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Yield and Quality Response of Soybean to Full and Deficit Irrigation at Different Growth Stages under Sub-Humid Climatic Conditions

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ABSTRACT

This study investigated the yield and quality response of soybean [*Glycine max (L.) Merr.*] to full and deficit irrigation applied at different growth stages under sub-humid climate conditions over a two-year period. A rain-fed (non-irrigated) treatment and 13 different irrigation treatments (1 full and 12 deficit irrigations) were applied to soybeans at four critical development stages: vegetative (V), flowering (F), pod formation (P) and seed enlargement (S). Deficit irrigation had a significant effect on seed yield, crude oil content, crude protein content and various agronomic parameters. The highest seed yield (4004 kg ha^{-1}) was obtained with full irrigation (based on the replenishment of 100% of soil water depletion from a soil depth of 90 cm at 7-day intervals throughout the development period) and the lowest (1974 kg ha^{-1}) with the rain-fed treatment, with a 50.6% difference in average yield between full irrigation (VFPS) and rain-fed treatments. The rain-fed treatment also resulted in the lowest crude oil content (19.1%) and the highest crude protein content (33.6%). As a result, it may be concluded that while VFPS treatment may be the best choice for maximum yield under local conditions, irrigation schedules should be reconsidered when water cost is high and/or water is scarce; in such cases, an irrigation schedule that includes water deficit at the vegetative development stage can be applied.

Keywords: Deficit irrigation; Soybean; Seed yield; Yield components; Crude oil content; Crude protein content

Yarı Nemli İklimde Farklı Gelişme Dönemlerinde Uygulanan Tam ve Kısıntılı Sulamanın Soya Fasulyesinin Verim ve Kalitesine Etkisi

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ÖZET

Bu çalışmada, yarı nemli iklim koşulları altında iki yıl süreyle soya fasulyesinin farklı gelişme dönemlerinde uygulanan tam ve kısıntılı sulamaya verim ve kalite tepkileri araştırılmıştır. Deneme konularının oluşturulmasında soya fasulyesi bitkisinin dört kritik gelişme dönemi (vejetatif; V, çiçeklenme; Ç, bakla oluşumu; B ve tane gelişimi; T dönemleri) dikkate alınmıştır. Buna göre, 13 farklı sulama konusu (1 tam ve 12 kısıntılı sulama) ve susuz konu olmak üzere 14 deneme konusu oluşturulmuştur. Çalışma sonuçlarına göre; kısıntılı sulama, soya fasulyesi tane verimi, yağ oranı, protein oranı ve belirli agronomik parametreler üzerine önemli düzeyde etki göstermiştir. En yüksek tane verimi (4004 kg ha^{-1}) tam sulama konusundan (VÇBT konusu, her 7 günde bir 0-90 cm derinliğindeki mevcut nemi tarla kapasitesine tamamlayacak miktarda sulama suyu uygulanması), en düşük tane verimi (1974 kg ha^{-1}), tam sulama konusu ile karşılaştırıldığında % 50.6 azalma ile susuz konudan elde edilmiştir. Ayrıca, en düşük yağ oranı (% 19.1) ve en yüksek protein oranı (% 33.6) susuz konuda ölçülmüştür. Sonuç olarak, VÇBT konusunun yarı-nemli iklim koşulları altında en yüksek tane verimine ulaşmak için en iyi seçim olabileceği, ancak su ücreti yüksek ve/veya su kıt olduğunda, sulama programlarının tekrar ele alınmasının gerektiği, böyle koşullarda, vejetatif gelişme döneminde su kısıntısına yönelik bir sulama programının uygulanabileceği belirlenmiştir.

Anahtar Kelimeler: Kısıntılı sulama; Soya fasulyesi; Tane verimi; Verim bileşenleri; Yağ oranı; Protein oranı

1. Introduction

Drought has been the major environmental constraint to plant survival and crop productivity in recent years (Boyer 1982), and most climate-change scenarios envision increasing aridity in many regions of the world in the years to come (Petit et al 1999). Given that the major agricultural use of water is for irrigation, a decrease in water supply will require more efficient water use, with deficit irrigation one way of maximizing water use efficiency (WUE) and obtaining higher yields per unit of irrigation water applied. With deficit irrigation, crops are exposed to a degree of water stress during a particular period or throughout the growing season, with the expectation that any reduction in yield will be insignificant when compared to the benefits gained by diverting the saved water to other crops (Kirda 2002).

Full irrigation is economically justifiable only when water is readily available and irrigation costs are low (James 1993). In regions where there is a water deficit, irrigation can significantly increase soybean yields (Korte et al 1983a; Kadhem et al 1985; Scott et al 1987; Karam et al 2005). Irrigation has also been reported to increase profits from soybean in areas with soil-moisture deficits (Salassi et al 1984). However, soybean is produced in many arid, semi-arid and sub-humid regions where water resources are limited and deficit irrigation is a necessity. In such areas, new irrigation techniques that make use of deficient irrigation practices can result in a more efficient use of water resources (Rosadi et al 2005).

Soybean has adapted to a wide array of climatic, soil and growth conditions, although it is mostly grown on rain-fed land (Fageria et al 1997). Soybean yield is highly affected by soil-water availability (Ashley & Ethridge 1978; Korte et al 1983b). Depending on the hybrid, the growth period usually ranges from between 90-120 days and requires 450-700 mm of water (Doorenbos & Kassam 1979). Foroud et al (1993) reported that soybeans are most susceptible to water stress during stages R1 (beginning of flowering through) R5 (beginning of seed formation), whereas Yazar et al (1989) indicated soybean to be most susceptible to water stress during grain filling (R5-6), followed by the flowering (R1-2) and vegetative (Vn) stages. Dogan et al (2007) showed that any water stress imposed on soybeans during R3 (beginning of pod formation), R5 and R6 (full seed) resulted in substantial reductions in yield compared with full irrigation, with the greatest yield reduction at the R6 stage. Biomass and 1000-seed weight also showed significant differences.

Understanding the critical timing of irrigation for crops in humid and sub-humid areas may allow for a more judicious use of limited water supplies (Sweeney et al 2003). This study aimed to determine the yield and quality response of soybean to full and deficit irrigation applied at different growth stages under sub-humid climatic conditions.

2. Material and Methods

This study was conducted at the Uludag University Faculty of Agriculture Research and Training Centre (40º 11'N latitude; 29º 04'E longitude, 100 m altitude) in Bursa, Turkey under sub-humid climatic conditions during the 2005 and 2006 growing seasons. According to long-term climatic data (1975-2003), the annual mean rainfall, temperature and relative humidity of the region were 676 mm, 14.5 ºC and 66%, respectively. The soil of the experimental field at depths of 0-120 cm is characterized by its clay content (48.5% clay, 28.7% loam and 22.8% sand), with less than 1 percent organic matter (0.47%). Bulk densities of the 0-0.30, 0.30-0.60, 0.60-0.90 and 0.90-1.20 m soil profiles were 1.35, 1.36, 1.34 and 1.38 g cm^{-3}, respectively, and the total available moisture (TAM) of the experimental field for the 0-120 cm soil profile was 232.7 mm. Soil pH (saturated paste) and electrical conductivity (EC) were 6.9 and 0.6 dS m^{-1}, respectively.

The experiment was conducted on 23.4 m^2 (3.9 x 6.0 m) plots using a randomized complete block design with three replications. Soybeans (*Nova* variety) were planted on 21 April 2005 and 3 May 2006 at a seeding depth of approximately 3 cm with row spacing of 0.65 m and plant spacing of 5 cm. The crop phenological cycle was divided into four critical periods based on soybean growth stage, as follows: vegetative (V, V5-R1), flowering (F, R1-R3), pod formation (P, R3-R5) and seed enlargement (S, R5-R7), to determine the effects of irrigation treatments (Table 1). Irrigation water was applied at 7-day intervals as full and deficit according to the treatments given in Table 2. In 2005, rainfall was adequate for uniform emergence. In 2006, plots were irrigated by sprinkler irrigation after planting, and 60 mm of irrigation water was applied for seed-zone wetting to obtain uniform emergence. Following emergence, drip irrigation was used, with the amounts of irrigation water measured using a water meter, and the pressure for each plot stabilized according to pressure gauges mounted on the pipe for each plot. A polyethylene lateral drip line was designed for each row using 16 mm-dia. lateral pipes with 2 L h^{-1} in-line drippers spaced at 20 cm. Dripper discharge and spacing were selected based on clay soil texture and a soil infiltration rate of 5.8 mm h^{-1}. Based on a soil analysis conducted prior to sowing, 50 kg ha^{-1} fertilizer containing N, P and K were applied prior to sowing, and an additional 50 kg ha^{-1} N was added in the form of urea when plants reached 25-30 cm in height. Given that the tested soybeans were not inoculated and that no soybeans had been previously grown on the same plot, the absence of any beneficial nitrogen-fixing rhizobia was assumed.

Table 1- Soybean growth stages

Çizelge 1- Soya fasulyesi gelişme dönemleri

	Vegetative stages
VE	Emergence
VC	Cotyledon
V1	First node
Vn	nth node
	Reproductive stages
R1	Beginning of bloom
R2	Full bloom
R3	Beginning pod
R4	Full pod
R5	Beginning seed
R6	Full seed
R7	Beginning maturity
R8	Full maturity

Soil water content (SWC) of the 0-120 cm soil profile was measured in the centre of the plot at depths of 0.16, 0.45, 0.75 and 1.05 m once per week prior to irrigation using a neutron probe (503 DR Hydroprobe, CPN International, Inc., Martinez, CA, USA), and volumetric water content at a depth of 0.3 m was assessed on the basis of soil sampling. Crop evapotranspiration (ET) for each treatment, defined as the residual soil water balance for the time between two successive SWC measurement dates was calculated by using Equation 1.

Table 2- Irrigation treatments

Çizelge 2- Sulama konuları

Treatments	*Description*
VFPS	100% soil water depletion (SWD) replenished for a soil depth of 90 cm on a 7-day basis throughout the development period (full irrigation)
$V_{75}FPS$	The same as S1, but 75% SWD replenished at vegetative stage
$V_{50}FPS$	The same as S1, but 50% SWD replenished at vegetative stage
$V_{25}FPS$	The same as S1, but 25% SWD replenished at vegetative stage
$VF_{75}PS$	The same as S1, but 75% SWD replenished at flowering stage
$VF_{50}PS$	The same as S1, but 50% SWD replenished at flowering stage
$VF_{25}PS$	The same as S1, but 25% SWD replenished at flowering stage
$VFP_{75}S$	The same as S1, but 75% SWD replenished at pod formation stage
$VFP_{50}S$	The same as S1, but 50% SWD replenished at pod formation stage
$VFP_{25}S$	The same as S1, but 25% SWD replenished at pod formation stage
$VFPS_{75}$	The same as S1, but 75% SWD replenished at seed enlargement stage
$VFPS_{50}$	The same as S1, but 50% SWD replenished at seed enlargement stage
$VFPS_{25}$	The same as S1, but 25% SWD replenished at seed enlargement stage
Rain-fed	Non-irrigated

$$ET = I + P + \Delta S - R - D \quad (1)$$

Where; I, the depth of irrigation water (mm) as measured using water meters; P, precipitation (mm) as recorded by the meteorological station; ΔS, the change in soil-water content (mm); R, the depth of runoff (mm), and D, the drainage below the root zone (mm). Because the amount of irrigation water was controlled, run-off was assumed to be zero. Percolation was accounted for by using moisture measurements related to the 120-cm soil profile for soil water budget calculations.

The applied irrigation amounts were calculated for each soil layer up to 90 cm soil depth. The amount of water required per irrigation was determined with the Equation 2 (James 1993).

$$I = \sum_{i=1}^{n}\left(\frac{(\mathrm{fc}_1 - \theta_{\mathrm{w}_1}) \times D_1 \times \rho_{\mathrm{b}_1}}{10} + \cdots + \frac{(\mathrm{fc}_n - \theta_{\mathrm{w}_n}) \times D_n \times \rho_{\mathrm{b}_n}}{10}\right)P \quad (2)$$

Where; I, applied irrigation water (mm); fc, gravimetric soil water content at field capacity (%); θ_w, initial gravimetric soil water content (%); D, depth of the soil layer (cm); ρ_b, dry bulk density (g cm^{-3}); n, number of soil layers; P, ratio of wetting area (%).

Plant height at maturity was measured by randomly selecting and measuring 10 plants from each plot. Number of pods and number of seeds per plant were also recorded. Leaf area index (LAI) was measured at four developmental stages from three plants per plot using a portable leaf area meter (Model LI 3000A, LI-COR Inc., Lincoln, NE, USA). Crops were harvested on 20 September 2005 and 2 October 2006, and 1000-seed weight, oil and protein contents were measured, with crude oil assessed using the Soxhlet extraction technique (Pomeranz & Clifton 1994), and protein content evaluated according to Kjeldahl (Ivanov 1974).

WUE values were calculated separately for each treatment as the ratio of seed yield to seasonal ET (Bos 1980; Howell 2001; Pala et al 2007), and irrigation water use efficiency (IWUE, kg m^{-3}) was determined by using the Equation 3 (Bos 1985; Zhang et al 1999).

$$IWUE = \frac{(Y_I - Y_r)}{IRR} \quad (3)$$

Where; Y_I, seed yield of irrigated soybean (kg da^{-1}); Y_r, seed yield of rain-fed soybean; IRR, the amount of applied irrigation (mm).

Data for all parameters were subjected to analysis of variance (ANOVA). The F-test was used to determine the effects of irrigation treatment, year, block and treatment × year interaction at the 0.05 and 0.01 probability levels, with F-protected least significant difference (LSD) calculated at 0.05, according to Steel & Torrie (1980).

3. Results and Discussion

3.1. Weather conditions

Table 3 provides a comparison between long-term meteorological data and monthly climate data during both growing seasons. The measured temperature and relative humidity values for the 2005 and 2006 growing seasons were typical, considering the long-term means of the region. However, the total rainfall values recorded from April to October were 212 and 193 mm in 2005 and 2006, respectively, which were approximately 27% (2005) and 34% (2006) below the long-term mean rainfall of 292 mm.

3.2. Growth stages

Emergence was observed about two weeks from sowing in both years (Table 4). Five-node vegetative growth period of experimental years was observed about 45-50 days from sowing and flowering observed after 24-25 subsequent days. Pod formation was observed about 16-18 days after flowering and seed enlargement was observed 17-19 days from pod formation. Seed enlargement period of experimental years lasted about 13-16 days and seeds reached to maturing period. The total growth period of experimental cultivar *(Nova)* was then calculated about to be 150 and 152 days. Karam et al (2005) reported soybean total growth period under semi-arid climate conditions of Lebanon as 138-140 days. Such a difference might have been resulted from climate, plant and irrigation program.

Table 4- Soybean growth stages under experimental conditions

Çizelge 4- Denemenin yürütüldüğü koşullarda soya fasulyesinin gelişme dönemleri

Stages	*Date*	
	2005	*2006*
Planting	21.04	03.05
Emergence	06.05	19.05
Vegetative (five node)	05.06	22.06
Flowering	30.06	16.07
Pod formation	18.07	01.08
Seed enlargement	04.08	20.08
Maturity	20.08	02.09
Harvest	20.09	30.09

Table 3- Total monthly precipitation, mean temperature and relative humidity of the study location during the 2005 and 2006 growing seasons and long-term averages

Çizelge 3- Araştırma alanına ilişkin 2005 ve 2006 gelişme dönemleri ve uzun yıllar ortalaması olarak aylık toplam yağış, ortalama sıcaklık ve oransal nem değerleri

Months	*Precipitation (mm)*			*Temperature (°C)*			*Relative humidity (%)*		
	LT	*2005*	*2006*	*LT*	*2005*	*2006*	*LT*	*2005*	*2006*
April	70	56	20	12.9	13.7	12.1	68	60	74
May	47	23	9	17.6	17.6	16.6	65	68	61
June	33	21	43	22.3	21.2	21.5	58	58	64
July	20	55	2	24.5	24.7	23.8	57	62	52
August	15	4	3	24.1	25.1	26.4	60	63	50
September	35	16	91	20.1	20.1	19.9	65	68	65
October	72	37	25	15.3	13.2	16.7	72	72	63
Total/Mean	292	212	193	19.5	19.4	19.6	64	64	58

LT, longterm averages

3.3. Leaf area index, plant height, seed yield and components

All measured characteristics showed significant differences among treatments for 2005, 2006 and for the 2005-2006 average (with the exception of 1000-seed weight, which showed no significant differences for 2006). The two-way interaction of irrigation treatment × year also resulted in significant differences for seed yield (at 5%) and crude oil (at 1%) (Table 5).

Maximum leaf area index (LAI) values were observed at the pod-formation growth stage. LAI was significantly affected by deficit irrigation at all growth stages, with the highest LAI values observed in the $VFPS_{50}$ treatment at the pod-formation growth stage (7.41) and the lowest values in the rain-fed treatment at the vegetative growth stage (2.81) (Table 6). These findings are in agreement with the results reported by Cox & Jolliff (1986), De Costa & Shanmugathasan (2002) and Karam et al (2005). The LAI values observed in $VFPS_{50}$ treatment of seed enlargement period, LAI value at the end of pod formation period and LAI values of VFPS, $V_{75}FPS$, $V_{50}FPS$, $V_{25}FPS$, $VFPS_{75}$ and $VFPS_{25}$ treatments of pod formation period were all placed in the first group. Such a case indicated that water deficits respectively at flowering period and pod formation period resulted in decreased LAI values at pod formation period. Especially 50 and 75% water deficits at flowering period (respectively the treatments of $VF_{50}PS$ and $VF_{25}PS$) caused significant decrease in LAI values through defoliation and increases were then observed in LAI values after the irrigations performed at pod formation period. Karam et al (2005) stated that the compensation mechanisms of the growth parameters, mainly leaf area, did occur under deficit irrigation conditions, assuming that water stress of a certain period during flowering did not limit the plant ability to recover from water stress.

It was observed that deficit irrigations significantly reduced plant heights. VFPS treatment resulted in plant height (98.2 cm) significantly

Table 5- ANOVA results for seed yield, crude oil percentage, crude protein percent and certain agronomic parameters of soybean under different irrigation treatments in 2005, 2006 and 2005-2006 average

Çizelge 5- Farklı sulama konularına göre soya fasulyesinde gözlenen tane verimi, yağ oranı, protein oranı ve belirli agronomik parametrelere ilişkin 2005, 2006 ve 2 yılın birleştirilmiş verilerine ait ANOVA sonuçları

Source	*df*		*Significance of F-values*		
	1	*2*	*2005*	*2006*	*2005-2006*
					Plant height
Years (Y)	-	1			ns
Blocks	2	4	ns	ns	*
Treatments (T)	13	13	**	**	**
Y x T	-	13			ns
Error	26	52			
					Number of pods per plant
Years (Y)	-	1			ns
Blocks	2	4	ns	ns	**
Treatments (T)	13	13	**	**	**
Y x T	-	13			ns
Error	26	52			
					Number of seeds per plant
Years (Y)	-	1			ns
Blocks	2	4	ns	*	**
Treatments (T)	13	13	**	**	**
Y x T	-	13			ns
Error	26	52			
					Seed yield
Years (Y)	-	1			**
Blocks	2	4	ns	ns	ns
Treatments (T)	13	13	**	**	**
Y x T	-	13			*
Error	26	52			
					1000 seed weight
Years (Y)	-	1			**
Blocks	2	4	ns	ns	ns
Treatments (T)	13	13	*	ns	**
Y x T	-	13			ns
Error	26	52			
					Crude oil percent
Year (Y)	-	1			**
Blocks	2	4	ns	ns	ns
Treatments (T)	13	13	**	*	**
Y x T	-	13			**
Error	26	52			
					Crude protein percent
Years (Y)	-	1			**
Blocks	2	4	ns	ns	ns
Treatments (T)	13	13	**	**	**
Y x T	-	13			ns
Error	26	52			

df, degrees of freedom; 1, individual year; 2, combined over 2 years; ns, non-significant; *, significant at the 5% of probability level ($P < 0.05$); **, significant at the 1% of probability level ($P<0.01$)

Table 6- Effects of irrigation treatment on leaf area index (LAI) measured at four growth stages (2005-2006 average)

Çizelge 6- Sulama konularının dört gelişme döneminde ölçülen yaprak alan indeksine (YAİ) etkileri (2 yılın ortalaması)

Treatments	*Growth stages*			
	Vegetative	*Flowering*	*Pod formation*	*Seed enlargement*
VFPS	3.56 tuv[+]	6.45 def	7.23 ab	5.70 hıj
$V_{75}FPS$	3.52 tuv	6.24 efg	7.10 ab	5.61 ıjk
$V_{50}FPS$	3.48 tuv	5.91 ghı	7.17 ab	5.57 ı-l
$V_{25}FPS$	3.27 v	5.93 ghı	7.16 ab	5.52 j-m
$VF_{75}PS$	3.49 tuv	5.99 gh	6.27 efg	5.57 ı-l
$VF_{50}PS$	3.50 tuv	5.66 h-k	5.32 k-o	5.52 j-m
$VF_{25}PS$	3.60 tuv	5.06 n-q	4.78 q	5.19 m-p
$VFP_{75}S$	3.55 tuv	6.36 def	6.91 bc	5.42 j-n
$VFP_{50}S$	3.59 tuv	6.25 efg	6.72 cd	5.42 j-n
$VFP_{25}S$	3.54 tuv	6.53 def	6.20 fg	5.00 opq
$VFPS_{75}$	3.72 st	6.60 cde	7.20 ab	5.41 j-n
$VFPS_{50}$	3.37 tuv	6.42 def	7.41 a	5.22 l-o
$VFPS_{25}$	3.64 stu	6.39 def	7.21 ab	4.84 pq
Rain-fed	2.81 w	3.98 s	4.39 r	3.32 uv
LSD (0.05)	0.367			

Source	*df*		*Significance of F-values*		
	1	*2*	*2005*	*2006*	*2005-2006*
Years (Y)	-	1			**
Blocks	2	4	ns	ns	ns
Treatments (T)	13	13	**	**	**
Y x T	-	13			ns
Main plot error	26	52			
Stages (S)	3	3	**	**	**
T x S	39	39	**	**	**
Y x S	-	3			ns
Y x T x S	-	39			ns
Sub plot error	84	168			

[+], means with different letters in the same column are significantly different (P<0.05); df, degrees of freedom; 1, individual year; 2, combined over 2 years; ns, non-significant; *, significant at the 5% of probability level (P<0.05); **, significant at the 1% of probability level (P<0.01) higher than all the other treatments, whereas rain-fed treatment resulted in plant height (64.8 cm) significantly lower than all the other treatments. On the other hand, significant differences were not observed in plant heights of $V_{75}FPS$, $VF_{75}PS$, $VFP_{75}S$, $VFP_{50}S$ and $VFPS_{75}$ treatments (Table 7). These findings are in agreement with those of Brady et al (1974), Korte et al (1983b), Kadhem et al (1985), Specht et al (1989), Karam et al (2005) and Rosadi et al (2005) who reported that irrigation applications significantly increased plant height when compared to rain-fed conditions. Results revealed decreasing plant heights with increasing water deficits in four growth stages. The 75% water deficit at flowering period ($VF_{25}PS$ treatment) decreased plant height by 22.3%. Plant height decrease ratios of $V_{25}FPS$, $VFPS_{25}$ and $VFP_{25}S$ treatments were respectively observed as 17.0%, 15.9% and 13.7%. Such findings indicated that plant heights were more sensitive to water deficit applied during flowering and vegetative growth period than the other periods since the plants already completed substantial portion of vegetative growth during pod formation and seed enlargement periods.

Number of pods per plant and number of seeds per plant were also significantly affected by deficit irrigation, with values for all irrigation treatments higher than those for rain-fed treatment (Table 7). Several previous studies (Korte et al 1983b; Kadhem et al 1985; Karam et al 2005) have reported similar results.

The highest (56.9) and the lowest (23.4) number of pods per plant were respectively observed in VFPS and rain-fed treatments (Table 7). Increasing water deficit in each growth stage (75% water deficit), especially in seed enlargement period, resulted in significant decreases in number of pods per plant. The decrease in number of pods per plant in $V_{25}FPS$, $VF_{25}PS$, $VFP_{25}S$ and $VFPS_{25}$ treatments were respectively observed as 18%, 22%, 31% and 35%. These results indicted decreased number of pods per plant with increasing water stress and the greatest decrease was observed in seed enlargement period. Ul-Haq & Brown (1985) applied 15-day water stress at different growth periods of soybean and observed the decrease in number pods per plant of flowering, pod formation and seed enlargement periods respectively as 19%, 32% and 42%. Current findings on decrease in number of pods per plant are parallel to findings of those studies.

While the highest number of seeds per plant was observed in VFPS full irrigation treatment with 159.4, the lowest value was observed in rain-fed treatment with 62.2 (Table 7). Such results indicated that water deficit throughout the total growth period resulted in significant decreases in number of seeds per plant. Except for seed enlargement period, 25% water deficit applied in each growth stages ($V_{75}FPS$, $VF_{75}PS$ and $VFP_{75}S$ treatments) yielded similar number of seeds per plant. The greatest water deficit treatments (75%) of four different growth stages made the plant resistance levels against water deficits more remarkable. The decrease in number of seeds per plant in $V_{25}FPS$, $VF_{25}PS$, $VFP_{25}S$ and $VFPS_{25}$ treatments were respectively observed as 18.3%, 23.3%, 30.7% and 36.1%. Such results indicated under water deficit conditions that the greatest decrease in number of seeds per plant was observed in seed enlargement and pod formation periods and these periods were followed by flowering period. Karam et al (2005) reported insignificant decreases in number of seeds per plant in soybean grown under semi-arid climate conditions and water deficit at flowering period and indicated a 20% decrease compared to full irrigation at seed enlargement period. Hodges & Heatherly (1983) reported decreased yields with water stress applied at flowering and pod formation periods soybean since water stress decreased number of plants per unit area. Current findings comply with the results of those previous studies.

In the present study, the highest seed yield (4004 kg ha^{-1}) was observed with the VFPS irrigation treatment, followed by the $V_{75}FPS$ (3910 kg ha^{-1}) and $V_{50}FPS$ (3889 kg ha^{-1}) deficit irrigation treatments (Table 7). Evett et al (2000) carried out a drip irrigation water deficit experiment over clay-loam soils of Bushland-Texas and reported the highest mean soybean yield of full irrigation treatment as 3830 kg ha^{-1}. Doss et al (1974), Ashley

Table 7- Effects of irrigation treatment on seed yield, crude oil content, crude protein content and certain plant characteristics (2005-2006 average)

Çizelge 7- Sulama konularının tane verimi, yağ oranı, protein oranı ve belirli bitki özelliklerine etkileri (2 yılın ortalaması)

Treatments	*Plant height (cm)*	*Number of pods per plant*	*Number of seeds per plant*	*Seed yield (kg ha^{-1})*	*1000-seed weight (g)*	*Crude oil content (%)*	*Crude protein content (%)*
VFPS	98.2 a^{+}	56.9 a	159.4 a	4004 a	136.1 a	22.7 a	30.5 g
V_{75}FPS	90.2 abc	52.9 a-d	149.7 abc	3910 ab	131.2 abc	22.3 abc	31.5 def
V_{50}FPS	86.7 bc	49.5 a-e	141.0 a-d	3889 ab	128.5 b-e	22.2 a-d	32.3 bc
V_{25}FPS	81.5 cd	46.8 c-f	130.2 b-f	3798 bc	127.9 b-e	21.7 cde	31.4 ef
VF_{75}PS	89.1 abc	53.9 abc	147.8 abc	3793 bc	131.8 ab	22.2 a-d	31.1 fg
VF_{50}PS	86.2 bc	45.8 def	128.8 c-f	3528 ef	128.9 bcd	21.7 cde	32.4 bc
VF_{25}PS	76.3 d	44.3 efg	122.2 d-g	3174 hı	125.3 def	21.1 ef	32.9 ab
VFP_{75}S	93.6 ab	54.8 ab	151.2 ab	3687 cd	128.2 b-e	21.9 bcd	32.2 bcd
VFP_{50}S	90.0 abc	47.7 b-e	131.4 b-f	3385 fg	127.0 b-e	21.6 de	32.4 bc
VFP_{25}S	84.7 bcd	39.3 fg	110.4 fg	3095 ı	124.4 def	20.6 f	32.5 bc
$VFPS_{75}$	92.6 ab	48.6 b-e	134.3 b-e	3554 de	126.3 cde	22.6 a	30.6 g
$VFPS_{50}$	87.7 bc	41.9 efg	117.9 efg	3256 gh	125.9 cde	22.3 abc	32.1 cde
$VFPS_{25}$	82.6 cd	37.1 g	101.8 g	2932 j	123.3 ef	22.4 ab	32.1 cde
Rain-fed	64.8 e	23.4 h	62.2 h	1974 k	120.4 f	19.1 g	33.6 a
LSD (0.05)	9.298	7.865	21.94	14.83	5.413	0.6314	0.7184

$^{+}$, means with different letters in the same column are significantly different ($P<0.05$)

& Ethridge (1978) and Kabalan (1998) indicated the highest seed yields as between 3500-4200 kg ha^{-1}. Paltineanu et al (1994) in another study reported the highest seed yield of sprinkler-irrigated soybean as 4010 kg ha^{-1}. The seed yields of the present study at full irrigation were similar to values reported by above specified studies. Full VFPS irrigation produced a seed yield 50.6% greater than that of the rain-fed treatment, whereas V_{75}FPS and V_{50}FPS deficit irrigation treatments produced yields 49.5% and 49.2% greater, respectively, than rain-fed treatment, and V_{25}FPS VF_{25}PS, VFP_{25}S and $VFPS_{25}$ treatments produced yields 48%, 37.8%, 36.2% and 32.6% greater, respectively, than rain-fed treatment. Seed yield significantly reduced as the level of water deficit increased. These results indicated that soybean seed yield was not affected by deficit irrigation during the vegetative development stage, but seed yield was significantly reduced when deficit irrigation was applied during flowering, pod formation, or seed enlargement (Figure 1), with soybeans exhibiting the greatest sensitivity to deficit irrigation at the seed enlargement stage. In general, this is in agreement with Chang (1983), Karam et al (2005) and Dogan et al (2007). Other researchers (Eck et al 1987; De Costa & Shanmugathasan 2002; Karam et al 2005; Rosadi et al 2005; Dogan et al 2007; O'Shaughnessy et al 2011) have also reported reductions in soybean seed yields under water deficit and drought-stress conditions.

In the present study, the highest 1000-seed weight value was obtained from the VFPS (136.1 g) irrigation treatment and the lowest from the rain-fed treatment (120.4 g) (Table 7). These results are in line with those of Griffin et al (1985) and Shafii et al (2011). Considering the growth periods, the lowest

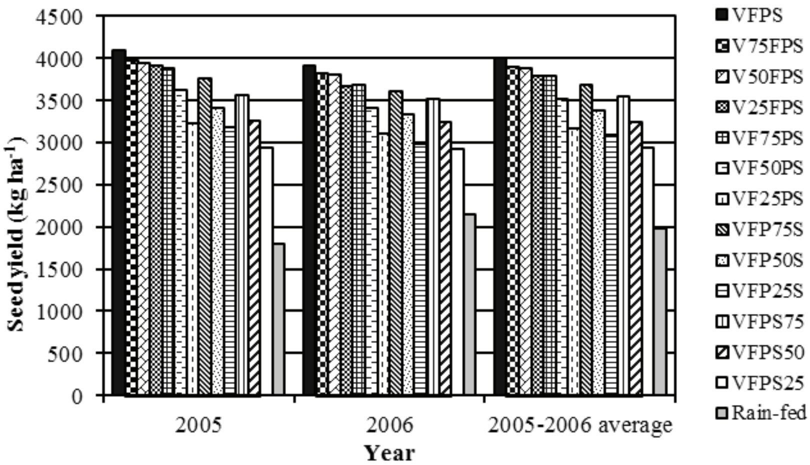

Figure 1- Variations in seed yield among irrigation treatments for 2005, 2006 and 2005-2006 average

Şekil 1- Sulama konularına göre 2005, 2006 ve 2 yılın birleştirilmiş verileri için tane verimi değişimleri

mean 1000-seed weight (123.3 g) was observed in 75% water deficit treatment of seed enlargement period ($VFPS_{25}$). Karam et al (2005) reported significant decreases in 1000-seed weight of soybean grown under semi-arid climate conditions of Lebanon with water deficit at flowering period and indicated 10% decrease compared to water deficit treatment of seed enlargement period. Smiciklas et al (1992), De Souza et al (1997) and Dogan et al (2007) also reported decreased seed weights of soybean with water stress exerted at seed enlargement period.

3.4. Quality components

Soybean crude oil and crude protein contents were significantly affected by irrigation treatment (Table 7). The VFPS treatment had the highest crude oil content (22.7%), and rain-fed treatment had the lowest crude oil content (19.1%). Results revealed increased crude oil contents with increasing irrigation treatments. The highest crude oil content of soybean seeds was observed in full irrigation in which water requirements were fully met during the irrigation season. Maximum seed yield in full irrigation of the present study is in line with a previous study showing that both soybean oil content and yield were highest with the application of both irrigation and fertilizer (Xiaobing et al 2004). Other studies have also demonstrated soybean yields to increase when sufficient water and fertilizer are available, and they have also shown positive correlations between soybean yield and oil content (Schoner & Fehr 1979; Calpten 1986; Xu & Zhang 1995). Crude oil contents of 75% water deficits of $V_{25}FPS$ $VF_{25}PS$, $VFP_{25}S$ and $VFPS_{25}$ treatments were respectively 1%, 1.6%, 2.1% and 0.3% lower than the crude oil content of full irrigation treatment. Such findings indicated that decreases in crude oil contents under water deficit conditions at different growth periods were not much different from each other and the ratios were quite low.

Full irrigation (VFPS) resulted in the lowest crude protein value (30.5%), which is in line with Xiaobing et al (2004), who reported protein content decreased as soybean yield was maximized with irrigation and fertilizer application. Xiaobing et al (2004) reported that maintaining a higher level of field water capacity during the growing season is detrimental to seed protein accumulation in soybeans. Hartwig & Kilen (1991) indicated a general inverse relationship between soybean seed yield and seed protein content. Complied with that study, while the highest yield was observed in full irrigation (VFPS) treatment of the present study, the lowest crude protein content (30.5%) was also observed in full irrigation treatment. Crude protein contents of 75% water deficit treatments of $V_{25}FPS$ $VF_{25}PS$, $VFP_{25}S$ and $VFPS_{25}$ were respectively 2.9%, 7.9%, 6.5% and 5.2% higher than the crude protein content of full irrigation treatment. Such findings again indicated that decreases in crude protein contents under water deficit conditions at different growth periods were not much different from each other and the ratios were again quite low.

With regard to crude oil and protein contents, Bellaloui & Mengistu (2008) reported different responses of cultivars to irrigation. Such different responses may underline maturity or/and genotype differences and their adaptations to environmental stress factors such as soil water content and temperature (Bellaloui & Mengistu 2008).

3.5. Applied irrigation water, evapotranspiration and soil water content

The average annual amount of irrigation water applied in 2005-2006 varied from 30 mm for the rain-fed treatment to 622 mm for the VFPS treatment. For all treatments, an average 30 mm of irrigation water was applied for plant emergence in 2005-2006. The present study found seasonal ET (2005-2006 average) varied between 355 mm (rain-fed treatment) and 809 mm (VFPS) (Table 8). Doorenbos & Kassam (1979) reported water requirements (ETm) for maximal soybean production to vary between 450-700 mm per season, depending on climate and length of growing season, which they reported to range, in general, from between 100-130 days. By comparison, the present study had longer growing periods (152 days in 2005 and 150 days in 2006), which could account for the higher ETm value observed for full VFPS irrigation in the present study when compared to Doorenbos & Kassam (1979). Another similar study conducted by Karam et al (2005) in 2000 and 2001 reported a mean ETm value of 763 mm and a mean growing season of 139 days.

The soil water content courses of irrigation treatments for 90 cm soil profile, in 2005 and 2006 growing season are presented in Figure 2 and 3.

Table 8- Total amounts of irrigation water, seasonal evapotranspiration (ET), water use efficiency (WUE) and irrigation water use efficiency (IWUE) for soybeans (2005-2006 average)

Çizelge 8- Soya fasulyesi için toplam sulama suyu miktarı, mevsimlik bitki su tüketimi (BST), su kullanım etkinliği (SKE) ve sulama suyu kullanım etkinliği (SSKE) (2 yılın ortalaması)

Treatments	*Total irrigation (mm)*	*Seasonal ET (mm)*	*WUE ($kg\ m^{-3}$)*	*IWUE ($kg\ m^{-3}$)*
VFPS	622	809	0.49	0.33
$V_{75}FPS$	585	766	0.51	0.33
$V_{50}FPS$	547	743	0.52	0.35
$V_{25}FPS$	510	698	0.54	0.36
$VF_{75}PS$	589	756	0.50	0.31
$VF_{50}PS$	556	712	0.50	0.28
$VF_{25}PS$	523	675	0.47	0.23
$VFP_{75}S$	579	761	0.48	0.30
$VFP_{50}S$	536	721	0.47	0.26
$VFP_{25}S$	493	664	0.47	0.23
$VFPS_{75}$	588	763	0.47	0.27
$VFPS_{50}$	554	732	0.44	0.23
$VFPS_{25}$	519	696	0.42	0.18
Rain-fed	30	355	0.56	0.00

According to irrigation programs of experimental treatments, limited irrigation water were applied for different phenological stages. Due to this irrigation scheduling consideration, water stress was observed for one individual period of each irrigation treatment. Because of this, soil water content fluctuations of different treatments throughout the growing season, except water limited periods, were very close to each other (Figure 2 and 3).

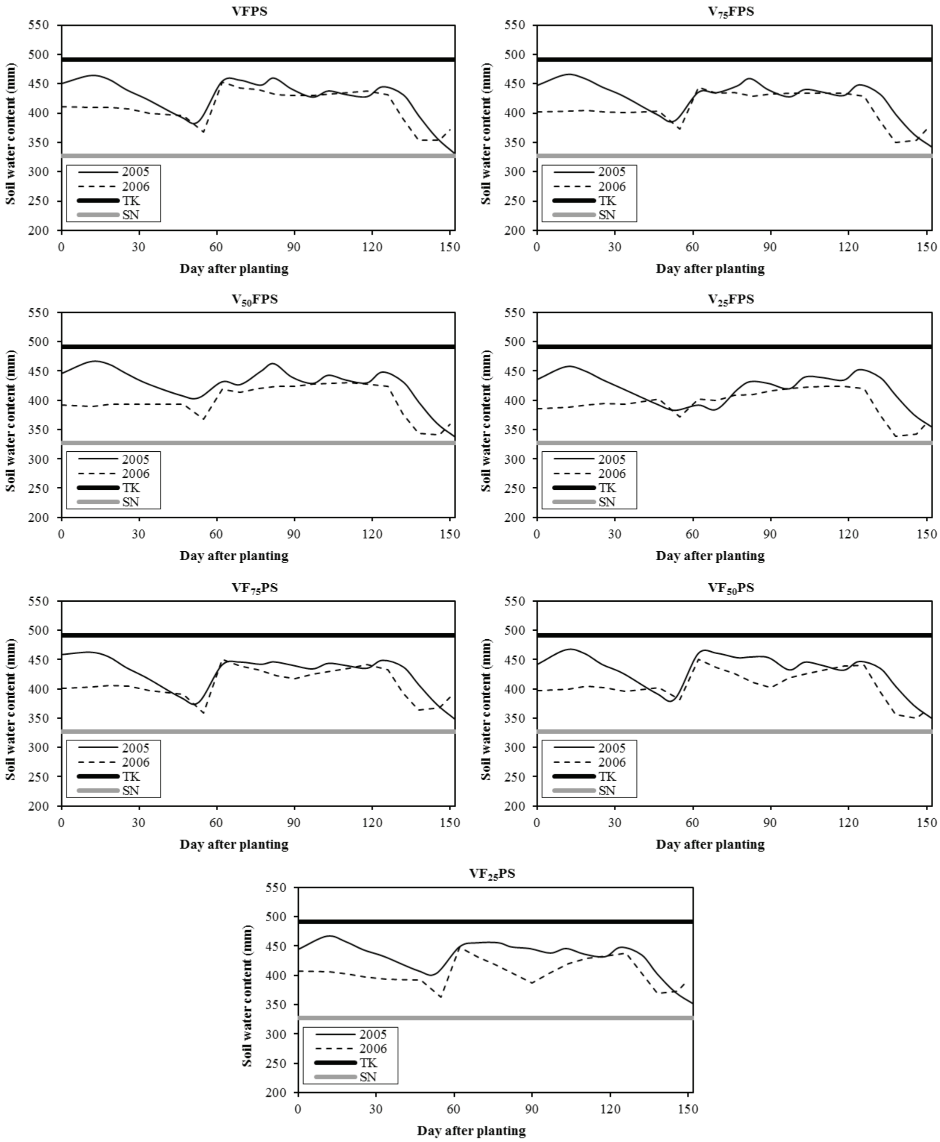

Figure 2- Variations of soil water content of VFPS, V_{75}FPS, V_{50}FPS, V_{25}FPS, VF_{75}PS, VF_{50}PS and VF_{25}PS treatments

Şekil 2- VÇBT, V_{75}ÇBT, V_{50}ÇBT, V_{25}ÇBT, $VÇ_{75}$BT, $VÇ_{50}$BT ve $VÇ_{25}$BT konuları toprak su içeriği değişimleri

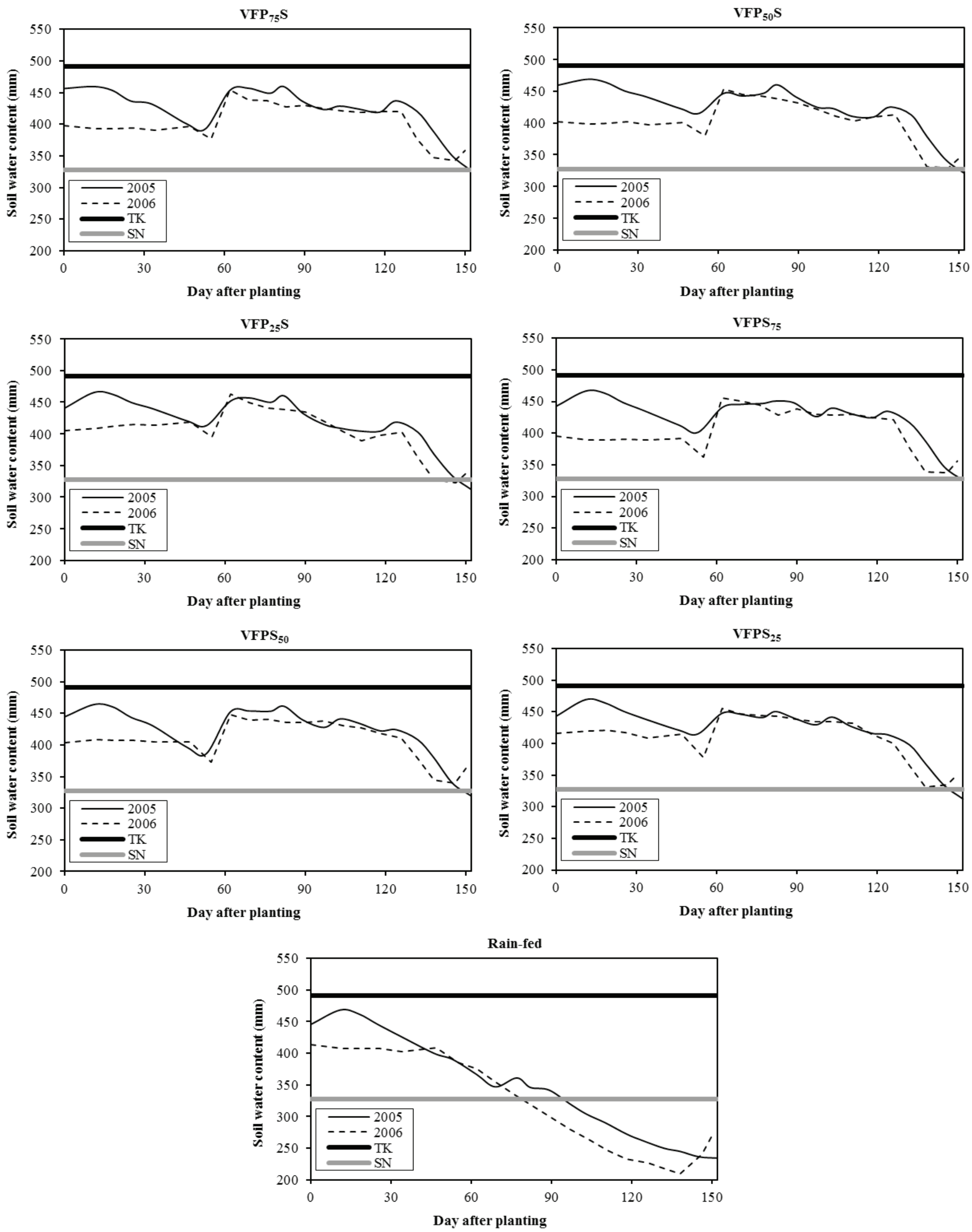

Figure 3- Variations of soil water content of VFP$_{75}$S, VFP$_{50}$S, VFP$_{25}$S, VFPS$_{75}$, VFPS$_{50}$, VFPS$_{25}$ and Rain-fed treatments

Şekil 3- VÇB$_{75}$T, VÇB$_{50}$T, VÇB$_{25}$T, VÇBT$_{75}$, VÇBT$_{50}$, VÇBT$_{25}$ ve susuz konular için toprak su içeriği değişimleri

3.6. Water use efficiencies

The present study found WUE values ranging from 0.42 kg m^{-3} ($VFPS_{25}$) to 0.56 kg m^{-3} (Rain-fed treatment) and IWUE values ranging from 0.18 kg m^{-3} ($VFPS_{25}$) to 0.36 kg m^{-3} ($V_{25}FPS$) (Table 8). Among the deficit irrigation treatments, the highest WUE (0.52 and 0.54 kg m^{-3}) and IWUE (0.35 and 0.36 kg m^{-3}) values were obtained from $V_{50}FPS$ and $V_{25}FPS$ deficit irrigation treatments, respectively (Table 8). Scott et al (1987) reported average WUE values for soybean ranging between approximately 0.60 kg m^{-3} for full irrigation and 0.73 kg m^{-3} for rain-fed irrigation treatments. Evett et al (2000) found WUE and IWUE values of 0.44 and 0.62 kg m^{-3}, respectively, for full irrigation treatment. Kırnak et al (2013) found WUE values of 0.64 kg m^{-3} for full irrigation and 0.35 kg m^{-3} for rain-fed treatment, whereas IWUE values for full irrigation and rain-fed treatment were 0.67 kg m^{-3} and 0.41 kg m^{-3}, respectively.

4. Conclusions

The results of this study showed that deficit irrigation had significant effects on LAI, plant height, number of pods per plant, number of seeds per plant, seed yield, 1000-seed weight, crude oil content and crude protein content. The highest seed yield (4004 kg ha^{-1}) was obtained with full irrigation (VFPS) and the lowest seed yield (1974 kg ha^{-1}) with rain-fed treatment, with an average difference in yield between the two treatments of 50.6%. $V_{75}FPS$ and $V_{50}FPS$ deficit irrigations had seed yields 49.5% and 49.2% higher than those of rain-fed treatment, and $V_{25}FPS$, $VF_{25}PS$, $VFP_{25}S$ and $VFPS_{25}$ deficit irrigations had seed yields that were, respectively, 48%, 37.8%, 36.2% and 32.6% higher than those of rain-fed treatment. These results indicated that deficit irrigation during the vegetative development period did not significantly affect soybean seed yield, whereas yield was significantly reduced when deficit irrigation was applied during the flowering, pod formation, or seed enlargement periods. In addition to the highest seed yield, VFPS treatment also produced the highest crude oil content (22.7%), whereas the rain-fed treatment had the lowest crude oil content (19.1%). In contrast, the highest crude protein content was obtained with rain-fed treatment (33.6%) and the lowest with VFPS (30.5%). However, when WUE and IWUE values are taken into consideration, $V_{50}FPS$ and $V_{25}FPS$ deficit irrigation treatments can be recommended instead of VFPS irrigation in areas where water costs are high and/or water is scarce.

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References

Ashley D A & Ethridge W J (1978). Irrigation effects on vegetative and reproductive development of three soybeans cultivars. *Agronomy Journal* **70**: 467-471

Bellaloui N & Mengistu A (2008). Seed composition is influenced by irrigation regimes and cultivar differences in soybean. *Irrigation Science* **26**: 261-268

Bos M G (1980). Irrigation efficiencies at crop production level. *ICID Bulletin* **29**: 18-25

Bos M G (1985). Summary of ICID definitions of irrigation efficiency. *ICID Bulletin* **34**: 28-31

Boyer J S (1982). Plant productivity and environment. *Science* **218**: 443-448

Brady R A, Stone L R, Nickell C D & Powers W L (1974). Water conservation through proper timing of soybean irrigation. *Journal of Soil and Water Conservation* **29**: 266-268

Calpten J A (1986). Genetic variability for agronomic traits in population containing *Glycine soja* germplasm. *Crop Science* **26**: 681-686

Cox W J & Jolliff G D (1986). Growth and yield of sunflower and soybean under soil water deficits. *Agronomy Journal* **78**: 226-230

De Costa W A & Shanmugathasan K N (2002). Physiology of yield determination of soybean under different irrigation regimes in the sub-humid zone of Sri Lanka. *Field Crops Research* **75**: 23-35

De Souza P I, Egli D B & Bruening W P (1997). Water stress during seed filling and leaf senescence in soybean. *Agronomy Journal* **89**(5): 807-812

Dogan E, Kirnak H & Copur O (2007). Deficit irrigations during soybean reproductive stages and CROPGRO-soybean simulations under semi-arid climatic conditions. *Field Crops Research* **103**: 154-159

Doorenbos J & Kassam A H (1979). Yield Response to Water. Irrigation and Drainage Paper No: 33, FAO, Rome

Doss B D, Pearson R W & Rogers H T (1974). Effect of soil water stress at various growth stages on soybean yield. *Agronomy Journal* **66**(2): 297-299

Eck H V, Mathers A C & Musick J T (1987). Plant water stress at various growth stages and growth and yield of soybeans. *Field Crops Research* **17**: 1-16

Evett S R, Howell T A, Schneider A D, Upchurch D R & Wanjura D F (2000). Automatic Drip Irrigation of Corn and Soybean. In: *Proceedings of the 4th Decennial National Irrigation Symposium*, 14-16 November, Phoenix, AZ, USA, pp. 401-408

Fageria N K, Baligar V C & Jones C A (1997). Growth and Mineral Nutrition of Field Crops. 2nd Ed. Marcel Dekker, Inc., New York

Foroud N, Mundel H H, Saindon G & Entz T (1993). Effect of level and timing of moisture stress on soybean yield components. *Irrigation Science* **13**: 149-155

Hartwig E E & Kilen T C (1991). Yield and composition of soybean seed from parents with different protein, similar yield. *Crop Science* **31**(2): 290-292

Hodges H F & Heatherly L G (1983). Principles of water management for soybean production. Bull. 919, Mississippi State University, Starkville

Howell T A (2001). Enhancing water use efficiency in irrigated agriculture. *Agronomy Journal* **93**: 281-289

Ivanov P (1974). Biochemical differentiation of sunflower varieties as a result of breeding. In: *Proceedings of the 6th International Sunflower Conference*, 22-24 July, Bucharest, Romania, pp. 225-229

James L G (1993). Principles of Farm Irrigation System Design. Krieger Publishing Company, Malabar, Florida

Kabalan R (1998). Consomation en eau et productivite´ d'une culture du soja a` la Be´kaa. DEA, AUPELF-UREF, Bureau du Monde Arabe, Beyrouth, pp. 25

Kadhem F A, Specht J E & Williams J H (1985). Soybean irrigation serially timed during stages R1 to R6. II. Yield component responses. *Agronomy Journal* **77**: 299-304

Karam F, Masaad R, Sfeir T, Mounzer O & Rouphael Y (2005). Evapotranspiration and seed yield of field grown soybean under deficit irrigation conditions. *Agricultural Water Management* **75**: 226-244

Kirda C (2002). Deficit irrigation scheduling based on plant growth stages showing water stress tolerance. Deficit Irrigation Practice, Water Report 22, FAO, Rome, pp. 3-10

Kırnak H, Doğan E, Çopur O & Gökalp Z (2013). Irrigation and yield parameters of soybean as effected by irrigation management, soil compaction and nitrogen fertilization. *Tarım Bilimleri Dergisi-Journal of Agricultural Sciences* **19**(4): 297-309

Korte L L, Williams J H, Specht J E & Sorensen R C (1983a). Irrigation of soybean genotypes during reproductive ontogeny. I. Agronomic responses. *Crop Science* **23**: 521-527

Korte L L, Williams J H, Specht J E & Sorensen R C (1983b). Irrigation of soybean genotypes during reproductive ontogeny. II. Yield component responses. *Crop Science* **23**: 528-533

O'Shaughnessy S A, Evett S R, Colaizzi P D & Howell T A (2011). Using radiation thermography and thermometry to evaluate crop water stress in soybean and cotton. *Agricultural Water Management* **98**: 1523-1535

Pala M, Ryan J, Zhang H, Singh M & Harris H C (2007). Water-use efficiency of wheat-based rotation systems in a Mediterranean environment. *Agricultural Water Management* **93**: 136-144

Paltineanu I C, Negrila C, Craciun M & Craciun I (1994). Long term trials on irrigated field crops in semiarid area of Romania. *Romania Agricultural Research* **1**: 85-92

Petit J R, Jouzel J, Raynaud D, Barkov N I, Barnola J M, Basile I, Bender M, Chappellaz J, Davis M, Delaygue G, Delmotte M, Kotlyakov V M, Legrand M, Lipenkov V Y, Lorius C, Pepin L, Ritz C, Saltzman E & Stievenard M (1999). Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* **399**: 429-436

Pomeranz Y & Clifton E (1994). Food Analysis Theory and Practice, 3rd Ed. Kluwer Academic Publisher, San Diego

Rosadi R A B, Afandi M S, Senge M, Ito K & Adomako J T (2005). Critical water content and water stress coefficient of soybean (*Glycine max* [L.] Merr.) under deficit irrigation. *Paddy and Water Environment* **3**: 219-223

Salassi M E, Musick J A, Heatherly L G & Hamill J G (1984). An economic analysis of soybean yield response to irrigation of Mississippi River Delta soils. *Mississippi Agricultural and Forestry Experiment Station Bulletin* **60**: 928-935

Schoner C S & Fehr W R (1979). Utilization of plant introduction in soybean breeding population. *Crop Science* **11**: 185-188

Scott H D, Ferguson J A & Wood L S (1987). Water use, yield, and dry matter accumulation by determinate soybean grown in a humid region. *Agronomy Journal* **79**: 870-875

Shafii F, Ebadi A, Golloje K S & Eshghi-Gharib A (2011). Soybean response to nitrogen fertilizer under water deficit conditions. *African Journal of Biotechnology* **10**(16): 3112-3120

Smiciklas K D, Mullen R E, Carlson R E & Knapp A D (1992). Soybean seed quality response to drought-stress and pod position. *Agronomy Journal* **84**(2): 166-170

Specht J E, Elmore R W, Eisenhauer D E & Klocke N W (1989). Growth stage scheduling criteria for sprinkler-irrigated soybeans. *Irrigation Science* **10**: 99-111

Steel R G D & Torrie J H (1980). Principles and Procedures of Statistics, 2nd Ed. McGraw-Hill, New York

Sweeney D W, Long J H & Kirkham M B (2003). A single irrigation to improve early maturing soybean yield and quality. *Soil Science Society of America Journal* **67**: 235-240

Ul-Haq A & Brown D A (1985). Effect of soil moisture deficit in the upper root zone on growth and yield of soybeans. *Arkansas Farm Research* **34**(3): 4

Xiaobing L, Herbert S J, Jin J, Zhang Q & Wang G (2004). Responses of photosynthetic rates and yield/quality of main crops to irrigation and manure application in the black soil area of Northeast China. *Plant and Soil* **261**(1-2): 55-60

Xu X B & Zhang X T (1995). Density and fertilizer doses in relation to soybean yield. *Tillage and Culture* (in Chinese) **2**: 18-19

Yazar A, Çevik B, Tekinel O, Tülücü K, Başbuğ R & Kanber R (1989). Çukurova Koşullarında Yağmurlama Yöntemiyle Sulanan Ikinci Ürün Soyada ET-Verim Ilişkisinin Belirlenmesi, TÜBİTAK-TOAG-551

Zhang H, Wang X, You M Z & Liu C M (1999). Water-yield relations and water-use efficiency of winter wheat in the North China Plain. *Irrigation Science* **19**: 37-45