.33	2.28	2.50	4.05	5.07
Line-1	1.67	1.71	2.29	2.39	2.51	2.79	3.95	5.20
Line-2	1.35	1.35	2.16	2.04	2.02	2.21	3.72	4.44
Line-3	1.86	1.96	2.86	2.66	2.79	3.20	4.94	5.79
Line-4	1.41	1.36	2.08	2.10	2.12	2.22	3.60	4.58
Line-5	1.59	1.58	2.55	2.64	2.39	2.58	4.41	5.74
Line-6	1.94	1.92	3.04	3.08	2.91	3.14	5.26	6.70
Line-7	1.42	1.54	2.03	2.42	2.13	2.52	3.51	5.28
Line-8	1.40	1.44	2.12	2.18	2.11	2.36	3.67	4.74
Line-9	1.41	1.44	2.39	2.17	2.12	2.36	4.12	4.73
Line-10	1.51	1.53	2.46	2.30	2.27	2.50	4.24	5.00
Line-11	1.91	1.89	3.01	2.99	2.86	3.08	5.20	6.51
Line-12	1.64	1.55	2.60	2.28	2.47	2.52	4.49	4.97
Line-13	1.81	1.74	2.46	2.51	2.72	2.85	4.25	5.47
Line-14	1.57	1.53	2.50	2.27	2.36	2.50	4.31	4.94
Line-15	1.38	1.44	2.15	2.27	2.07	2.35	3.71	4.94
Line-16	1.78	1.77	2.48	2.60	2.67	2.89	4.29	5.67
Line-17	1.75	1.69	2.56	2.46	2.63	2.75	4.42	5.37
Line-18	1.66	1.65	2.51	2.22	2.49	2.70	4.33	4.84

3.4.2. Drought tolerance indices for barley genotypes

Drought tolerance indices for the studied barley genotypes are presented in Table 11. The results indicated that the highest values of MP and GMP indices were found for line-8and line-13 in the first season, as well as line-5, line-8and line-13 in the second season, where its values were> 6.0. Similar results were obtained by Ahmadzadeh [1]). However, Shiraziet al. [35])criticize MP index and pointed out that it is expected to have high value of it under low irrigation water application, thus it cannot be used as a valid indicator to identify the tolerant genotypes.

Based on TOL index, the tolerance genotypes can be identified as line-3, line-15 and line-18 in the first seasons, where they have higher values between 1.26-1.42 in the first season, and 1.14-1.30 in the second season, compared to the values of the other studied genotypes. Whereas, in the second season, line-5 and line-20 have the highest values, namely 1.30 and 1.14. Zangi [47]) indicated that the low value of Ysorhigh value of Ypleads to an increase in TOLindex. Criticism of TOL index was reported bySio-Semardehet al. [36]) and Dorostkar [10]), asthey considered itnot worthy indexto screen drought tolerantgenotypes and stated that TOL failed to recognize the best genotypes, because it tends to select low-yielding genotypes.

Table 11.**Drought tolerance indicesfor the studied barley genotypes under full irrigated and water stress treatments in bothgrowing seasons.**

Genotypes	MP	GMP	TOL	STI	SSI	MP	GMP	TOL	STI	SSI
	First season					Second season				
Giza 123	4.60	4.59	0.50	0.32	0.69	4.86	4.86	0.26	0.31	0.49
Giza 133	4.78	4.77	0.64	0.33	0.85	5.11	5.10	0.50	0.33	0.87
Line-1	4.99	4.95	1.27	0.34	1.53	5.47	5.45	0.98	0.35	1.53
Line-2	4.32	4.31	0.44	0.30	0.65	4.49	4.48	0.48	0.29	0.95
Line-3	5.85	5.83	0.81	0.40	0.87	6.20	6.17	1.30	0.40	1.77
Line-4	4.36	4.34	0.79	0.30	1.12	4.58	4.57	0.37	0.29	0.72
Line-5	5.11	5.10	0.52	0.35	0.65	5.52	5.52	0.03	0.35	0.05
Line-6	6.15	6.14	0.72	0.42	0.74	6.56	6.56	0.29	0.42	0.41
Line-7	4.32	4.30	0.91	0.30	1.29	5.23	5.22	0.33	0.33	0.57
Line-8	4.38	4.36	0.68	0.30	0.97	4.79	4.78	0.50	0.31	0.93
Line-9	4.65	4.65	0.21	0.32	0.30	4.79	4.78	0.50	0.31	0.93

Line-10	4.88	4.87	0.42	0.33	0.56	5.08	5.07	0.57	0.32	1.00
Line-11	6.07	6.06	0.69	0.42	0.73	6.42	6.41	0.36	0.41	0.50
Line-12	5.24	5.23	0.59	0.36	0.72	5.08	5.07	0.64	0.32	1.10
Line-13	5.39	5.34	1.42	0.37	1.57	5.67	5.65	0.84	0.36	1.29
Line-14	5.02	5.01	0.53	0.34	0.68	5.04	5.03	0.62	0.32	1.09
Line-15	4.36	4.35	0.56	0.30	0.81	4.88	4.88	0.29	0.31	0.54
Line-16	5.35	5.31	1.26	0.37	1.42	5.80	5.79	0.74	0.37	1.12
Line-17	5.38	5.36	1.03	0.37	1.18	5.51	5.50	0.75	0.35	1.18
Line-18	5.17	5.16	0.81	0.35	0.98	5.21	5.17	1.14	0.33	1.84
Sum	100.34	100.07	14.78	6.88	0.93	106.26	106.11	11.49	6.78	0.96
Mean	5.02	5.00	0.74	0.34	0.93	5.31	5.31	0.57	0.34	0.96

MP= Mean productivity, GMP=Geometric mean productivity, TOL= Tolerance index, SSI= Stress susceptibility index, STI= Stress tolerance index.

Table 11 also showed that the studied genotypes that high values of MP and GMP indices tends to have higher value of STI index, namely line-8 and line-13 in the first season, as well as line-5, line-8 and line-13 in the second season, where its values were ≥ 0.4.Moghaddam& Hadizadeh [26]) reported that STI was more useful index to select the proper cultivars under drought stress.

Winter et al. [45]) reported that cultivars with low SSI values were considered as stress tolerant, as they exhibited a lower reduction in grain yield under low applied irrigation water amounts compared to application of full irrigation. The results in Table (11) indicated that line-7 and line-11 in the first season, as well as line-7 and line-8 in the second season showed the least values of SSI index, namely < 1.0. Guttieriet al. [17]) indicated that SSI value >1.0 refers to above-average susceptibility, whereas SSI <1.0 indicates below-average susceptibility to drought stress.

4. CONCLUSIONS

In this investigation, we tested twenty barley genotypes for its ability to tolerate imposed water stress by applying sowing irrigation only and the plants continued its growth seasons using rain fall. It was found that line-6 and line-11 could be selectedbased on its highest water productivity and use efficiency values. Furthermore, based on drought tolerance indices, line-7, line-8, and line-13 have the ability to withstand the imposed water stress and could be selected genotypes with high yield at both environments.

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