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Full Length Research Paper

Effects of deficit irrigation on yield and yield components of vegetable soybean [*Glycine max* L. (Merr.)] in semi-arid conditions

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Vegetable soybeans [*Glycine max* L (Merr.)] are very sensitive crops to environmental conditions during their growth stages, especially in term of water scarcity. Water scarcity is one of the major environmental factors influencing sustainable agricultural production in arid and semi-arid regions. Careful management irrigation strategies need to save irrigation water with marginal yield reduction. The objective of this research was to investigate the effects of the water deficit on yield and yield components of soybean in semi-arid conditions. This research was carried out at the Agricultural Experimental Field of the Harran University (Sanliurfa, Turkey) on clay soil during the growth periods of 2006 and 2007. The irrigation treatments were 33% (I_{33}), 67% (I_{67}), 100% (I_{100}) and 133% (I_{133}) ratios of total irrigation water applied (IW)/cumulative pan evaporation (CPE) with four day irrigation interval. The average amount of irrigation water applied to treatments (I_{133}, I_{100}, I_{67} and I_{33}) was 1058, 795, 533 and 263 and 1094, 823, 551 and 272 mm for Toyokomachi and Toyohomare cultivars, respectively. The maximum green pod yields were 20.6 and 29.1 t ha^{-1} with 997 and 922 mm water consumption for Toyohomare and Toyokomachi, respectively in I_{133} treatments. Yield response factor (k_y) values of I_{100}, I_{67} and I_{33} treatments were determined as 2.17, 0.92 and 0.59 for Toyohomare and 3.50, 0.61 and 0.61 for Toyokomachi, respectively. The results of the study implied that at least equal (I_{100}) or excess of the evaporated water amount is required to produce high yield in soybean. Differences of yield between cultivars in response to irrigation levels make it necessary to select less sensitive cultivars to water stress especially in semi-arid and arid areas. Varietal characteristics must be considered for successful growing of soybean.

Key words: Soybean, *Glycine max*, deficit irrigation, water deficit.

INTRODUCTION

Soybeans are widely cultivated and are one of the world's most important crops, with a world production of 210.9 million tones (Anonymous, 2010). In Turkey, soybean production began after World War II and steadily increased (as the second most cultivated crop) until 1987 when the amount of production reached 250,000 tones.

However, its production was decreased to 75.000 tons in 2002 and to 25.000 tons in 2004 (Haskinaci, 2004). As a result, Turkey had to import soybean to supplement local production and meet national consumption. Soybeans are rich in protein (40%), oil (20%), phospholipids, minerals, vitamins and diet fiber and are used for both human and animal consumption as well as for industrial purposes (Mentreddy, 2002; Anonymous, 2007; Singh, 2010). Soybeans are generally divided into two major classes (Young et al., 2000). The first group (known as field or grain soybean) is usually grown for the production of oil and is widely used as an ingredient in various food, feed and industrial products (consumed as

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Abbreviations: GPY, Green pod yield per plant; **PWt,** pod weight; **PL,** pod length; **PWh,** pod width; **NPP,** number of pod per plant; **NSPP,** number of seed per pod; **PH,** plant height; **WUE,** water use efficiency; **IWUE,** irrigation water use efficiency; **IW,** irrigation water applied; ***ET_a*,** actual evapotranspiration.

soy flour, soy meal, soy sprouts, soy milk, soy meat, soy sauce, tofu, etc). The second group, known as vegetable soybean (edamame, green soybean, sweet bean, edible soybean), has large green seeds with a sweet, nutty taste (Wszelaki et al., 2005). Vegetable soybean is harvested when immature at 80% pod fill or at the R6 stage of development when the pods have full size seeds (Fehr et al., 1971; Rao et al., 2002).

The worlds' population continues to rise and water is a limited resource. Thus, it is becoming increasingly difficult to continue with current irrigation practices in arid and semi-arid region of the world. The world's population has grown more than twice that of water use and regions with chronic water shortage have increased in the last century. It is projected that 1.8 billion people will be living in regions with absolute water scarcity and two-thirds of the world's population may be under water-stress conditions by 2025 (FAO, 2010). Therefore, the sustainable use of water in irrigated agricultural systems, with an emphasis on reducing water use, requires careful planning and management. Yield stability and productivity will depend highly upon developing crop varieties and cropping systems that are better adapted to water deficit. Recent research has focused on saving significant amounts of irrigation water, improving water use and developing high performance irrigation programs for growing high quality crops that utilize less water.

The aims of this research were to evaluate the production and yield potential of vegetable soybean, using two soybean cultivars, Toyokomachi and Toyohomare, in similar maturity group, grown under semi-arid climatic conditions to investigate the effects of water stress on the yield and various yield components.

MATERIALS AND METHODS

Two determinate cultivars, developed at Japan and that had similar maturity, were chosen to determine their responses to deficit irrigation treatments under semiarid conditions. The first soybean cultivar was Toyohomare with gray pubescence, white flower, yellow seed coat and hilum, high yield and excellent seed quality (Yumoto et al., 1995). The second was Toyokomachi, with grey pubescence, purple flowers, yellow seed coat and hilum, elect canopy, broad leaflets and large seed with high and stable yield. Toyokomachi is one of the most early maturity varieties (Sasaki et al., 1990).

Experimental site and meteorological data

Field experiments were conducted on clay soil at the Agricultural Experimental Field of the Harran University (Sanliurfa, Turkey) during the growth periods of 2006 and 2007. The site is situated on the latitude of 37°08' North, longitude 38°46' East and 464 m above the sea level.

The soil water contents, calculated according to gravimetrical method (James, 1988), (w/w %) at field capacity were 33.1, 33.2 and 33.7% and at permanent wilting point were 21.6, 21.9 and 22.8%, in 0 to 30, 30 to 60 and 60 to 90 cm soil depths. The study area was located in a semi-arid climate. Table 1 shows some recorded meteorological data of the experimental site.

Crop management, experimental design and irrigation treatments

Two cultivars of vegetable soybean were grown. The seeds were sown 25 cm in a row with 70 cm between the rows space on July 25 in both years. Three to four seeds were sown and thinning was done to maintain 2 plants per hole after germination. The plants were fertilized with 40, 60 and 80 kg ha^{-1} of N, P_2O_5 and K_2O_5, respectively.

The crop was harvested at an immature (R6) stage (Fehr et al., 1971) and green pod yield (GPY) per plant was measured and mean values per hectare (t ha^{-1}) were calculated. Samples of 50 pods were randomly chosen to determine pod weight (PWt), pod length (PL), pod width (PWh) and number of seeds per pod (NSPP). The total number of pods per plant (NPP, containing 1, 2 or 3 beans per pod) and the plant height (PH) were also recorded.

This study was conducted twice in 2006 and 2007 separately. The experiments were arranged in a randomized block design. Each plot had 30 hills (60 plants) with three replications. The data were subjected to standard analysis of variance using TARIST (Acikgoz et al., 2004) statistical software. Least significant difference (LSD) test was used for means separation.

Irrigation was applied using a drip method. Each row had its own irrigation line positioned near the plants. The irrigation treatments were 33% (I_{33}), 67% (I_{67}), 100% (I_{100}) and 133% (I_{133}) ratios of total irrigation water applied (IW)/cumulative pan evaporation (CPE) with a four day irrigation interval. Crop evapotranspiration under varying irrigation regimes was calculated using the water balance model, as seen in equation 1 (Garrity et al., 1982):

$$ET_c = IW + P - D - R \pm S \qquad (1)$$

Where, ET_c is the seasonal crop evapotranspiration (mm); IW is the total irrigation water applied (mm); P is the precipitation (mm); D is the drainage (mm); R is the run-off (mm); S is the variation in water content (mm) of the soil profile. All terms were expressed in mm of water in the root zone. The effective root depth was taken as 60 cm. Run-off was taken as to be nil since no run-off was observed using the drip irrigation system.

To calculate the amount of irrigation water applied, a pan evaporation equation was applied (Doorenbos and Pruitt, 1975) (Equation 2):

$$IW = A \times E_{pan} \qquad (2)$$

Where, IW is the amount of irrigation water applied (L); A is the plot area (m^2); E_{pan} is the amount of cumulative evaporation during an irrigation interval (mm).

Water use efficiency and irrigation water use efficiency

Water use efficiency (WUE) is the ratio of fruit yield to the seasonal crop ET_c. Irrigation water use efficiency (IWUE) is the fruit weight per unit of irrigation water applied.

Yield response factor (k_y)

The k_y values are the experimentally derived data from the relationship between relative yield loss ($1-Y_a/Y_m$) and the relative evapotranspiration deficit ($1-ET_a/ET_m$) calculated using equation 3 (Doorenbos and Kassam, 1979):

$$(1 - \frac{Y_a}{Y_m}) = k_y (1 - \frac{ET_a}{ET_m}) \qquad (3)$$

Table 1. Monthly mean value of air temperature (T_a), maximum air temperature (T_{max}), minimum air temperature (T_{min}), relative humidity (RH), class A pan evaporation (E_0), precipitation (P), total solar radiation ([R_s) and wind speed (u_2) of the experimental site.

Year	T_a (°C)	T_{max} (°C)	T_{min} (°C)	RH (%)	E_0 (mm)	P (mm)	R_S (MJ m^{-2} day^{-1})	u_2 (km hr^{-1})
2006								
July	32.2	43.0	20.8	45.5	448	0	27.25	7.2
August	33.4	44.5	22.8	44.6	414	0	19.35	5.4
September	27.2	40.0	16.0	42.3	249	0	19.06	6.5
October	20.6	33.5	10.1	61.5	206	42.5	12.21	3.2
2007								
July	34.0	43.7	22.0	31.3	454	8.0	23.16	7.6
August	32.2	44.8	20.0	41.9	419	0	21.82	5.8
September	28.4	42.0	16.5	36.4	233	0	17.89	6.1
October	21.6	34.2	9.8	47.7	179	3.2	13.42	4.7

Table 2. Analysis of variance for soybean yield and yield components.

Source of variation	Degree of freedom	Mean square						
		GPY	PWt	PL	PWh	NPP	NSPP	PH
Year (Y)	1	31392.8**	0.08ns	177.9**	0.82ns	963.02**	0.02 ns	535.67**
Cultivar (C)	1	66314.3**	0.00ns	8.3ns	0.89ns	7625.52**	0.19 ns	4436.17 **
Y X C	3	15341.0**	0.20ns	24.1ns	1.23ns	1111.69**	0.02 ns	81.25*
Irrigation (I)	3	13071.6**	0.01ns	13.3ns	0.12ns	2704.84**	0.13 ns	253.99**
Y X I	3	463.4ns	0.22ns	32.3**	0.04ns	98.52ns	0.35 ns	151.72**
C X I	3	744.9ns	0.06ns	18.0ns	0.60ns	535.02**	0.08 ns	46.75*
YXCXI	30	150.6ns	0.09ns	2.9ns	0.85ns	814.85**	0.24 ns	60.80**
Error	47	495.2	0.10	7.1	0.37	41.63	0.31	11.27
Total	1	3669.1	0.10	13.3	0.42	498.20	0.26	147.73

*Significant at P < 0.05, ** at P < 0.01; ns, not significant, GPY, green pod yield per plant; PWt, pod weight; PL, pod length; PWh, pod width; NPP, number of pod per plant; NSPP, number of seed per pod; PH, plant height.

Where, Y_a and ET_a are the actual yield and actual evapo-transpiration; Y_m and ET_m the maximum yield and maximum evapotranspiration; k_y the yield response factor.

RESULTS AND DISCUSSION

Yield and yield components

Seeds germinated in 4 to 5 days. Toyohomare and Toyokomachi cultivars flowered 31 and 38 days after sowing (DAS), respectively. The harvest was done manually when the pods contained full green seed (72 and 79 DAS for the Toyohomare and Toyokomachi cultivars, respectively).

The GPY significantly varied (P < 0.01) between years (Y) being higher in 2006 than 2007 (Table 2). One possible explanation for this difference could be associated with greater water stress in 2007 due to the greater ET_a (Table 9). Low air relative humidity combination with high air temperature caused high transpiration rates in 2007 (Table 1). This unfavorable weather condition might cause low yield. The GPY was also significantly higher (P < 0.01) for the Toyokomachi cultivar (C) at R6 (full seed) stage compared with that of the Toyohomare cultivar, ranging from 128.34 to 253.83 g $plant^{-1}$, respectively (Tables 2, 3). It is possible to explain this variation with varietal characteristics, such as, number of branch, node and total number of pods per plant and genotype x environment interaction. In all the irrigation levels, the GPY per plant of Toyokomachi was higher than Toyhomare (Table 8). The interaction between Y x C was also significant (Table 2). The amount of applied irrigation water also significantly affected the GPY, which increased as the amount of irrigation water applied increased (Table 2). The highest yield was at I_{133} (217.20 g $plant^{-1}$), followed by I_{100} (175.93 g $plant^{-1}$), I_{67} (160.66 g $plant^{-1}$) and I_{33} (139.04 g $plant^{-1}$) (Table 4). The results showed that Toyohomare was more sensitive to water stress than Toyokomachi under

Table 3. Green pod yield per plant (g) of the two years.

Year	Cultivar		Average
	Toyohomare	Toyokomachi	
2006	143.74[b]	253.83[a]	198.78[a]
2007	128.34b	166.93[a]	147.64[b]
LSD (P < 0.01)	24.98		17.66

Numbers followed by the same letters (horizontally for cultivars and vertically for year averages) were not significantly different using LSD-test.

Table 4. The green pod yield per plant for each irrigation treatment.

Irrigation	Green pod yield (g plant $^{-1}$)
I_{133}	217.20[a]
I_{100}	175.93[b]
I_{67}	160.66[bc]
I_{33}	139.04[c]
LSD (P < 0.01)	24.98

Numbers followed by the same letters were not significantly different using LSD-test.

different water stress. The relative yield decreases of Toyohomare under medium and low water shortage (I_{100} and I_{67}) were 27 and 34%, respectively. However, under high water stress (I_{33}) relative yield decreases were similar (37 and 35%) in both cultivars (Table 9). Similar results have also been reported by Frederick et al. (1991), Rao et al. (2002), Isoda et al. (2006), Bustomi (2007) and Demirtas et al. (2010). Gungadurdoss and Hanoomanjee (1998) reported that fresh pod yield of ten vegetable soybean cultivars ranged from 11 to 15 t ha^{-1}, whereas the GPY obtained in our study was higher. The possible reasons for such difference could be associated with their work which was conducted in different environmental conditions with other maturity groups of soybean.

The differences in pod weights (PWt) between cultivars under all the irrigation treatments were not significant (Table 2). In this study, limited irrigation was a factor and it stimulated flower and pod abortion. However, if the flowers were pollinated, successfully set seed and seed bearing pods developed. Both cultivars had minimum two seeds per pod and this resulted in similar individual pod weight. Osumi et al. (1998) noted that plants probably abort flower buds to adjust seed set. Soybean pods bear few ovules and responded to water stress mostly by reducing pod set.

The pod length (PL) varied significantly (P < 0.01) between the years (Table 2) been higher in 2007 (with mean PL 57.10 mm) than 2006 (with mean PL 53.25 mm). The interaction between years and irrigation treatments (Y x I) was also significant at P < 0.01 level. The cultivars produced similar size pods, ranging from 50.93 to 59.81 mm in length (Table 5). The length of pods differed slightly in the number of seed per pod. The results showed that the perfect pods (3-seed and 2-big seed pod) were longer than the imperfect pod (2-small seed, 1-seed, atrophied, twisted and defected pod).

The pod weights (PWh) was not significantly different for either cultivar under all the irrigation treatments (Table 2). The average pod weights (PWh) are presented in Table 8.

There were significant differences (P < 0.01) between years, cultivars, irrigation treatments and the interaction among years, cultivars and irrigation treatments (Y x C x I) in total number of pods per plant (NPP) (Table 2). Indeed, NPP was the most sensitive yield component to the limited irrigation. Table 6 shows the mean NPP for cultivars grown under irrigation treatment of the two years. The NPP was significantly reduced by decreasing the amount of the irrigation water applied. The average NP NPP varied from 54.33 to 111.33 depending on the cultivars and the irrigation treatments. The highest NPP for the two cultivars (111.33 and 106.00) was recorded from I_{133} and the lowest (54.33 and 59.33) was from I_{33} in both years. The NPP were greater for Toyokomachi cultivar than for Toyohomare. It has been reported that under favorable cultivation conditions, high yielding soybean cultivars produced more than 60 pods per plant (Isoda et al., 2006). The NPP recorded in our experiment was higher than the value reported by Isoda et al. (2006). The variation between cultivars in GPY could be explained by NPP as in previous reports by Wang et al. (1995) and Board and Modali (2005). Marketable pods should have an average pod length of 4.5 to 5.0 cm and pod width of 1.3 cm and not more than 175 pods weighing 500 g.

Since the increasing NPP was positively correlated with the irrigation water amount, an adequate supply of water may be required for pod setting and high yield in soybean. Previous studies showed that water deficit during the vegetative growth stage had little effect on yield, whereas it increased the flower and pod abortion during the early reproductive stage (Stegman et al., 1990; Frederick et al., 1991; Demirtas et al., 2010). Karam et al. (2005) reported that limited irrigation at the reproductive stages reduced soybean seed yield, but did not significantly reduce seed number or seed weight. The authors also concluded that deficit irrigation occurring during the early reproductive growth stage increased flower and pod abortion and resulted in greater yield loss than at pod elongation stage.

Although flower and pod abortion were not considered in this study, it was observed that deficit irrigation caused significant increases in flower and pod abortion. In fact, during the growth periods in the field, it was observed that high temperature stress occurred simultaneously with low irrigation water applied, thus, negatively affected the flowering and fertilization, whilst increasing flower

Table 5. Pod length (mm) of the two years.

Year	Irrigation				
	I_{133}	I_{100}	I_{67}	I_{33}	Average
2006	55.44^{a}	53.77^{ab}	50.93^{c}	52.84^{ab}	53.25^{b}
2007	56.12^{ab}	55.14^{b}	57.31^{ab}	59.81^{a}	57.10^{a}
LSD ($P < 0.01$)		4.22			2.11

Numbers followed by the same letters (horizontally for irrigation treatments and vertically for year averages) were not significantly different using LSD-test.

Table 6. Number of pod per plant for cultivars and irrigation treatments in 2006 and 2007.

Year	Cultivar	Irrigation			
		I_{133}	I_{100}	I_{67}	I_{33}
2006	Toyohomare	99.33^{a}	65.67^{b}	57.67^{b}	54.33^{b}
	Toyokomachi	106.00^{a}	104.67^{a}	105.33^{a}	90.33^{b}
2007	Toyohomare	83.00^{a}	66.67^{b}	68.33^{b}	61.67^{b}
	Toyokomachi	111.33^{a}	107.67^{a}	63.67^{b}	59.33^{b}
LSD ($P < 0.01$)	14.49				

Numbers followed by the same letter (horizontally) were not significantly different using LSD-test.

Table 7. Plant height for cultivars of the two years.

Year	Cultivar	Irrigation			
		I_{133}	I_{100}	I_{67}	I_{33}
2006	Toyohomare	86.67^{a}	69.42^{b}	70.25^{b}	69.50^{b}
	Toyokomachi	99.17^{a}	96.00^{a}	88.58^{b}	78.58^{c}
	Toyohomare	76.78^{a}	82.18^{a}	76.16^{a}	77.03^{a}
2007	Toyokomachi	101.60^{a}	100.90^{a}	101.25^{a}	95.72^{a}
LSD ($P < 0.01$)	7.54				

Numbers followed by the same letter (horizontally) were not significantly different using LSD-test.

abscission and the number of undeveloped pods and decreasing pod set. Similar results was previously reported by Kokubun et al. (2001), Koti et al. (2005) and Karam et al. (2005). Our data showed that PL and PWh of limited watered plants remained unchanged. While reducing the NPP responding to the deficit irrigation, pod size was regulated and similar size of pods was obtained from the well watered plants.

In both years, the number of seeds per pod (NSPP) showed no significant reduction under water limiting conditions (Table 2). The difference between cultivars was also not significant (Table 2). According to soybean pod quality and the criteria of Gaskell (2001), both cultivars met the quality criteria having a minimum of two beans per pod. The mean NSPP was 2.47 and the highest was recorded for cultivar Toyohomare both in I_{133} and I_{100} (Table 8). The results showed that, deficit irrigation treatments were not significantly affected by the process of fertilization. The NSPP was related to fertilization rate. The number of ovule and seed per pod were not affected by the limited irrigation and neither seed number nor individual pod weight decreased.

Based on the findings, plant heights were affected by limited irrigation treatments significantly. Moreover, the Toyokomachi cultivar grew taller than the Toyohomare cultivar each year of the experiment (Table 7). Significant differences in pH varying from 69.42 to 99.17 cm were recorded for the cultivars in year 2006. The pH was not greatly different among the irrigation treatments in 2007 for both cultivars. Reduction in plant heights could be explained by decrease in the formation of node on the main stem due to water stress throughout the growth period. Plants exposed to water stress had less branch, leaf area and vegetative growth. Karam et al. (2005) reported that irrigation treatments significantly increased the plant height. **.** Irrigation water applied (IW), actual evapotranspiration (ET_a).

The average values of irrigation water applied (IW) for treatments $I_{133,}$ I_{100}, I_{67} and I_{33} were 1058, 795, 533 and 263 mm and 1094, 823, 551 and 272 mm, for

Table 8. Mean values of green pod yield per plant and yield components in 2006, 2007 and an average of the two years.

Year	Cultivar	Irrigation	Yield Plant^{-1} (g)	Pod weight (g)	Pod length (mm)	Pod width (mm)	Seed pod^{-1}	Plant height (cm)	Pod no plant^{-1}
2006	Toyohomare	I_{133}	195.39	2.72	56.00	12.06	2.67	86.67	99.33
		I_{100}	147.70	2.59	53.43	11.76	3.00	69.42	65.67
		I_{67}	122.99	2.66	51.84	12.66	2.33	70.25	57.67
		I_{33}	108.86	2.88	50.54	11.77	2.33	69.50	54.33
	Toyokomachi	I_{133}	300.52	2.67	54.88	11.40	2.33	99.17	106.00
		I_{100}	265.97	2.34	54.11	11.71	2.33	96.00	114.67
		I_{67}	242.29	2.53	50.02	11.09	2.33	88.00	105.33
		I_{33}	206.55	2.77	55.14	11.68	2.67	78.58	90.33
2007	Toyohomare	I_{133}	164.37	2.69	56.78	12.07	2.67	76.98	83.00
		I_{100}	116.54	2.59	57.13	12.50	2.33	82.18	66.67
		I_{67}	115.36	2.56	59.49	12.00	2.67	76.16	68.33
		I_{33}	117.10	2.19	59.47	11.45	2.33	77.03	61.67
	Toyokomachi	I_{133}	208.53	2.40	55.46	11.80	2.67	101.60	111.33
		I_{100}	173.52	2.75	53.15	11.80	2.33	100.90	107.67
		I_{67}	162.01	2.76	55.12	12.32	2.67	101.25	63.66
		I_{33}	123.65	2.63	60.15	12.30	2.00	95.72	59.33
Average	Toyohomare	I_{133}	179.88	2.71	56.39	12.07	2.67	81.72	91.17
		I_{100}	132.12	2.59	55.28	12.13	2.67	75.80	66.17
		I_{67}	119.77	2.61	55.67	12.33	2.50	73.21	63.00
		I_{33}	112.98	2.54	55.01	11.61	2.33	73.27	58.00
	Toyokomachi	I_{133}	254.53	2.54	55.17	11.60	2.50	100.38	108.67
		I_{100}	219.74	2.55	53.63	11.76	2.33	98.45	111.17
		I_{67}	202.15	2.67	52.57	11.71	2.50	94.92	84.50
		I_{33}	165.10	2.70	57.65	11.99	2.33	87.15	74.83

Toyohomare and Toyokomachi respectively. The actual evapotranspiration (ETa) was 997, 875, 632 and 364 mm and 922, 886, 612 and 388 for Toyohomare and Toyokomachi, respectively. Irrigation water use efficiency (IWUE), and water use efficiency (WUE) varied significantly in the different irrigation treatments.WUE and IWUE showed a strong increase by increasing the water stress. Applying irrigation water as 25% of the full amount throughout the whole growing season improved the water use efficiency. IWUE and WUE values ranged from 1.90 to 4.91 and 1.73 to 3.55 kg m^{-3} for Toyohomare and 2.66 to 6.94 and 2.83 to 4.87 kg m^{-3} for Toyokomachi, respectively. The IWUE and WUE values of I_{33} treatments were higher than that of the other treatments for both cultivars (Table 9). Mean of WUE was ratio of yield to water consumed. Under deficit irrigation conditions, accumulation of total crop biomass was higher than well-irrigated plant (Sinclair et al., 1984). Similar results have also been reported in cotton (Onder et al., 2009) and in soybean plants grown under water stress conditions (Sincik, 2008; Bustomi et al., 2005).

The k_y values of I_{100}, I_{67} and I_{33} treatments were determined as 2.17, 0.92 and 0.59 for Toyohomare and 3.50, 0.61 and 0.61 for Toyokomachi,

Table 9. Irrigation water applied (IW), actual evapotranspiration (*ET_a*), green pod yield, relative evapotranspiration deficit [*$1-(ET_a/ET_m)$*], relative yield loss[(*$1-Y_a/Y_m$*)], yield response factor (ky), irrigation water use efficiency (IWUE), water use efficiency (WUE) and relative water saving [$1-(IW_a/IW_c)$].

Cultivar	Treatment	IW			ET_a			Gren pod yield (t ha^{-1})			$1-(ET_a/ET_m)$	$1-(Y_a/Y_m)$	ky	IWUE	WUE	$1-(IW_a/IW_c)$
		2006	2007	Average	2006	2007	Average	2006	2007	Average						
Toyohomare	I_{133}	1099	1016	1058	1012	981	997	22.3	18.8	20.6	0.00	0.00	0.00	1.94	2.06	0.00
	I_{100}	826	764	795	923	826	875	16.9	13.3	15.1	0.12	0.27	2.17	1.90	1.73	0.25
	I_{67}	553	512	533	665	598	632	14.1	13.2	13.6	0.37	0.34	0.92	2.56	2.16	0.50
	I_{33}	273	252	263	351	377	364	12.4	13.4	12.9	0.63	0.37	0.59	4.91	3.55	0.75
Toyokomachi	I_{133}	1136	1052	1094	936	908	922	34.3	23.8	29.1	0.00	0.00	0.00	2.66	3.16	0.00
	I_{100}	854	791	823	904	868	886	30.4	19.8	25.1	0.04	0.14	3.50	3.05	2.83	0.25
	I_{67}	572	530	551	618	606	612	27.7	18.5	23.1	0.34	0.21	0.61	4.19	3.77	0.50
	I_{33}	282	261	272	401	374	388	23.6	14.1	18.9	0.58	0.35	0.61	6.94	4.87	0.75

respectively. These results indicated that yield loss was more important thanevapotranspiration deficit *(k_y>1)* in I_{100} treatment. The results of this experiment showed that water saving by 10% during the whole growing season caused yield reductions by 9.2, 14.7 and 20.3% for the Toyohomare cultivar and 17.9, 23.8 and 21.4% for the Toyokomachi cultivar in I_{100}, I_{67} and I_{33} treatments, respectively. This mean soybean yields decrease significantly under deficit irrigation treatment. The k_y of soybean determined in this study for the whole growing period under deficit irrigation were similar with the results reported earlier by Doorenbos and Kassam (1979) and Simsek et al. (2001).

It is important to assess the highest yield per unit of irrigation water used. However, the maximum yield of soybean was obtained from full irrigation treatment (at 133% IW/CPE ratio) and the average crop water requirement was 960 mm. The yield increased as irrigation water increased for both cultivars. The maximum yield was 20.6 and 29.1 t ha^{-1} with 997 and 922 mm water consumption in I_{133} treatments for Toyokomachi and Toyohomare, respectively. As an expected result, irrigation treatments below I_{133} resulted in significant yield reductions. The relative yield loss of Toyokomachi and Toyohomare in I_{100}, I_{67} and I_{33} were 27, 34, 37% and 14, 21 and 35%, respectively compared with the yield in I_{133}. Demirtas et al. (2010) noted similar result that deficit irrigation treatments significantly affected NPP which resulted to yield. Based on the findings, an optimum supply of irrigation water was essential for producing maximum yield. NPP was the most important yield component and the most sensitive to deficit irrigation.

In conclusion, the soybean cultivars used in the study were very sensitive crops to water stress and during the growth season at least equal (I_{100}) or excess of the evaporated water amount was required to produce high yield. The yield of Toyokomachi was significantly higher compared with that of Toyohomare under the study conditions with irrigation treatments applied.

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