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Water productivity and sensitivity tolerance stress indices in five soybean cultivars (*Glycine max* L.) at different levels of water deficit

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Abstract

In order to measure the water deficit stress effects on seed yield and water productivity of soybean cultivars, a two field experiments wad conducted out via split plot in a randomized complete block design with four replications in 2010-2011 and 2011-2012. Irrigation treatments were three levels (S_1; 50, S_2; 62.5 and S_3; 150 mm) that applied based on evaporation from the 'class A' pan. Cultivars were L_{17}, Clean, T.M.S, Williams x Chippewa and M_9, too. The results showed that, only extreme water deficit stresses (S_3) was reduced number of pods per plants, dry weight, seed yield and also water productivity and water economic productivity, significantly. Among cultivars and at the first and second levels of irrigation (S_1, S_2) cultivar of L_{17} and at the third level (S_3) cultivar of Wiiliams x Chippwea had the highest seed yield, water productivity and water economic productivity. There were observed a positive and significant correlation between seed yield with number of pods per plants and plants dry weight, too. Also, despite the reduction in water consumption at level of S_2 than S_1 and due to the lack of a significant reduction in seed yield, water productivity and water economic productivity was also increased, significantly ($P<0.01$). All indices of sensitivity and tolerance (SSI, STI and GMP) investigated in this study showed that at the moderate and extreme water deficit stresses (S_2, S_3), the cultivars of L_{17} and Wiiliams x Chippwea had the highest tolerance and lowest sensitivity among the cultivars.

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Introduction

Water deficit is one of factors limiting crop production in arid and semiarid regions of the world. Water stress and high temperature can reduce crop yield by affecting both source and sink for assimilates. Because of water deficit in most arid regions, resistance of crop plants against drought has always been of great importance and has taken into account as one of the breeding factors (Talebi, 2011). A long term drought stress effects on plant metabolic reactions associate with plant growth stage, water storage capacity of soil and physiological aspects of plant. Breeding for drought resistance is complicated by the lack of fast, reproducible screening techniques and the inability to routinely create defined and repeatable water stress conditions when a large amount of genotypes can be evaluated efficiently. Achieving a genetic increase in yield under these environments has been recognized to be a difficult challenge for plant breeders while progress in grain yield has been much higher in favourable environments. Thus, drought indices which provide a measure of drought based on yield loss under drought conditions in comparison to normal conditions have been used for screening drought-tolerant genotypes (Mitra, 2011). Different indices (Stress Sensitivity Index; SSI, Mean Production; MP, Geometric Mean Productivity; GMP) are suggested to determine the tolerant and sensitive variants against water deficit stress (Fisher and Maurer 1987, Rosielle and Hamblin 2010). These indices are formed based on the operation of genotypes individually in both with and without stress conditions and also the average operation of all genotypes in the both conditions.

Productivity is a ratio between a unit of output and a unit of input. Here, the term water productivity is used exclusively to denote the amount or value of product over volume or value of water depleted or diverted. Producing more food for each drop of water will be a crucial strategy to address both challenges (Tilman *et al.*, 2011). Issues of global water availability and scarcity have been considered in a variety of ways, including identifying areas of water availability, water stress, impacts of water use and projections of future water scarcity (Pfister *et al.*, 2010). Many recent studies have tied water scarcity to agricultural water consumption (Ali and Talukder, 2012). When water is scarce, understanding the magnitude of water consumption is important. In most cases, however evaluation for decision making requires information about efficiency. When water is being used, is it being used wisely?

The objective of this experiment was to determine best cultivar based on influences of water stress on seed yield of soybeans cultivars in Varamin, Iran. There is a high potential for expansion of soybean cultivation in these regions as a promising alternative crop for diversification and economical use of land and water resources. The suitability of indicators seems to depend on the timing and severity of stress in drought prone environments. The objective of this study was to test this hypothesis in order to identify the most suitable indices-cultivars for each environment.

Material and methods

Geographic coordinates and environmental conditions (climate, soil and water) of the experimental field

This study carried out during the 2010-2011 and 2011-2012 growing seasons in Varamin (Iran). Based on long term statistics (30 years) of Pishva climatology station, mean temperature of the experiment site in years 2011 and 2012 were 26.31 and 26.67$^{\circ c}$, respectively. Mean annual precipitation during the growing season were 31.63 and 33.32 mm, too (Table 1). Prior to the experiment, two composite soil samples were taken at depths of 0-30 and 30-60 cm. The samples were sent to laboratory and analysed for pH, electrical conductivity (EC), organic carbon, total N, available P and available K. Details of soil properties are shown in Table 2. Also, field water quality results are presented in Table 3.

Table 1. Average monthly of temperature and precipitation on during the growing season of 2010-2011 and 2011-2012 in experimental location.

Month	Precipitation (mm)		Average of temperature (°c)					
			Minimum		Mean		Maximum	
	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012	2010-2011	2011-2012
May	16.49	17.66	12.36	13.16	22.22	20.78	28.09	26.79
June	0.10	0.30	20.12	19.29	29.94	27.38	37.19	39.05
July	4.43	3.83	20.72	23.45	29.89	34.03	44.68	37.87
August	1.32	1.67	22.23	22.01	28.23	31.98	39.31	39.80
October	0.18	0.37	18.43	18.00	26.37	25.70	35.44	36.40
November	9.11	9.49	13.85	13.26	21.21	20.14	27.73	29.32
Average	31.63	33.32	17.95	18.20	26.31	26.67	35.41	34.87

Statistics were gathered from Pishva Climatology station.

Table 2. Physical and chemical properties of experimental soil.

Soil properties	Content in different depths			
	2010-2011		2011-2012	
	0-30 (cm)	30-60 (cm)	0-30 (cm)	30-60 (cm)
Electrical Conductivity (ds/m)	1.0	1.2	1.2	1.25
pH	7.2	7.5	7.00	7.00
Organic carbon (%)	0.6	0.55	0.55	0.61
Total nitrogen (%)	0.05	0.04	0.05	0.05
Available phosphor (mg/kg)	7	5.5	7.4	6.7
Available potassium (mg/kg)	155	159	160	163

Table 3. Results of water quality.

Parameters	Content	
	2010-2011	2011-2012
Electrical Conductivity (Ec) ($ds.m^{-1}$)	1.3	1.11
pH	7.52	7.29
TDS ($Mg.l^{-1}$)	545.4	548.08
Sodium Absorption Rate (SAR)	3.87	3.89
Na^{+} ($eq.l^{-1}$)	5.11	5.07
Ca^{++} ($eq.l^{-1}$)	130	133
Mg^{++} ($eq.^{-1}$)	48	48
So_4^{--} ($eq.l^{-1}$)	72	74
Cl^{-} ($eq.l^{-1}$)	3.9	3.7
Hco_3 ($eq.l^{-1}$)	135	131

Statistical design and irrigation treatments

The experimental design was a split plot in a randomized complete block design with four replications. The irrigation treatments (three levels) were randomized to the main plots and soybean cultivars (five cultivars) were randomly distributed within the subplots of the water deficit treatments (main plots). The water deficit treatments were applied by changing in irrigation intervals. Irrigations were carried out when an amount of evaporated water from the class "A pan" evaporation reached 50 (S_1; optimum conditions of irrigation), 62.5 (S_2; moderate water deficit) and 150 (S_3; extreme water deficit) mm, respectively. Amount of irrigation was identical for all water deficit treatments from the beginning of planting time till complete establishment of plants. In order to make sure the identical amount of water discharge to every plot, the water contour instruments were used. Total irrigation water applied in S_1, S_2 and S_3 were 2790, 2110.6 and 879.36 $m^3.ha^{-1}$, respectively. After this stage, the plots were irrigated according to their prescribed treatment.

Soybean cultivars

Soybean cultivars were: V1; L_{17}, V2; Clean, V3; T.M.S, V4; Williams×Chippewa and V5; M_9. The Seeds were obtained from the Iran oilseeds corporation.

- L17, Clean (group III maturity) and M9 (group II maturity) are commercial cultivars in Iran and are being cultivated in many arid and semi-arid regions of the country.
- T.M.S and Williams×Chippewa (group II maturity) are the two of the promising lines which have been selected for assessment of their tolerances to water deficit stress in Iran.

Agricultural practices

Before planting, the soil surface was ploughed during autumn and then disked twice in the spring (at the beginning of April and middle of May). Triple super phosphate fertilizer was applied before sowing at a rate of 150 kg ha^{-1}. Also, the nitrogen fertilizer (15 $kg.ha^{-1}$) in the form of urea was applied before planting (one third of the application). The rest of nitrogen fertilizer, distributed before starting the first stress treatment. Plots were 7-m long and consisted of six rows, 0.6 m apart. Between all main plots, a 3-m wide strip was left bare to eliminate all influences of lateral water movement. Soil surface of cultivated area was thoroughly irrigated 6 days before planting. The soybean seeds were inoculated with *Rhizobium japonicum* before planting and were handplanted on 24th May 2011 and 26th May 2012 at the rate of 20 seeds per m^2 of row and then were thinned to achieve a density of approximately 333,333 ha^{-1}. During the whole growth season, weeds and insects were effectively controlled.

Number of pods per plant and seed yield

To measurement number of pods per plant, picked 10 plants in a treatment and counted the pods on each plant separately, and then averaged. Also, after the soybean cultivars reached physiological maturity, seed yield was determined by harvesting two central rows (to avoid border effects) in the first week of October in both years. Then, the seed were separated from pods and were weighted with a precision balance. Finally, seed were calculated based on $kg.ha^{-1}$, too.

Sensitivity and tolerance of cultivars to different levels of irrigation

In this section, three indices of sensitivity to stress (Fisher and Maurer, 1987), tolerance to stress (Fernandez, 1992) and geometric mean productivity were calculated by using the following mathematical equation:

- **Stress Sensitivity Index (SSI)**

$SSI=[1-Ys/Yp)]/SI$

$SI= 1-(\overline{Y}s/\overline{Y}p)$

- **Stress tolerance Index (STI)**

$STI=(Yp.Ys)/(\overline{Y}p)^2$

- **Geometric Mean Productivity (GMP)**

$GMP=(Yp.Ys)^{1/2}$

Components of the above equations are: Yp; yield of cultivars in non stress conditions, Ys; yield of cultivars in stressed condition, Yp; mean yield of all cultivars in non stress condition, Ys; mean yield of all cultivars in stressed condition and SI; stress intensity.

Calculation of water productivity and water economic productivity

Water productivity index was calculated via division of yield ($kg.ha^{-1}$) to amount of water used ($m^3.ha^{-1}$).

Water economic productivity is calculated by dividing the economic value of the yield to water used ($m^3.ha^{-1}$), too (Abdullaev and Molden, 2012).

Statistical analysis

Main and interaction effects of experimental factors were determined from analysis of variance (ANOVA) in SAS (SAS Institute Inc., 2006). The assumptions of variance analysis were tested by ensuring that the residuals were random and homogenous, with a normal distribution about a mean of zero. The LSMEANS command was used to compare means at a $P<0.05$ probability. Correlation analyses using PROC CORP in SAS were conducted to determine the correlation between measured parameters together.

Results and discussion

Number of pods per plant

Results of variance analysis showed that, the irrigation levels, cultivars and interaction effects of irrigation level in cultivars has significant effect on number of pods per plant (table 4). So the increasing irrigation decreased this value in all of the cultivars. Of course this decrease is significant in conditions of extreme water deficit stress (S3) than the optimum conditions of irrigation (table 5). Due to results, the most number of pods per plant at the optimum conditions of irrigation (S_1) and moderate water deficit stress (S_2) were observed in L_{17}. The most number of pods per plant in extreme water deficit stress, measured in Williams x Chippewa cultivar, too. Assessment of correlations tables between traits showed, there was observed a positive and significant correlations between number of pods per plant and dry weight in optimum conditions of irrigation (S_1) and moderate water deficit stress (S_2) (table 6). The reason of decreasing numbers of pods in water deficit stress could be attributed to the lower production of pods and flowers and also increasing flower and pod loss at high frequency irrigation (Pourmousavi *et al.*, 2010). In full irrigation conditions, the plant will produce the most number of pods by using all environment conditions, growth of vegetative organs and photosynthetic production materials. But the water stress and low photosynthetic production and storage materials will decrease the number of pods per plant (Mohagheghin *et al.*, 2012). Bokaei *et al.* (2011) and Zarea *et al.*, (2009) in their research announced the flowering and pod formation as the most sensitive stages in soybean growth in regard to the water deficit stress. In another study indicated that, the water deficit stress leads to the significant loss of yield in these stages that is more due to the loss number of pods per plant (Sionit and Kramar, 2007; Sneller and Dombek, 2009). Kumar and Turner, (2012) at a study on the effect of irrigation regimes on seed yield and yield components of soybean demonstrated that, the number of pods per plant is the most important component in determining the seed yield, so that it can be alone explained about 58% of changes in seed yield in different treatments. Guttieri *et al.* (2010) reported the water deficit stress during the reproductive stages (especially flowering and pods formation) can decrease the number of pods significantly. They stated the water deficit stress influence on flowering and the growth of young pods of soybeans. They also shown the water amount in plant tissue and the hormone abscise acid is responsible for setting pods under drought conditions. Thus, the loss of water in soil before and after flowering leads to the significant loss of water in flower which may disturb the ovary activity and finally prevent its growth. In a study Farooq *et al.* (2009) showed that, the water deficit stress leads to the significant loss of average number of pods per plant and seed number in pods. As Ohashi *et al.* (2010) also stated the highest damage on soybean due to the water deficit stress is related to the yield of plant and this damage is cause of extreme loss of traits such as seed number, pods number and number of seed in pods.

Dry weight of plant

The main effects of irrigation levels, cultivars and interaction effects of irrigation levels in cultivars on dry weight of plants are offered in table 4. Both moderate and extreme water deficit stress have decreased the dry weight of plant in all cultivars, but the significant loss of this trait is just seen in extreme water deficit stress. In optimum conditions of irrigation (S_1), the highest and lowest dry weight was shown in cultivars of L_{17} and T.M.S, respectively. In moderate water deficit stress (S_2), the plants dry weight has the decreasing order as L_{17} > Clean > Williams x Chippewa > M_9 > T.M.S, respectively. In extreme water deficit stress (S_3), the highest and lowest dry weight was shown in T.M.S and Clean respectively (Table 5). The same result is offered in study of Manavalan *et al.* (2009). In this experiment, the loss of dry matter in water deficit stress was related to the loss of photosynthesis effectiveness in leaves and assimilation production before physiologic maturation. Based on the report of Pandey *et al.*, (2011), the water deficit stress in filling time of pods leads to the shorter seed maturation period with decreasing the leaf area and finally the loss of dry matter in seed. In another study Majnooni *et al.* (2014) were observed, the lower dry matter than the moderate irrigation treatment in extreme water deficit stress. They also showed that, there is a close relationship between the loss of evaporation and dry matter in plants. In report of Gao *et al.* (2009) were also demonstrated, the extreme water deficit stress was decreased the dry weight, shoot growth, seed thousand weight, seed yield, biological yield and harvest index, significantly. Habibi *et al.* (2010) in investigating the effect of water deficit stress and using selenium on some cropping traits of two cultivars of soybean were stated that, there was a significant difference between control treatment and water deficit stress for all measured traits including seed yield and total dry matter. Due to the studies of Kumar and Turner (2012), increase in water deficit stress regardless the tolerance or sensitivity of cultivar, decrease the shoot dry weight in comparison control treatment.

Seed yield

The results of variance analysis (ANOVA) was showed the significant difference between main irrigation levels, cultivars and also interaction effects of irrigation in cultivars in regard to the seed yield (Table 4). The results also showed, the loss of seed yield in all cultivars from the optimum conditions of irrigation to the moderate and extreme water deficit stress, but this decrease was significant only in extreme water deficit stress (S_3) than the optimum conditions of irrigation. In optimum conditions of irrigation (S_1) and moderate water deficit stress (S_2), the highest seed yield was produced by the cultivar of L_{17}. While in extreme water deficit stress (S_3), the cultivar Williams x Chippewa has the highest seed yield. In all irrigation levels, the cultivar of T.M.S showed the lowest yield (Table 5).

According to idea of Pandey *et al.* (2011), reduction in seed yield of soybean is result of the shortage of water in soil, loss of dry matter and evapotranspiration. Sionit and Kramer, (2007) also announced this view when they studied the effect of water deficit stress as cut of water in greenhouse conditions. They shown the seed yield has decreased as 17% in moderate water deficit stress and as 87% in extreme water deficit stress. Reduction of seed yield in result of water deficit stress and increasing in irrigation intervals were reported by Loveli *et al.* (2007), too. In the study, main reasons of decreasing in yield of crops at the water deficit stresses is titled decreasing in length of growth period, leaf area (as the main photosynthesis organ), number of flowers (as the main reproductive organ) and seed weight (due to decreasing assimilate transfer and photosynthesis). Many studies have shown, there is a positive correlation between seed yield and amount of water consumed (Chaudhuri and Kanemasa, 2007). Also Clark *et al.*, 2013 declared plants which are exposed under the water deficit stress during their growth, decreased the stored nutrition in stem and growth organs and this cause to decrease the current photosynthesis, remobilization of materials and finally the loss yield.

Table 4. The mean square of ANOVA for effect of irrigation levels on number of pods per plants, plant dry weight, seed yield, water productivity and economical water productivity.

Sources of Variation	Degree of freedom (df)	Number of pods per plant	Plant dry weight	Seed yield	Water productivity	Economical water productivity
Year	1	ns	ns	ns	ns	ns
Irrigation levels	2	**	**	**	**	**
Year*Replication	2	ns	ns	ns	ns	ns
Cultivars	4	**	**	**	**	**
Cultivars*Irrigation levels	8	**	**	**	**	**
Cultivars *Year	4	ns	ns	ns	ns	ns
Year*Cultivars*Irrigation levels	8	ns	ns	ns	ns	ns

*and**: significant at the 5% and 1% levels of probability, respectively. Numbers without symbols are non significant.

Table 5. Effects of irrigation levels and interaction effects of irrigation levels with cultivars on number of pods per plants, seed yield (kg.ha^{-1}) and plant dry weight (kg.ha^{-1}).

Irrigation levels	Cultivars	Number of pods per plant	Seed yield	Plant dry weight
S_1		27.65[a]	2339.31[a]	5063.22[a]
S_2		26.30[a]	2228.65[a]	4791.97[a]
S_3		14.45[b]	468.82[b]	1679.03[b]
	L_{17}	27.11[a]	1957.78[a]	4814.14[a]
	Clean	23.90[b]	1817.08[ab]	4762.34[a]
	T.M.S	20.12[d]	1011.18[c]	2408.43[c]
	Williams x Chippewa	22.48[c]	1867.03[a]	3806.14[b]
	M_9	20.37[d]	1736.06[b]	3732.66[b]
S_1	L17	33.41[a]	2869.17[a]	6265.02[a]
S_1	Clean	29.58[b]	2458.74[b]	5735.23[b]
S_1	T.M.S	25.82[c]	2002.83[e]	4266.14[d]
S_1	Williams x Chippewa	25.39[c]	2245.03[c]	4481.13[c]
S_1	M_9	24.04[d]	2120.80[d]	4568.60[c]
S_2	L_{17}	30.91[a]	2725.71[a]	6507.35[a]
S_2	Clean	27.27[b]	2340.72[b]	6422.17[a]
S_2	T.M.S	26.12[b]	1902.69[e]	1696.54[c]
S_2	Williams x Chippewa	24.71[c]	2152.98[c]	5176.92[b]
S_2	M_9	22.49[d]	2021.12[d]	5056.87[b]
S_3	L_{17}	17.02[a]	418.22[d]	1670.04[c]
S_3	Clean	14.85[b]	456.52[c]	2129.63[a]
S_3	T.M.S	8.42[c]	252.62[e]	1262.61[e]
S_3	Williams x Chippewa	17.35[a]	634.97[a]	1760.38[b]
S_3	M_9	14.59[b]	581.75[b]	1572.50[d]

- Levels of irrigation: S1; optimum condition of irrigation, S2; moderate water deficit stress level, S3; extreme water deficit stress level.
- For a given means within each column of each section followed by the same letter are not significantly different (P<0.05).

Stress sensitivity and tolerance indices

To determine the sensitivity or tolerance of cultivars water deficit stresses, their yield was used in both non stress (Y_p) and under stress (Y_s) conditions. In this regard, the index of SSI is used to study the sensitivity and two indices of STI and GMP to investigate the cultivar's tolerance level. In stress Sensitivity Index (SSI), the smaller number indicates more possibility of stress (majnooni *et al.*, 2014). In the present study and in the based on performed calculations, the cultivars of M_9 and Williams x Chippewa demonstrated the highest tolerance to the water deficit stress while, T.M.S cultivar had the lowest tolerance to water deficit (Table 7). According to results of Gomez *et al.*, 2009, this index leads to select the cultivars with the highest stress tolerance, but in full irrigation condition, their yield isn't so good. In other hand, in stress tolerance index (STI) and geometric mean productivity (GMP), the bigger numbers indicate the cultivar tolerance or their genotypes. In this research, the bigger values of these indices in Williams x Chippewa indicated this cultivar had the highest stress tolerance against water deficit stress. In another research, Gharib eshghi *et al.* (2012) stated two indices of STI and GMP are the best indices to assess dry tolerance in soybean cultivars and can be used to determine the cultivars with highest yield in both optimum condition and water deficit stress. Also, Arwoth *et al.* (2011) in their assessment on evaluation of stress tolerance indices of soybean cultivar in limited and optimum conditions were shown, the geometric mean productivity index (GMP) is the best index to separate the genotypes with the possibility of water deficit stress because there is high yield correlation in both conditions.

The investigation of seed yield correlation coefficients with the sensitivity and tolerance indices showed, there was a positive correlation between seed yield with stress sensitivity index (SSI), stress tolerance index (STI) and geometric mean productivity (GMP) in water deficit stress (S_3). Of course, this correlation is just significant between the seed yield and geometric mean productivity ($P<0.01$). In extreme water deficit stress (S3) there was negative significant correlation between seed yield and stress sensitivity index (SSI) ($r=-0.61$) and as well as positive significant correlation between seed yield and stress tolerance index (STI) and geometric mean productivity (GMP) ($r=0.86$ and $r=0.85$, respectively). Also there is negative significant correlation between stress tolerance index (STI) and geometric mean productivity (GMP) ($P<0.01$). In this study, the indices of STI and GMP were showed high correlation with seed yield in both optimum conditions of irrigation and extreme water deficit stress (Table 8). Since these indices have good effectiveness to determine the cultivars with possibility of high yield potential, this is shown the priority of these two indices than other indices.

Water productivity and water economic productivity in deficit conditions of irrigation

The study results of variance analysis (ANOVA) of irrigation levels on water productivity indicated, this index was higher in moderate water deficit stress (S_2) than optimum water deficit stress (S_1) and extreme water deficit stress (S_3) (Table 6). In other words, despite of the loss 20% of consuming water in moderate water deficit stress than optimum water deficit stress, the productivity of water factor has been increased because of insignificant difference in yield components and also seed yield of the studied cultivars. So that this value is increased to 0.64 $kg.m^{-3}$ in moderate water deficit stress from 0.5 $kg.m^{-3}$ in optimum conditions of irrigation. Also, the results indicated the water productivity in extreme water deficit stress (S_3) or in other words in lower water consumption is decreased significantly than the optimum conditions of irrigation and moderate water deficit stress (S1, S2) and reached to 0.32 $kg.m^{-3}$. The study of interaction effects of irrigation levels and cultivars indicated, there is significant difference between cultivars in regard to water productivity. So, in optimum conditions of irrigation and moderate water deficit stress, the L_{17} cultivar and in extreme water deficit stress, the Williams x Chippewa cultivar have the highest water productivity index respectively.

Regarding to announcing of Board (2012), the water productivity is related to different factors such as pattern, environment, irrigation technology, irrigation management in field, soil and its fertility, agriculture inputs such as workers, fertilizer, machinery and etc. So many factors influence on water productivity. Researchers found different results about the effect of different irrigation levels on water productivity. The increasing productivity in low conditions of irrigation has reported in (Khajoee-nezhad *et al.*, 2008). But Asadi and Aghili, (2007) found the highest water productivity in optimum condition of irrigation. Also, Farahani and Oweis, (2008) announced the total water productivity in cereal in Karkhe region as about 0.4$kg.m^{-3}$, while Sepahvand (2012) estimated its changes in Urmia, Mashhad and Karaj between 0.5 to1.8 $kg.m^{-3}$. Also, the study of ANOVA results showed there was significant difference between irrigation levels in regard to water economic productivity ($P<0.01$). So that the highest economic productivity with 0.26 $\$.m^{-3}$ is dedicated to the moderate water deficit stress (S_2). The optimum conditions of irrigation and extreme water deficit stress were as 0.21 and 0.13 $\$.m^{-3}$ of water economic productivity, respectively. The study of interaction effects of irrigation levels and cultivars showed that in optimum conditions of irrigation and moderate water deficit stress, the L_{17} cultivar and also in extreme water deficit stress, the Williams x Chippewa cultivar have the highest water economic productivity as 0.25, 0.48 and 0.18 $\$.m^{-3}$, respectively (Table 9).

Table 6. Correlation coefficient between number of pods per plants, seed yield and plant dry weight in different levels of irrigation.

Irrigation levels	Features	number of pods per plants	seed yield	plant dry weight
Optimum conditions of irrigation (S_1)	number of pods per plants	1		
	seed yield	0.97*	1	
	plant dry weight	0.95*	0.95*	1
Moderate water deficit (S_2)	number of pods per plants	1		
	seed yield	0.96*	1	
	plant dry weight	0.95*	0.92	1
Extreme water deficit (S_3)	number of pods per plants	1		
	seed yield	0.77	1	
	plant dry weight	0.64	0.46	1

Table 7. Evaluation of sensitivity and tolerance indices to different levels of irrigation.

Cultivars	Seed yield (kg.ha⁻¹)			Stress Sensitivity Index (SSI)		Stress Tolerance Index (STI)		Geometric of Mean Productivity (GMP)	
	S_1	S_2	S_3	S_3 to S_1	S_2 to S_1	S_3 to S_1	S_2 to S_1	S_3 to S_1	S_2 to S_1
L17	2869.17	2725.71	418.22	0.82	1.06	0.22	1.43	1095.42	2796.52
Clean	2458.74	2340.72	456.52	0.77	1.01	0.21	1.05	1059.46	2399.00
T.M.S	2002.83	1902.69	252.62	0.84	1.06	0.09	0.70	711.31	1952.12
Williams x Chippewa	2245.03	2152.98	634.97	0.65	0.87	0.26	0.88	1193.95	2198.53
M_9	2120.8	2021.12	581.75	0.66	0.99	0.23	0.78	1110.75	2070.36

- Levels of irrigation: S1; optimum condition of irrigation, S2; moderate water deficit stress level, S3; extreme water deficit stress level.
- Stress index (SI) at the S_2; 0.047 and at the S_3; 0.799.

Table 8. Correlation between seed yield to sensitivity and tolerance indices at the optimum conditions of irrigation (S_1) and extreme water deficit (S_3).

Features	Seed yield		Sensitivity and Tolerance indices		
	S_1	S_3	SSI	STI	GMP
S_1	1				
S_3	0.227	1			
SSI	0.48	-0.61*	1		
STI	0.82	0.85**	-0.09	1	
GMP	0.8**	0.86**	-0.11	0.996**	1

S_1; optimum conditions of irrigation, S_3; extreme water deficit, SSI; Stress Sensitivity Index, STI; Stress tolerance Index, GMP; Geometric Mean of Productivity.

Table 9. Value of water productivity and economical water productivity in water deficit conditions than optimum conditions of irrigation.

Irrigation levels	Cultivars	Water productivity (kg.m^{-3})	Economical water productivity (\$.M^{-3})
S_1		0.50^{b}	0.21^{b}
S_2		0.64^{a}	0.26^{a}
S_3		0.32^{c}	0.13^{c}
S_1	L17	0.62^{a}	0.25^{a}
	Clean	0.53^{b}	0.22^{b}
	T.M.S	0.43^{d}	0.18^{e}
	Williams x Chippewa	0.48^{c}	0.2^{c}
	M9	0.46^{c}	0.19^{d}
S_2	L17	1.16^{b}	0.48^{a}
	Clean	1.00^{b}	0.41^{b}
	T.M.S	0.81^{c}	0.33^{e}
	Williams x Chippewa	0.92^{a}	0.38^{c}
	M9	0.86^{b}	0.35^{d}
S_3	L17	0.29^{c}	0.12^{d}
	Clean	0.31^{d}	0.13^{c}
	T.M.S	0.17^{e}	0.07^{e}
	Williams x Chippewa	0.43^{a}	0.18^{a}
	M9	0.40^{b}	0.16^{b}

- Levels of irrigation: S_1; optimum condition of irrigation, S_2; moderate water deficit stress level, S_3; extreme water deficit stress level.

Conclusion

In conclusion, the results obtained in this study indicated that, severity water deficit stress has decreased cropping traits (including number of pods per plant, dry weight and seed yield) in all cultivars, significantly ($P<0.01$). Also, it can be announced that the moderate water deficit stress can be as effective option to increase water productivity and water economic productivity in soybean cultivars.

Finally, It is better to give priority to the L17 cultivar in optimum conditions of irrigation and moderate water deficit stress (S1, S2) and the Williams x Chippewa cultivar in extreme water deficit stress.

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