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Soybean yield under water deficit conditions

Siros Ekhtiari, Soheil Kobraee*, Keyvan Shamsi

Department of Agronomy and Plant Breeding, Kermanshah Branch, Islamic Azad University, Kermanshah, Iran

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Key words: irrigation regime, seed filling period, soybean, water deficit, yield components.

Abstract

Drought stress is the main environmental factor that limiting crops growth and productivity in Iran. Therefore, in order to evaluate effects of water deficit on yield and yield components of soybean, an experiment was performed in the research field of the Islamic Azad University of Kermanshah, Iran. Response of four soybean cultivars at four irrigation regimes investigated based on randomized complete block design with three replications. At the end of growth season, ten plants were selected randomly from each plot and then final yield and yield component were measured. The results of this experiment show that there are significant differences among cultivars in yield and yield components at different irrigation regimes. The lowest values of grain and biological yield were obtained under condition in which water stress occurred in R_1 that indicating the importance and sensitivity of this stage in plant life cycle. Also, number of pod and seed per plant decreased when that withholding irrigation occurred at the early of flowering stage. Withholding irrigation at seed-filling stage had the most effects on reducing seed weight. Therefore, the lowest 100-seed weight per plant was obtained when withholding irrigation at R_6. The results of path coefficient analysis were shown that seed/plant and seed weight had high and positive direct effects on seed yield. In addition, Withholding irrigation at R_3 had more effect on reducing pod and seed dry weight.

***Corresponding Author:** Soheil Kobraee ✉ kobraee@yahoo.com

Introduction

Soybean (*Glycine max* L.) is cultivated as pulses, oil seed and forage crop and drought stress is the most important limiting factor for it production in Western part of Iran. Soybean yield is determined by number of pod per plant, number of seed per pod and seed weight (Ohashi and Nakayama, 2009). Final yield in soybean determined by environmental and genetic factors, therefore, an increasing effort has been conducted towards the choice of varieties suitable for stress land conditions (Abayomi, 2008; Ashley and ethridge, 1978). Drought stress decreases soybean yield by decline in yield components, although there is a differential responses in yield components to changes in environmental conditions. Partitioning and translocation of assimilates is dependent to water availability in soil (Mohapatra *et al.,* 2003; Wardlow and Wilenbrink, 1994; Schnyder, 1993; Whan *et al.*, 1991), thus Soybean yield and its components were markedly reduced in non irrigated plants compared with irrigated plants (Kerbauy, 2004; Ferederick *et al.*, 2001; Andriani *et al.*, 1991). Water deficit at early of flowering and pod set increased flower and pod abortion (Osborne *et al.*, 2002). Decrease in during of vegetative and reproductive growth stages in plant occurring when that plants subjected by drought stress (Levitt, 1980). Environmental condition during the reproductive phase has a major impact on final yield. Abayomi, (2008) and Desclaux *et al.*, (2000) reported that maximum reduction in soybean yield, due to drought stress that occurred during the pod and seed filling period. In western parts of Iran, soybean is sown at May, and flowering, pod set, and seed filling period of Soybean Will coincide with the mid-summer high temperature and water shortage. Therefore, the main objective in our experiment is determine effects of drought stress on yield components and final yield of soybean and sensitivity of growth stages to water deficit in Kermanshah climatic conditions.

Materials and methods

Plant material

Soybean cultivars (V_1=M_7, V_2=M_9, V_3=Gorgan$_3$ and V_4=Williams) supplied by the oilseed company of the Kermanshah agricultural administration were selected as the experimental materials.

Site description and soil analysis

This study was conducted at 2010 in the research field of the Islamic Azad University of Kermanshah province, Iran ($34^o23'$ N, $47^o8'$ E; 1351 m elevation). The texture of the soil based on silty clay with pH 7.2 , electrical conductivity (EC_e) 0.42 dsm^{-1}, total organic matter 2.8%, total nitrogen 0.15%, available phosphorus 9.1 mg kg^{-1} and available potassium 583 mg kg^{-1}.

Table 1. The results of analysis of variance in yield and yield components of soybean.

		MS									
S.O.V	df	PDW	SDW	TDW	NNP	NSS	NPP	NSP	SWP	SY	BY
Block	2	0.21	1.00	3.01	1.65	0.01	1.73	1.57	0.35	165676.46	79625.28
Irrigation (I)	3	7.66**	58.47**	141.33**	144.77**	2.34*	232.96**	1758.22**	29.39**	5803969.03**	23885930.56**
Error a	6	0.16	0.31	1.88	4.48	0.24	0.71	9.76	0.27	31880.84	119446.75
Cultivar (V)	3	5.19**	45.76**	198.57**	216.26**	2.78**	742.78**	1426.21**	4.24**	5169320.91**	17037221.56**
Interaction (V) ×(I)	9	0.11^{ns}	2.17**	3.14^{ns}	2.68^{ns}	0.17^{ns}	8.46**	45.76**	0.20 ^{ns}	96696.77**	860107.57**
Error b	24	0.12	0.45	4.21	4.45	0.27	1.00	7.71	0.27	29145.99	167366.15
CV (%)	-	14.27	10.73	10.04	10.92	19.21	5.86	8.84	3.96	7.97	7.60

-ns, * and **: Non significant, significant at 5 and 1% levels of probability, respectively. -PDW: pod dry weight, SDW: seed dry weight, TDW: total dry weight, NNP: number of node per plant, NSS: number of sub branch, NPP: number of pod per plant, NSP: number of seed per plant, WSP: 100-seed weight, SY: seed yield, and BY:biologicalyield.

Experimental design and treatments

The experiment was based on split plot in a randomized complete block design with three replications. The main plots consisted of four different irrigation regimes: I_1: irrigation during all growth stages as control treatment, I_2: withholding irrigation at the early of flowering stage (R_1), I_3: withholding irrigation at the early of pod development stage (R_3) and I_4: withholding irrigation at the early of seed–filling period (R_6). The Subplot included four cultivars: V_1=M_7, V_2=M_9, V_3=Gorgan$_3$ and V_4=Williams. Before planting, fertilizers were used as follows: 200kgP_2O_5/ha and 50kgN/ha and mixed with soil. Seeds were inoculated with Brady*Rhizobium japonicum* and sown at a high-planting rate the field. When the unifoliate leaves were expanded, the plots were hand-thinned to obtain a uniform plant population of 33 plants per m^2. The experiment included 16 treatments that placed in 48 test plots each of which with the width of 5 m. The quantity of irrigation water in each plot was calculated according to Karam *et al*., (2005), controlled by counter and exercise irrigation treatments at different growth stages. Phonological stages were defined according to Fehr and Caviness, (1977).

Plant sampling

At the end of growth season, ten plants were selected randomly from each plot and yield component such as number of sub branch, number of node; pod and seed per plant and seed weight were measured. To calculate final yield, two middle rows of each plot were completely harvested considering the sides. Weight 13% deduction of moisture, grain dry weight was calculated and considered as economic yield. To determine biological yield, total plant dry weight was employed as biological yield.

Table 2. Means comparison of yield and yield components of soybean.

	Means									
Treatment	PDW (gr)	SDW (gr)	TDW (gr)	NNP	NSS	NPP	NSP	SWP (gr)	SY (kg/ha)	BY (kg/ha)
Irrigation (I)										
I_1	3.1a	9.3a	24.4a	21.6a	2.8a	19.8a	42.6a	14.6a	3173a	7039a
I_2	1.8b	4.7b	17.2c	14.2c	2.0b	10.6c	19.3b	14.8a	1688c	4121c
I_3	1.6b	4.3b	17.9c	20.0b	2.0b	18.1b	19.8b	15.0a	1774bc	4299c
I_4	3.0a	4.6b	22.2b	21.4a	2.6a	19.3a	41.1a	11.7b	1927b	6061b
Cultivar (V)										
V_1	2.5b	6.4b	19.6b	19.3b	2.4b	16.7b	32.4b	14.1b	2107b	5465b
V_2	2.6b	5.9b	18.7bc	18.2b	2.4b	15.7c	30.8b	13.7bc	2026b	5565b
V_3	1.4c	4.1c	17.0c	14.8c	1.9c	8.4d	17.9c	13.5c	1419c	3799c
V_4	2.9a	8.8a	26.3a	24.9a	3.1a	27.4a	44.5a	14.8a	3010a	6691a
Interaction (V) × (I)										
I_1V_1	3.1b	8.8b	25.2bc	22.7bc	2.8b	19.8cd	44.9b	14.7bc	3311b	7389b
I_1V_2	3.4b	8.6b	23.3cde	19.5cd	2.7b	18.2def	41.6b	14.3c	3265b	7598b
I_1V_3	2.0c	6.3d	19.7fg	16.8de	2.2bcd	9.7g	23.7e	14.1c	2086d	4686fg
I_1V_4	4.0a	13.5a	29.3a	27.3 a	3.8a	31.5a	60.2a	15.4ab	4031a	8483a
I_2V_1	1.9c	5.0e	15.3i	13.6 e	2.1bcd	9.1g	21.7e	14.7bc	1635efg	4176gh
I_2V_2	2.0c	4.5ef	15.1i	14.1 e	2.1bcd	8.9g	20.4e	14.4c	1473fg	3996hi
I_2V_3	1.0d	3.3gh	14.6i	9.7 f	1.7cd	4.8h	13.3f	14.2c	1078i	3173j
I_2V_4	2.1c	7.2cd	23.7cd	19.4cd	2.5bc	19.6cde	33.2c	15.9a	2565c	5138ef
I_3V_1	1.7c	4.3efg	16.3ghi	19.2cd	2.1bcd	18.2def	20.4e	14.9bc	1718ef	4325gh
I_3V_2	1.9c	4.0efgh	16.2hi	20.1cd	2.2bcd	18.7f	20.0e	14.5bc	1628efg	4078gh
I_3V_3	0.9d	3.0h	14.8i	15.4 e	1.6d	9.5g	10.5f	14.3c	1139hi	3373ij
I_3V_4	2.0c	6.3d	24.4bcd	25.3ab	2.3bcd	26.9b	28.4d	16.1a	2611c	5419de
I_4V_1	3.2b	7.2cd	21.6def	21.5 c	2.7b	20.0c	42.7b	11.8d	1763e	5996cd
I_4V_2	3.3b	6.4d	20.3ef	19.2cd	2.7b	18.1ef	41.3b	11.7d	1739ef	6587c
I_4V_3	1.9c	3.7fgh	19.0fgh	17.1de	2.1bcd	9.5g	24.1de	11.2d	1371gh	3965hi
I_4V_4	3.7ab	8.2bc	27.7ab	27.9 a	3.7a	31.9a	56.4a	12.0d	2835c	7725b

-Similar letters in each column shows non-significant difference according to LSD test in %5 level. PDW: pod dry weight, SDW: seed dry weight, TDW: total dry weight, NNP: number of node per plant, NSS: number of sub branch, NPP: number of pod per plant, NSP: number of seed per plant, WSP: 100-seed weight, SY: seed yield, and BY: biological yield.

Statistical analysis

Data for evaluated traits were statistically analyzed using a standard analysis of Variance technique using the MSTATC software. Means were separated by the Least Significance Difference Test (LSD) at 5 percent probability level. Path analysis was done by Path-2 software.

Table 3. Correlation coefficients among evaluated traits of soybean.

	PDW	SDW	TDW	NNP	NSS	NPP	NSP	SWP	SY	BY
PDW	1.00									
SDW	0.838**	1.00								
TDW	0.732**	0.813**	1.00							
NNP	0.613**	0.651**	0.750**	1.00						
NSS	0.932**	0.727**	0.622**	0.721**	1.00					
NPP	0.698**	0.735**	0.812**	0.896**	0.705**	1.00				
NSP	0.904**	0.879**	0.837**	0.764**	0.181^{ns}	0.802**	1.00			
SWP	-0.206^{ns}	0.133^{ns}	0.005^{ns}	-0.01^{ns}	-0.083^{ns}	0.082^{ns}	-0.187^{ns}	1.00		
SY	0.742**	0.916**	0.821**	0.691**	0.687**	0.753**	0.805**	0.303*	1.00	
BY	0.868**	0.883**	0.816**	0.752**	0.770**	0.787**	0.944**	-0.100^{ns}	0.854**	1.00

-ns, * and **: Non significant, significant at 5 and 1% levels of probability, respectively.-PDW: pod dry weight, SDW: seed dry weight, TDW: total dry weight, NNP: number of node per plant, NSS: number of sub branch, NPP: number of pod per plant, NSP: number of seed per plant, WSP: 100-seed weight, SY: seed yield, and BY: biological yield.

Table4. Path coefficient analysis for soybean yield.

	Direct effect	Indirect effect				
		NNP	NSS	NPP	NSP	SWP
NNP	-0.037	-	0.027	-0.033	-0.029	0.004
NSS	0.090	0.065	-	0.063	0.074	-0.008
NPP	-0.089	-0.079	-0.063	-	-0.071	-0.062
NSP	0.932**	0.712**	0.762**	0.747**	-	-0.174
SWP	0.488*	-0.005	-0.040	0.040	-0.094	-
Residual	0.361					

** Significant at the 0.01 probability level

* Significant at the 0.05 probability level

-NNP: Number of node per plant; NSS: Number of sub branch; NPP: Number of pod per plant; NSP: Number of seed per plant; SWP: 100-seed weight.

Results and discussion

The relationships between yield and its components were shown in regression equations [Eq. 1, 2, 3, 4, 5 and 6].

[1] SY= -76.3+ 114.9 NNP $r^2=0.48$

[2] SY= 137.3+ 815.8 NSS $r^2=0.47$

[3] SY= 658.9+ 47.2 NSP $r^2=0.65$

[4] SY= 758.2+ 80.9 NPP $r^2=0.57$

[5] SY= -246.0+ 169.9 SWP $r^2=0.09$

[6] SY= -3430.8-44.09NSS+14.93NNP-9.53NPP+54.59NSP+273.28WSP $r^2=0.87$

Whereas SY is seed yield, and NNP, NSS, NSP, NPP, and SWP are the number of node per plant, number of sub branch, number of seed per plant, number of pod per plant and seed weight, respectively. These equations are shown that pod/plant and seed/plant have important role in variation of soybean yield. The results of this experiment show that there are significant differences among cultivars in yield and yield components at different irrigation regimes. Grain yield and biological yield was significantly affected by irrigation regimes, cultivar and interaction irrigation ×cultivar (α=0.01). Check treatment (I_1) with yield equal to 3173 kg/ha, and treatment withholding irrigation at flowering stage (I_2) with 1688 kg/ha had the highest and the lowest yield, respectively. Westgate and Grant, (1989) and Desclaux *et al.*, (2000) stated that soybean yield is more sensitive to drought stress during the early reproductive stage than other developmental stages. Among different cultivars, Williams and Gorgon 3 had the highest and the lowest grain yield values. The highest (4031 kg. ha $^{-1}$) and the lowest (1078 kg. ha $^{-1}$) grain yield values belonged to treatments I_1V_4 and I_2V_3, respectively. Drought stress at any stage of soybean development can reduce yield, but the extent and degree of damage, the capacity for recovery, and the impact on yield and yield components depend on the timing of a stress episode (Brevedan and Egli, 2003). In this experiment, the lowest values of grain and biological yield were obtained under condition in which water stress occurred in R_1 that indicating the importance and sensitivity of this stage in plant life cycle. In present research, when the stress occurred at during flowering, pod number was reduced. Therefore, number of pod per plant decreased when that withholding irrigation occurred at the (I_2). The results showed that seed number and seed weight per plant affected by irrigation regimes and cultivar (α=0.01). Drought stress occurring during the flowering to early pod expansion period increases the rate of pod abortion (Westgate and Peterson, 1993), leads to a less number of pods per plant (Desclaux *et al.*, 2000), and ultimately decreases seed yield (Kokubun *et al.*, 2001). Number of pod and seed per plant the most important yield components of soybean that reduced under water stress conditions. Both yield components are performed at during reproductive development and affected by environmental conditions (Fageria *et al.*, 1997). The individual seed weight is a product of the rate and the duration of seed filling, it is generally determined during seed filling after the pod number had been fixed. In comparison with other growth stages, withholding irrigation at seed filling stage (R_6) had the less effect on reducing number of sub branch, number of pod and seed per plant. Ahead Water deficit in R_1 (omit irrigation at the onset of flowering stage) had the most effect on these traits. Early pod development of soybean is characterized by active cell division in the young ovules and is marked by rapid pod expansion; both processes are very sensitive to drought stress. Water stress reduced number of pods per plant, and that if it would reduce the yield sharply. Means comparison shows that I_1 and I_2 had the highest (42.6) and the lowest (19.3) number of seed per plant, respectively. Withholding irrigation at seed-filling stage (R_6) had the most effects on reducing seed weight and the lowest 100-seed weight per plant was obtained when withholding irrigation at seed-filling during. Occurrence of water deficit at early of flowering to maturity shortening seed filling period and reduces grain weight (Royo *et al.*, 2000). Comparison of different treatment means showed that I_1V_4 had the highest number of sub branch and number seed per plant. Drought at later stages when pod filling had begun reduced seed size but had no significant effect on pod set. Withholding irrigation at R_3 had more effect on reducing pod and seed dry weight. Verslues *et al.*, (2006) emphasized that reduction in growth and dry matter accumulation in plant relates to reduce of turgor pressure in cells plant at water deficit conditions. The highest pod, seed and total dry weight was observed in complete irrigation treatment. Reduction in plant growth and dry matter accumulation in plant was reported by Fofana, (2005). The results of path coefficient analysis was shown that number of seed per plant (0.932) and 100- seed weight (0.488) had high and positive direct effects on seed yield. Evaluation of final yield and yield components for selection of high yielding cultivars is necessary and path analysis has been used to identify important yield components in soybean (Bali *et al.*, 2001). A positive and high correlation were observed between grain yield and biological yield (r=0.854**), number of seed/plant (r=0.805**), and number of pod/plant (r=0.753**). Therefore, as can be seen from correlation coefficients and path analysis, that the number of seed per plant has important role in variation of soybean yield.

Conclusions

Omitting irrigation during flowering stage (R_1) the most effects on reduce seed production of soybean and water deficit at grain–filling stage (R_6) had less effect on biological yield. When the stress occurs during flowering and early pod development, pod number is reduced, and when the stress occurs during seed filling, seed size is reduced while pod number remains largely unaffected. In this experiment, withholding irrigation at seed-filling stage (R_6) had the most effects on reducing seed weight and the lowest seed weight per plant was obtained when withholding irrigation at seed-filling during. The results showed that number of pod and seed per plant has important role in variation of soybean yield.

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