J. of Plant Production, Mansoura Univ., Vol. 13 (12) : 851 -859, 2022

Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Determination of Agro-Physiological Traits Related to Water Deficit Tolerance for some Soybean Genotypes

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ABSTRACT

Water deficit is the most important abiotic stress limiting soybean production. So find out new genotypes have high water use efficiency with high productivity became an urgent need. A field experiment was conducted during 2018 and 2019 summer seasons to evaluate the performance of six soybean genotypes (H4L4, Giza 83, H3L110, PI 416937, Giza 111 and H6L198) under three irrigation levels (100%, 85% and 70 % of soybean water requirements). Results revealed that, although the lowest seed yield was obtained from PI416937, it recorded the highest contents of relative water (RWC %) and proline along with the lowest and desirable values of leaf temperature and malondialdehyde (MDA) contents. PI416937 recorded the lowest reduction of seed yield under the two deficit irrigation levels (85 % and 70 %). On contrary H4L4 and H6L198 recorded the highest seed yields, chlorophyll pigments and productivity of irrigation water, and water productivity. While, Giza 83 and Giza 111 had the lowest relative water content (RWC), proline, chlorophyll pigments and the highest malondialdehyde (MDA) and seed yield reduction under 85 % and 70% levels respectively. It could be concluded that H4L4, H6L98 and H3L110 had moderate tolerant performance and suitable to cultivate under water deficit conditions (85 % with saving 15 % of water requirement) with yield reduction between 15 to 18 % of seed yield,while PI416937 was identified as a good tolerant genotype and it may be suitable to use in soybean breeding program.

Keywords: Soybean, water deficit, physiological, productivity of irrigation

INTRODUCTION

Due to its many uses, soybean [Glycine max (L.) Merr.] is the most important source of protein and oil in the world, where soybean seeds contain 40% protein, 20% oil, 35% carbohydrates, and 5% ash (Anna *et al.*, 2014), and its plants improve the soil fertility by fixing nitrogen with nitrogen-fixing bacteria.

In Egypt the demand for the edible soybean production has dramatically increased to reach more than four million ton from soybean seeds, oil and meal (USDA, 2022). Unfortunately, the national soybean production is far from the local requirements, which is covered through importation. So, the limited water resources make the horizontal expansion in soybean area is very limited. Therefore, in some circumstances, deficit irrigation became a must, in order to maximize the water use efficiency and water productivity. The most significant abiotic stress affecting soybean output globally is water scarcity, which alone causes around 40% of crop loss (Ceolin *et al.*, 2017 and Wei *et al.*, 2018). The soil water deficiency stress may reduce yield and yield components, resulting in a fundamental yield drop Sarkar *et al.*,(2015), Mimi *et al.*, (2016), and Wijewardana *et al.*, (2019). Water stress causes morphophysiological and biochemical responses that, restrict growth, and decreases chlorophyll content consequently photosynthesis reduces (Wijewardana *et al.*, 2019). As a result, it is important to use genotypes that could exploit available water and use it more efficient Basal (2017). The relative water content is a measure used for indicating drought stress tolerant (Dong *et al.*, 2019), which is decreased under water deficit stress (Hao *et al.*, 2013). Leaf temperature can be used to identify plant stress tolerance (Jones *et al.*, 2009, Costa *et al.*, 2013) where, the leaf temperature is increased with increasing water stress. The chlorophyll content may reflect the level of photosynthesis and could influence plant growth (Khaffagy *et al.*, 2022). A decrease in chlorophyll content was observed under water stress (Makbul *et al.*, 2011, Wijewardana *et al.*, 2019 and Basal *et al.*, 2020). Drought stress leads to the production of reactive oxygen species (ROS) such as $O2^-$ and H_2O_2, which induces membranes lipid peroxidation. Under water deficit stress the lipid peroxidation final product is malondialdehyde (MDA) which leads to membrane damage (Dong *et al.*, 2019 and Wu and Zhang 2019). Higher water stress tolerance was correlated with higher relative water content, higher proline accumulation, and less malondialdehyde accumulation in the leaf (Mutava *et al.*, 2015 and Sarkar *et al.*, 2015). Soybean requires a sufficient amount of water during the growth process to provide high yields (Buezo *et al.*, 2019). Understanding how crops react to water stress might help increasing yields even in water-stressed conditions by better water use efficiency (Wei *et al.*, 2018). García *et al.*, (2020) reported that increased production requires more effective water use, this demanded real-time data on soil, weather and plant conditions throughout the growth season. Drought stress could reduce soybean seed yield by 24-50% while increasing water usage efficiency He *et al.*, (2017). WUE is crucial for identifying plants that can tolerate water stress (Edwards *et al.*, 2012). Zhang *et al.*, (2017) reported that drought stress

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DOI: 10.21608/jpp.2022.173685.1186

affects badly soybean productivity but increases the water use efficiency.

Therefore the objectives of this work in the light of scarcity of water were to study the physiological, biochemical and agronomic criteria for water deficit tolerance of some soybean genotypes under two deficit irrigation levels to identify tolerant genotype.

MATERIALS AND METHODS

A field experiment was conducted during 2018 and 2019 summer seasons at Sakha Agricultural Research Station, Kafr El-Sheikh Governorate, Egypt, to study the response of six soybean genotypes to three irrigation treatments.

Plant materials

Six soybean genotypes were kindly provided by Food Legumes Research Department, FCRI, ARC, Egypt, to use in this research. The code, Pedigree, maturity group, growth type and origin of the studied soybean genotypes are presented in Table 1.

Soil characteristics of the experimental sites

The experiment's location is a representation of the Northern Nile Delta region's conditions. Soil samples from different depths were taken from the studied sites at every 20 up to 60 cm soil depth and some physical and chemical properties were analyzed and are presented in Tables 2 and 3, respectively. Also soil field capacity (F.C) of the experimental sites was determined at site. Available water and permanent wilting point (P.W.P) were determined according to James (1988) and soil bulk density was determined according to Klute, (1986). Chemical properties of the studied sites were determined according to Jackson, (1973).

Table 1. Pedigree, maturity group, growth type and origin of the tested soybean genotypes

No.	Genotype	Pedigree	Maturity group	Growth type*	Origin
G1	H4L4	DR 101 x Lamar	IV	I	FCRI*
G2	Giza 83	Selected from MBB-133-9Union x L 76-038 (Williams x PI 171451	III	I	FCRI*
G3	H3L110	DR 101 x PI 416937	V	D	FCRI*
G4	PI 416937	Exotic from Japan (drought tolerant)	V	D	Japan
G5	Giza 111	Crawford x Celest	IV	I	FCRI*
G6	H6L98	Toano x Nena	IV	I	FCRI*

***Field Crops Research Institute**
***D: Determinate, and I: Indeterminate**

Experimental design

The experiment was performed in a split plot design with three replicates. The three irrigation treatments, I_1(100%), I_2 (85 %) and I_3 (70 %) of soybean water requirements were allocated in the main plots, while, the six soybean genotypes were randomly assigned in the sub plots. The plot was consisted of five ridges 3 m long and 0.70 m apart. All genotypes were inoculated with the specific rhizobia directly before cultivation and other agricultural practices were applied as recommended to soybean fields in this region. The experiment was sown on 15th and 18th May and harvested on 2nd and 6th October in the two seasons respectively.

Table 2. Soil physical properties of the studied experimental sites in2018 and 2019 seasons

a -2018 season

Soil Depth, cm.	Particle Size Distribution Sand%	Silt %	Clay %	Texture Class	F.C %	P.W.P %	AW (%)	Bd, Mg/m³
0-20	14.6	22.6	62.8	Clay	45.2	24.6	20.6	1.23
20-40	20.4	21.3	58.3	Clay	40.6	22.1	18.5	1.21
40-60	22.1	20.7	57.2	Clay	38.8	21.1	17.7	1.17
mean	19.0	21.5	59.4	Clay	41.5	22.6	18.9	1.20

b -2019 season

Soil Depth, cm.	Particle Size Distribution Sand%	Silt %	Clay %	Texture Class	F.C %	P.W.P %	AW (%)	Bd, Mg/m³
0-20	15.1	23.2	61.7	Clay	44.9	24.4	20.5	1.22
20-40	22.4	21.4	56.2	Clay	40.0	21.7	18.3	1.21
40-60	28.8	20.2	51.0	Clay	38.2	20.7	17.5	1.19
mean	22.1	21.6	56.3	Clay	41.0	22.3	18.8	1.21

Where: F.C % = Soil field capacity, P.W.P % = Permanent wilting point, AW % = Available water and Bd, Mg/m³ = Soil bulk density.

Table 3. Soil chemical properties of the studied experimental sites in 2018 and 2019 seasons

a- 2018 season

Soil Depth, cm	EC dS m^{-1}	PH (1: 2.5) soil water suspension	Soluble ions (meq/l) Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0-20	3.57	8.25	11.7	6.5	16.9	0.26	0.00	4.7	14.0	16.67
20-40	3.91	8.16	12.5	8.3	17.8	0.28	0.00	4.5	14.8	19.58
40-60	4.01	8.13	14.4	9.8	19.7	0.31	0.00	4.4	15.3	24.51
Mean	3.83	-------	12.9	8.2	18.1	0.28	0.00	4.5	14.7	20.25

b- 2019 season

Soil Depth, cm	EC dS m^{-1}	PH (1: 2.5) soil watersuspension	Soluble ions (meq/l) Ca^{++}	Mg^{++}	Na^{+}	K^{+}	CO_3^{--}	HCO_3^{-}	Cl^{-}	SO_4^{--}
0-20	3.52	8.26	11.4	6.3	17.1	0.28	0.00	4.8	13.9	16.40
20-40	3.87	8.15	12.1	7.9	17.9	0.30	0.00	4.3	14.5	19.40
40-60	4.10	8.11	14.7	10.5	20.3	0.33	0.00	4.1	15.6	26.13
Mean	3.79	-------	12.7	8.2	18.4	0.30	0.00	4.4	14.7	20.64

So_4^{--} was calculated by the difference between soluble cations (meq/ L) and anions (meq/ L).

Applied irrigation water (IW, m^3 fed^{-1})

A flow meter was fixed in the irrigation pump's water delivery unit and was used to regulate and measure the amount of irrigation water applied. 100 % of soybean water irrigation requirement were calculated by irrigating plants to attain the field capacity plus 10 % as a leaching factor. The other treatments (85 and 70 %) were calculated based on the amount of 100 % treatment (Fig 1)

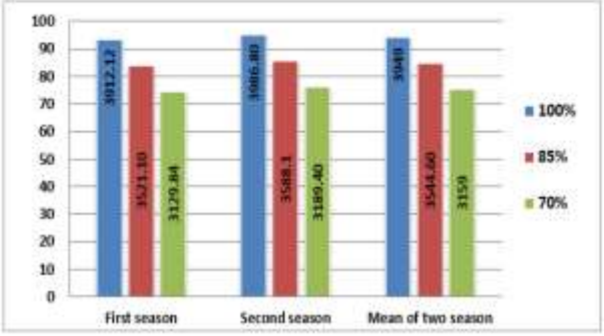

Figure 1. Amount of irrigation water (I W m3 fed^{-1}) applied to the three irrigation treatments (100, 85, 70 %) of soybean water requirements during 2018 and 2019 seasons.

Soil moisture depletion

According to Hansen *et al.*, (1979) soil moisture depletion which is considered as the actual water consumed by the crop using the following equation.

$$Cu = \frac{\Theta_2 - \Theta_1}{100} * Db * d * A$$

Where:

CU = Actual water consumptive use by the growing plants
ϴ2 = Average soil moisture percentage 48 hours after irrigation
ϴ1= Average percentage of soil wetness before the next irrigation,
Db = Average soil bulk density (Mg m^{-3}) of 60 cm soil depth,
d = Soil wetting depth i.e. effective root depth of 60 cm and
A =Irrigated area, m^2.

Physiological and biochemical determinations

Fully developed leaves from the top of ten plants from each plot were randomly taken at flowering stage (65 day after sowing) to determine physiological and biochemical characteristics

Chlorophyll a, b and total chlorophyll (chl. a ,b total chl µg ml^{-1}) using the equation of Moran (1982) as follows:

$$Chl\ a = 12.64\ A_{664} - 2.99 A_{647}$$
$$Chl\ b = -5.6\ A_{664} + 23.26\ A_{647}$$
$$Total\ chl = 7.04\ A_{664} + 20.27\ A_{647}$$

Relative water content (RWC %) was determined according to Gonzalez and Gonzalez (2001), Leaf temperature (◦c) was measured using porometer (L1-COR Model L1 1600) in the field. Proline content (mg g^{-1} FW.) was determined according to Bates *et al.*, (1973), and malondialdehyde (MDA), the amount of lipid peroxidation found in the cell malondialdehyde (MDA) content was determined according to Change *et al.*,(2015)

Agronomic traits

At harvest, ten plants were randomly taken to determine number of pods $plant^{-1}$ and number of seed pod^{-1}.

Seed yield (t fed^{-1}) plants of the central three ridges of each plot were harvested, weighted and converted to t fed^{-1}. A seed samples from each plot were randomly taken, 100 seed were counted and weighted to determine 100-seed weight (g).

Stress susceptibility index (SSI) was estimated according to Fischer and Maurer (1978) as:

$$SSI = (1 - Yd / Yp) / D.$$

Where: **Yd = mean yield under water deficit levels conditions, Yp= mean yield under normal conditions, D = water stress intensity = 1 - (mean Yd of all genotypes / mean Yp of all genotypes).**

Phenotypic variation among soybean genotypes

Hierarchical Cluster analysis was done using a computer software program Minitab v.19.

Productivity of irrigation water (PIW, kgm^{-3})

Productivity of irrigation water (kg m^{-3}) (Ali *et al.*, 2007) were calculated using the equation

$$PIW = Y / IW$$

Where:

Y = yield in kg fed^{-1}
IW = irrigation water applied ($m^3 fed^{-1}$.).

Water productivity (WP): it defined as crop yield per each unit of water consumption (Ali *et al.* 2007) and calculated using the equation

$$WP = \frac{Y}{CU}$$

Where:

Y = Yield (kg)
CU = Water used by the crop during growth season (m^3).

Statistical analysis

Data was statistically analyzed according to Gomez and Gomez (1984) using analysis of variance technique by means of "MSTAT-C"computer software package. Means of treatment were compared by Duncan's Multiple Range Test (Duncan 1955).

RESULTS AND DISCUSSION

Physiological and biochemical traits

Presented data in Table 4, show that chl. a, chl b and total chlorophyll were significantly reduced under reduced water deficit conditions (85% and 70%) compared to control treatment (100 %) of water requirements for all studied genotypes in the two studied seasons. These results are in harmony with those of Basal (2017), Wijewardana *et al.*, (2019) and Wu and Zhang, (2019).Where they reported that chlorophyll is an essential component of plant pigment-protein complexes and it is pivotal for photosynthesis process, water shortage stress causes a decrease in chlorophylls as a result of oxidative stress, which is related to chlorophyll degradation and inadequate chlorophyll synthesis; this decrease is regarded as the primary reason of reduced photosynthesis during drought stress.

Data in Table 4 also indicate that, among the six soybean genotypes H4L4 and H6L198 recorded the highest concentrations of chlorophyll a, b and total chlorophyll during the two seasons, while PI 416937 gave the lowest values and ranked last.

As can be seen in Table 5, the leaf relative water content (RWC %) was strongly affected by water deficit stress, where the highest values (59.63 and 57.60) were recorded by irrigating plants with I_1(100 %) in the two seasons respectively while decreasing the amount of irrigation water to 85 % or 70 % caused insignificant decrease in the content of water in the leaves for all genotypes in the first and second seasons. These results agree with Hao *et al.*, (2013) Basal, (2017), Chowdhury *et al.*, (2017), Verslues *et al.*, (2006) and

Sarkar *et al*., (2015). Where they reported that the reduction in leaf water content was occurred due to soil water deficiency and the plant water status has a direct impact on the metabolic process in plant, consequently affects plant growth.

Table 4. Chl. a ($\mu g\ ml^{-1}$), Chl. b ($\mu g\ ml^{-1}$) and total chlorophyll as affected by irrigation treatments and soybean genotypes in 2018 and 2019 seasons

Irrigation treatment (I)	Chl. A ($\mu g\ ml^{-1}$) 2018	Chl. A ($\mu g\ ml^{-1}$) 2019	Chl. B ($\mu g\ ml^{-1}$) 2018	Chl. B ($\mu g\ ml^{-1}$) 2019	Total chl. ($\mu g\ ml^{-1}$) 2018	Total chl. ($\mu g\ ml^{-1}$) 2019
I_1 (100%)	12.06a	11.61a	4.22a	4.18a	16.07a	15.80a
I_2 (85 %)	11.14b	10.91b	3.53b	3.46b	14.61b	14.38b
I_3 (70 %)	10.24c	10.08c	2.92c	2.85c	13.16c	12.94c
F- test	**	**	**	**	**	**
Genotype						
H4L4	12.71a	11.78a	3.96a	3.84a	16.34a	15.62a
Giza 83	11.18c	10.38bc	3.26ab	3.10c	14.32b	13.48b
H3L110	10.28d	10.61bc	3.25ab	3.39bc	13.42d	14.00b
PI 416937	10.22d	10.00c	3.16 b	3.32bc	14.09bc	13.79b
Giza 111	10.45d	10.83b	3.87ab	3.79 a	13.61cd	14.16b
H6L198	12.05b	11.62a	3.85ab	3.56ab	15.90a	15.18a
F- test	**	**	**	**	**	**

*** and ** indicate $P<0.05$ and $P<0.01$, respectively. Means within the same column for each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.**

Table 5. RWC %, leaf temperature, proline and MDA contents as affected by three irrigation treatments and six soybean genotypes in 2018 and 2019 seasons

Irrigation treatment	RWC (%) 2018	RWC (%) 2019	Leaf temperature (ºc) 2018	Leaf temperature (ºc) 2019	Proline mg g^{-1} FW. 2018	MDA nmol g^{-1}FW. 2019	2018	2019
I_1 (100%)	59.63a	57.60a	28.77b	30.03b	0.145c	0.247c	0.335c	0.545c
I_2 (85%)	57.39b	56.40a	29.43a	30.51ab	0.293b	0.304b	0.544b	0.755b
I_3 (70%)	54.64c	52.28b	29.87a	30.94a	0.375a	0.404a	0.962a	1.259a
F- test	**	**	**	*	**	**	**	**
Genotype								
H4L4	60.69a	56.67b	29.11cd	30.33bc	0.282b	0.321b	0.531b	0.807cd
Giza 83	54.68c	52.88e	29.62a	30.79a	0.236c	0.283c	0.735a	0.992a
H3L110	56.73b	55.56bc	29.51ab	30.50a-c	0.248c	0.298bc	0.678a	0.920ab
PI 416937	61.29a	59.39a	28.94d	30.23c	0.336a	0.387a	0.511b	0.745d
Giza 111	54.04c	53.55de	29.69a	30.63ab	0.256bc	0.308bc	0.682a	0.848bc
H6L198	57.08b	54.51cd	29.26bc	30.49a-c	0.267bc	0.315bc	0.546b	0.808cd
F- test	*	**	*	**	*	*	**	**
IxG	NS	NS	NS	NS	**	**	**	**

*** and ** indicate $P<0.05$ and $P<0.01$, respectively. Means within the same column for each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.**

Concerning genotypes, results in Table 5 show significant differences existed among the six soybean genotypes, where PI 416937 gave the highest percent of RWC (61.29 and 59.39 %) followed by H4 L4 (60.69 and 56.67 %) in both seasons respectively, while the lowest one was obtained from Giza111 (54.04 and 53.55%) and Giza83 (54.68 and 52.88%) in both seasons respectively.

Dong *et al.,* (2019) reported that the relative water content is used as a parameter for indicating drought stress tolerance. Chowdhury *et al.,* (20017) reported also that understanding the influence of water stress on leaf water relations is important for classifying the drought tolerance of a genotype. In the same manner, Mutava *et al*., (2015) and Basal (2017) reported that the decrease in relative water content is more for sensitive genotypes compared to the tolerance one.

On contrary, leaf temperature and MDA content (lipid peroxidation) were increased for all studied genotypes with decreasing the amount of irrigation water, where the lowest values of leaf temperature (28.77 and 30.03 ºc) and MDA (0.335 and 0.545nmol g^{-1} F wt.) were obtained from I_1 (control treatment) and increased in I_2 treatment while I_3(70 %) recorded the highest values of both leaf temperature (29.87 and 30.94ºc) and MDA content (0.962 and 1.259 nmol g^{-1} Fwt.) in the two seasons respectively. These results are in harmony with those of Jones *et al.,* (2009), Costa *et al.,* (2013), Dong *et al.,* (2019) and Wu and Zhang (2019). The soybean genotype PI416937gave the lowest values of both leaf temperature (28.94 and 30.23ºc) and MDA (0.511 and 0.745nmol g^{-1} F wt.) in 2018 and 2019 seasons respectively, followed by H4L4 and H6L198. It was reported that, the increase in leaf temperature due to water deficit stress might be attributed to the low transpiration under water deficit stress (Chowdhury *et al*., 2017), while the increase of MDA content under water stress may be due to the accumulating of reactive oxygen species (ROS) in plants in a large number caused in membrane lipid peroxidation, which leads to membrane damage and final product to this process is malondialdehyde (MDA). The level of MDA content can reflect the degree of membrane damage and that used as a tool for indicating water stress tolerance (Yang *et al*., 2003 and Dong *et al.,* 2019), so it's clear that the lowest value of MDA is desirable and reflect the ability of the genotype to tolerate water deficit stress.

Results in Figure. 2 (A and B) revealed that the highest and undesirable values of MDA were obtained at the third irrigation treatment I_3 (70%) for both Giza 83 (1.05and 1.40 nmol g^{-1} FW) and Giza 111 (0.977and 1.007nmol g^{-1} FW).) While control treatment (100%) recorded the lowest and the desirable value for genotype PI 416937 (0.368 and 0.506 nmol g^{-1} FW).) in 2018 and 2019 respectively. Regarding proline content, data demonstrated that proline was increased in plants which irrigated with 85% and 70% compared to plants irrigated with 100 % (control treatment). It is evident that proline accumulates with increased water stress Mwenye*et al*., 2016, proline accumulation is one of the mechanisms of crop tolerance to water stress (Sarkar *et* *al.*,2015). Soybean genotypes differed in their proline content under water deficit. The highest proline content was obtained from genotype PI 416937 (0.386 and 0.387), followed by H4L4 (0.282 and0.321mg g^{-1} FW) and H6L198 (0.267 and 0.315 mg g^{-1} FW) in the first and second seasons respectively, and the lowest were found in Giza 83 (0.236 and 0.283 mg g^{-1} FW) in the two seasons respectively. There is a positive correlation between proline accumulated in stressed plants and drought tolerance (Ashraf and Foolad 2007 and Mwenye *et al.,* 2016).

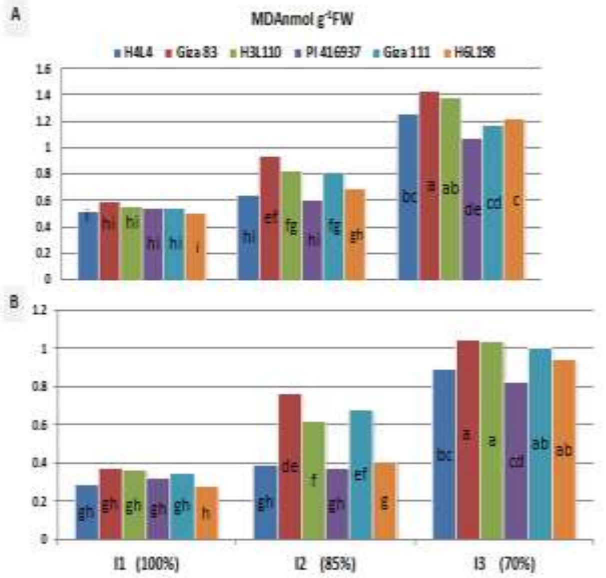

Figure 2(A and B). MDA content as affected by the interaction between irrigation treatments (100%, 85% and 70%) and six soybean genotypes in 2018 and 2019 respectively.

As shown in Fig.3 (A and B) the highest proline contents were recorded from PI 416937 irrigated with 70 % of soybean water requirements (0.406 and 0.451 mg g^{-1}FW.) in 2018 and 2019 seasons respectively.

Agronomic traits

Data in Table 6 show the mean values of agronomic traits (number of pods plant^{-1}, number of seed pod^{-1}, 100-seed (g) wt. and seed yield t fed^{-1}) as affected by three irrigation levels and six soybean genotypes. Results show that all agronomic traits were significantly affected by decreasing the amount of irrigation water, where treatment I$_1$ recorded the highest values of all agronomic traits and differed significantly from the other two irrigation levels (I$_2$ and I$_3$), while I$_3$ recorded the lowest values and ranked last for all traits. The highest soybean seed yields (1.56 and 1.43 t / fed) were obtained under the full irrigation water requirements(I$_1$) as shown in Table 6, while applying 85 and 70 % of the full requirement significantly decreased the seed yield per fad. In this aspect it was reported that water stress during flower formation led to a shorter flowering period and produced fewer flowers and, fewer pods, consequently, small number of seeds plant^{-1} (Basal 2017). Reduced seed number plant^{-1} under water stress was reported by Li *et al.,* (2013). The decrease in seed weight under water stress could be due to the loss of assimilate to seeds (Yordanov *et al.,* 2003), as a result of the decrease of chlorophyll content reduction in the photosynthetic rate and the short seed filling period consequently reduction in the final seed yield (Demirtas *et al.,* 2010).

The decrease in all agronomic traits as a result to water stress were reported previously by Sadeghipour and Abbasi (2012) and Mimi *et al*.,(2016), and García *et al*., (2020).

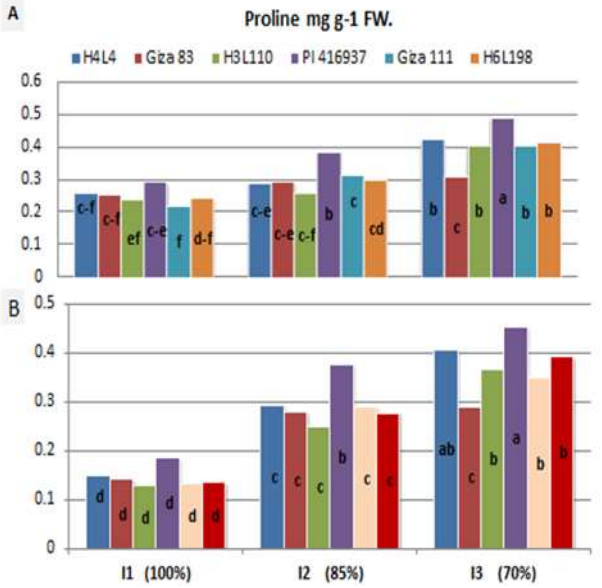

Figure 3 (A and B). Proline content as affected by the interaction between irrigation treatments (100%, 85% and 70%) and six genotypes in 2018 and 2019 respectively

Table 6. Number of pods plant^{-1}, number of seeds pod^{-1}, 100 seed wt. and seed yield t fed^{-1} as affected by irrigation treatments and soybean genotypes in 2018 and 2019 seasons.

Irrigation treatment (I)	Number of pods plant^{-1} 2018	Number of pods plant^{-1} 2019	Number of seed pod^{-1} 2018	Number of seed pod^{-1} 2019	100-seed weight (g) 2018	100-seed weight (g) 2019	Seed yield (t fed^{-1}) 2018	Seed yield (t fed^{-1}) 2019
I$_1$ (100%)	142.33a	140.1a	2.95a	3.04a	19.36a	18.83a	1.56a	1.43a
I$_2$ (85 %)	135.46b	133.1b	2.82b	2.79b	19.02a	18.22a	1.30ab	1.17ab
I$_3$ (70 %)	128.09c	125.7c	2.68c	2.72b	17.11b	16.39b	1.04b	0.92b
F test	**	**	**	**	**	**	**	**
Genotype(G)								
H4L4	138.99a	136.88a	2.84	2.92	19.39ab	18.47ab	1.68a	1.65a
Giza 83	132.58bc	131.27b	2.80	2.81	18.11b	17.09b	0.95bc	0.98cd
H3L110	135.93ab	134.24ab	2.83	2.84	19.17ab	18.16ab	1.30ab	1.17bc
PI 416937	129.38c	126.95c	2.76	2.77	16.31c	15.31c	0.860c	0.750d
Giza 111	136.00bc	133.62b	2.81	2.86	19.98a	19.91a	1.28ab	1.14b-d
H6L198	138.90a	134.82ab	2.85	2.89	18.00b	17.94b	1.56a	1.51ab
F test	**	**	NS	NS	**	**	**	**
I x G	**	**	NS	NS	NS	NS	**	**

*** and ** indicate P<0.05 and P<0.01, respectively. Means within the same column for each factor designated by the same letter are not significantly different at 5% level according to Duncan's Multiple Range Test.**

Concerning the differences among genotypes, data in Table 6 demonstrated that H4L4 produced the highest seed yields (1.68 and 1.65 t /fed.) in the two growing seasons respectively, followed by H6 L198 which recorded 1.56 and 1.51 t /fed. With no significant differences, while the lowest seed yields(0.86 and0.75 t /fed) were obtained from PI 416937 with slight differences from Giza 83(0.95 and 0.98 t / fed.) Giza 111 and H3L110 soybean genotypes were medium in seed yield potential among studied soybean genotypes. The superiority of H4L4 and H6L198 in seed yield per fad could be related to the high number of pods per plant and seeds per pod along with the heaviest seed weight. In the same time both genotypes recorded the highest RWC %, and chlorophyll pigments (a and b), which are considered the main factors for high efficiency of the photosynthetic process and the increase transported assimilation to the seed and that led to increase seed weight. In addition, the high content of proline and the low content of MDA in these genotypes made them able to cope with water stress and reduced its inferior effects on all physiological and biochemical processes in soybean plants.

Data illustrated in Figure 4 show that the highest seed yields fed-1were obtained from H4L4 followed by H6L198 under full irrigation I1 in both seasons. also the two genotypes H4L4 and H6L198 superior other genotypes and ranked first under water deficit conditions (85 and 70 %) followed by H3L110 , while Giza 83 and PI416937 recorded the lowest yields under the three irrigation treatments in the two seasons.

Stress susceptibility index

Data presented in Table 7 show that although the genotype PI 416937 was the lowest in seed yield per faddan, it recorded the lowest values of seed yield reduction and stress susceptibility index (SSI)under the two deficit irrigation levels. These results indicate that, PI 416937 is the most tolerant genotype to water stress. It was reported that, the high value of SSI characterize quite the more sensitive genotype to water deficit stress (Bouslama and Schapaugh(1984). On the other hand the two cultivars Giza83 and Giza 111, which had the highest values of SSI and seed yield reduction under deficit irrigation are the most sensitive genotypes to water deficit. Therefor the SSI and the reduction in seed yield values were found to be more useful indices for discriminating water stress tolerant and sensitive genotypes. These results agreed with the findings of those obtained by Mariey and Khder 2017). The two promising genotypes H4L4 and H6L198 recorded moderate values for seed yield reduction and SSI under deficit irrigation , which indicate that both genotypes are moderately tolerant to water deficit along with their high yield potentiality.

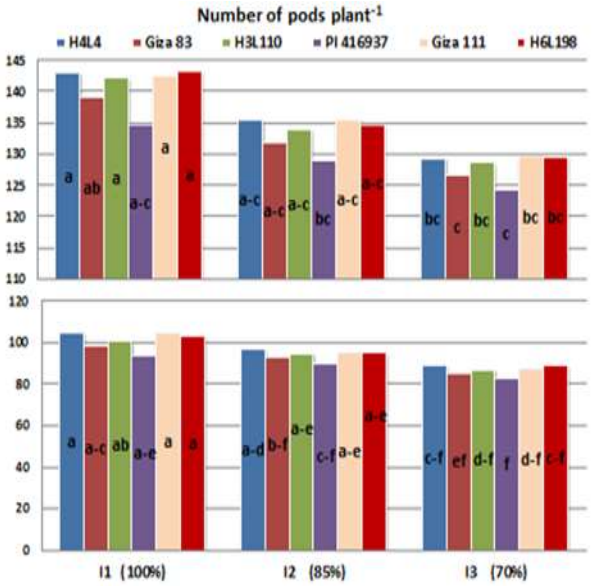

Figure 4(A and B). seed yield t fed^{-1} as affected by the interaction between irrigation treatments (100%, 85% and 70%) and six genotypes in 2018 (Fig. A) and 2019(Fig. B)

Table 7. Stress susceptibility index (SSI) of some soybean genotypes under deficit irrigation in 2018 and 2019 seasons

Genotype	2018				2019			
	R% I_2	R % I_3	SSI I_2	SSI I_3	R% I_2	R % I_3	SSI I_2	SSI I_3
H4L4	17.229	35.506	0.949	0.991	17.464	38.995	0.899	1.275
Giza 83	24.457	45.471	1.347	1.269	28.717	49.287	1.479	1.612
H3L110	21.287	36.304	1.173	1.013	21.127	36.620	1.088	1.198
PI416937	6.780	16.667	0.373	0.465	2.000	12.333	0.103	0.403
Giza 111	24.091	47.273	1.327	1.319	22.174	38.406	1.142	1.256
H6L98	12.166	27.674	0.670	0.772	18.478	29.348	0.951	0.960

R% reduction percentage compared with control treatment (I_1) and SSI stress susceptibility index

Phenotypic variation among soybean genotypes

Hierarchical Cluster analysis was used to classify the genotypes based on average of all the studied characters. In this study, the hierarchical cluster analysis was construct a distance matrix using the Euclidian coefficient average linkage method are graphically illustrated in dendrogram showing similarity among all the genotypes (Fig 5). The six soybean genotypes divided into two groups. The first group include only the tolerant genotype PI416937 which is the highest in most studied traits and had the lowest yield reduction. The second group divided in two sub groups, the first sub group include the moderate sensitive genotypes Giza83and Giza 111. The other sub-group include the three genotypes H4L4, H6L198 and H3L110, which had moderate tolerant performance for most traits. These results are in a good harmony with Mariey and Khedr (2017) who used cluster analysis for grouping genotypes based on their morphological and physiological traits.

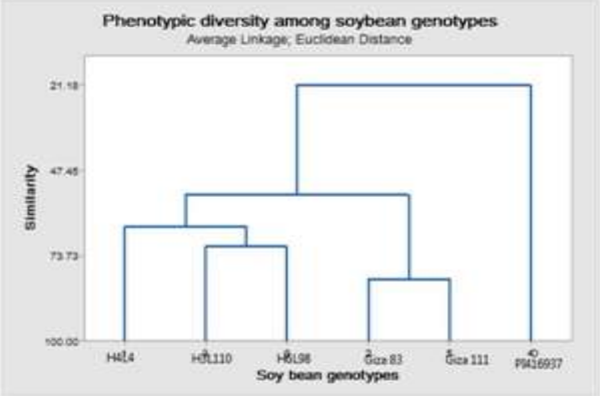

Figure 5. Dendrogram describing genetic relationships among six soybean genotypes based on their physiological traits and yield under three irrigation levels conditions

Irrigation water and water consumptive use for some soybean genotypes

Presented data in Fig. 6 indicate that the crop consumptive use (CU) was 2019 growing season was higher than 2018 season, which resulted from increasing air temperature and evapotranspiration rate. In the same study, the 100% water level treatment I_1 (traditional irrigation), had the highest amount of total IW and seasonal CU values. Regarding the influence of genotypes CU decreased with increasing sensitive genotypes to this lack of water and the ability of the genotype to withstand a shortage of water. The highest mean values are under genotypes H4L4 and H6L198 for seasonal CU, while the lowest mean values are under Giza 83 and PI 416937 in the two seasons, respectively (Fig.7).

Generally, the amount of CU can be ascended in order $I_3 < I_2 < I_1$ under water level treatments, while soybean genotypes can be ascended in order PI 416937 < Giza 83 < H3L110 < Giza 111 < H6L198 < H4L4, respectively. But Giza83 was lower than PI416937 under I_3 may be caused ability of the genotype tolerates water deficit. The obtained results are in agreement with those obtained by Buezo *et al.* (2019).

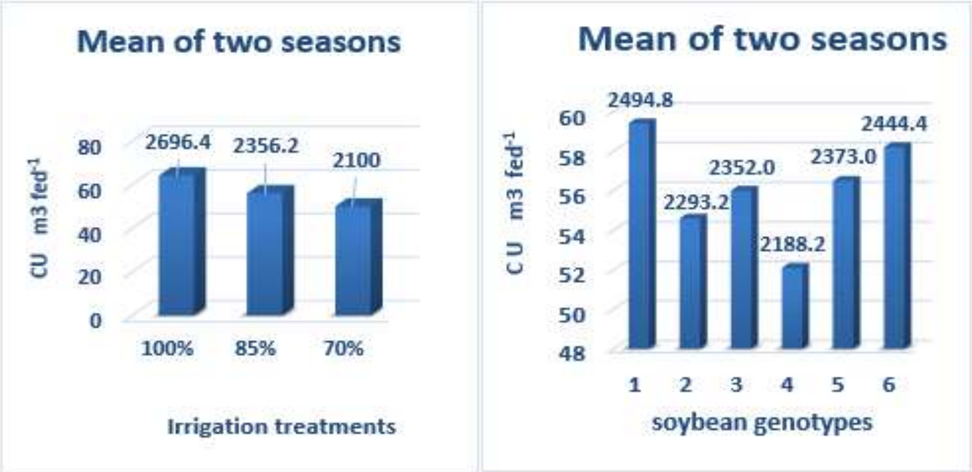

Figure 6. Effect of irrigation water treatments and soybean genotypes on seasonal crop consumptive use (CU, m3/ fed) over the two growing seasons

Some water-yield relationships:

Presented data in Figures (7and 8) indicated that Productivity of irrigation water (PIW) and water Productivity (WP).

Figure 7. Effect of irrigation treatments and soybean genotypes on productivity of irrigation water (PIW, kg m^{-3}) over the two growing seasons

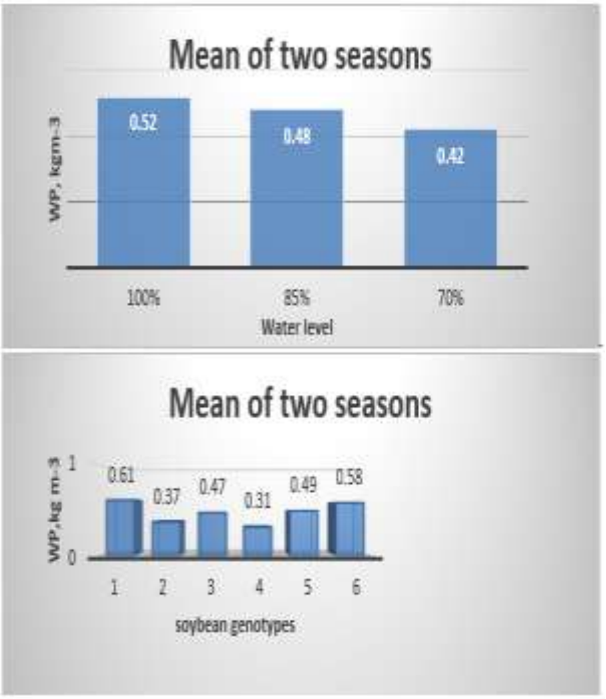

Figure 8. Effect of irrigation treatments and soybean genotypes on water productivity (WP, kg m^{-3}) over the two growing seasons

In this study, PIW and WP values under I1 treatment is higher than the other treatments (I2and I3). Productivity of irrigation water (PIW) was affected by the irrigation levels and sensitive of soybean genotypes to water deficit on yield. The highest mean values of PIW andWP are recorded under I1in the two growing seasons are 0.36 and 0.52 kg m-3 respectively, while the lowest mean values are under I3treatment of 0.29 and 0.42 kg m-3 respectively. Meanwhile, under soybean genotypes, the highest values were recorded under I1 treatment of 0.44 and 0.61kg m-3 (PIW and WP), respectively. Generally, the over mean values for PIW and WP under water level and soybean genotypes can be ascended in order I3< I2< I1and PI 416937 <Giza 83 < H3L110 < Giza 111 <H6L198 < H4L4 in the two seasons. Increasing the mean values of PIW and WP for I1 and H6L198 in comparison with other treatments in the two growing seasons may be due to increasing soybean yield resulted from plants which were not exposed to water deficit conditions, while H6L198 variety soybean is the least affected by the lack of water because of its ability to withstand water shortage. The obtained results are in agreement with those obtained by He et al. (2017), Garcíaet al. (2020).

CONCLUSION

Based on findings of the present study, it could be concluded under shortage of irrigation water, the deficit irrigation level 85 % of the total requirement, could be applied to enhance the water use efficiency of soybean crop, whereas, saving 15% of applied water was accompanied with sacrificing only 15 to 18 % of seed yield. The two promising genotypesH4L4 and H6L198 were moderately tolerant to water deficit and were higher in seed yield potential. On the other hand, although the genotype PI 416937 was the lowest in seed yield, it is a good genetic resource for water deficit tolerance and it could be used in breeding programs to improve these characters in the grown cultivars. The water deficit tolerance was associated with high contents of relative water content and proline along with low leaf temperature and malondialdehyde (MDA).

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تحديد الصفات الفسيولوجية والمحصوليه المتعلقة بتحمل نقص المياه لبعض التراكيب الوراثية لفول الصويا

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الملخص

يعتبر نقص المياه من أهم الاجهادات غير الحيويه التي تحد من إنتاج فول الصويا. لذلك ، أصبح ايجاد تراكيب وراثيه جديده ذات كفاءة عالية في استخدام المياه وذات إنتاجية عالية حاجة ملحة. أجريت تجربة حقلية خلال موسمي صيف 2018 و 2019 لتقييم ستة تراكيب وراثية من فول الصويا (H4L4 ، جيزة 83 ، H3L110 ، PI 416937 ، جيزة 111 ، H6L198) تحت ثلاثة مستويات ري (100٪ ، 85٪ ، 70٪ من متطلبات مياه الري لفول الصويا). أوضحت النتائج أنه بالرغم من حصول PI416937على أقل إنتاجية للبذور ، إلا أنه سجل أعلى محتوى نسبي من الماء للاوراق ومحتوي البرولين إلى جانب أقل القيم المرغوبة لدرجة حرارة الورقة ومحتوي malondialdehyde (MDA) كما سجل PI416937 أدنى انخفاض في محصول البذور تحت مستويي نقص الري (85 و 70٪). على العكس من ذلك ، سجلت H4L4 و H6L198 و H3L110 أعلى إنتاجية للبذور وأصباغ الكلوروفيل وإنتاجية مياه الري وإنتاجية المياه. بينما كان لجيزة 83 وجيزة 111 أقل محتوى مائي نسبي للاوراق، البرولين ، والكلوروفيل ، وأعلى مستوى من مالونديالديهيد (MDA) واعلي انخفاض لمحصول البذور تحت 85٪ و 70٪ على التوالي. يمكن الاستنتاج أن H4L4 و H3L110 و H6L98 كان لها تحمل معتدل وكانت مناسبة للزراعة في ظل ظروف عجز مائي (85٪ مع توفير 15٪ من الاحتياجات المائية) مع انخفاض محصول البذره بين 15 إلى 18٪ بينما تم تصنيف PI416937 على أنها تركيب وراثي جيد التحمل مناسبًا للاستخدام في برنامج تربية فول الصويا.