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Effect of drip irrigation intensity on soybean seed yield and quality in the semi-arid Harran plain, Turkey

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Abstract

Soybean (*Glycine max* L.) crops were grown in 2003 and 2004 to determine effect of different water stress levels on growth, some physiological variables and seed composition under semi-arid climatic conditions of Harran plain, Sanlıurfa, Turkey. Irrigation water treatments included 0 (I_0), 25 (I_{25}), 50 (I_{50}), 75 (I_{75}), and 100% (I_{100}) of full irrigation amounts with a 4 day irrigation interval. Water stress resulted in reduced vegetative growth, leaf relative water content and leaf chlorophyll content. In 2003 and 2004 seed yields ranged from 322 (I_0) to 3,684 kg ha^{-1} (I_{100}), and from 267 (I_0) to 3,952 kg ha^{-1} (I_{100}), respectively. Compared to I_{100}, the two-year average seed yield reduction for I_0, I_{25}, I_{50} and I_{75} were 92, 76, 50 and 25%, respectively. Water stress significantly decreased fatty acid content of C18:0, C18:1, C18:2, and C18:3 but not C16:0. I_{100} produced the highest protein value (39.60% in 2003 and 39.00% in 2004), while I_0 yielded the lowest values (35.41% in 2003 and 36.11% in 2004). A negative correlation between evapotranspiration (ET) and oil content and ET and protein content in both years was determined. Leaf chlorophyll content, leaf relative water content, leaf area index, number of branch per plant, number of node per plant and plant diameter correlated positively with seed protein content and negatively with oil content.

Additional key words: drought stress; irrigation level; seed oil and protein; semi-arid climatic conditions.

Resumen

Efecto de la intensidad del riego por goteo en el rendimiento y calidad de las semillas de soja en la llanura semiárida de Harran, Turquía

Se cultivó soja (*Glycine max* L.) en 2003 y 2004, en el clima semiárido de la llanura de Harran, Sanliurfa, Turquía, para determinar el efecto de diferentes niveles de estrés hídrico sobre el crecimiento, algunas variables fisiológicas y la composición de la semilla. Los tratamientos de riego incluyeron 0 (I_0), 25 (I_{25}), 50 (I_{50}), 75 (I_{75}), y 100% (I_{100}) de las cantidades de riego total con un intervalo de 4 días de riego. El estrés hídrico dio como resultado una reducción en el crecimiento vegetativo, y en el contenido relativo de agua y de clorofila en las hojas. En 2003 y 2004 los rendimientos de semilla variaron de 322 (I_0) a 3684 kg ha^{-1} (I_{100}), y de 267 (I_0) a 3952 kg ha^{-1} (I_{100}), respectivamente. En los dos años, la media de la reducción del rendimiento de semilla para I_0, I_{25}, I_{50} e I_{75} fue 92, 76, 50 y 25%, respectivamente, en comparación con I_{100}. El estrés hídrico redujo significativamente el contenido de ácidos grasos C18:0, C18:1, C18 2 y C18:3, pero no de C16:0. El tratamiento I_{100} produjo el valor más alto de proteínas (39,60% en 2003 y 39,00% en 2004), mientras que I_0 dio los valores más bajos (35,41% en 2003 y 36,11% en 2004). Se determinó una correlación negativa en ambos años entre la evapotranspiración (ET) y el contenido de aceite y entre ET y el contenido de proteínas. El contenido de clorofila, el del agua en las hojas, el índice de área foliar, número de ramas y de nodos por planta y el diámetro de la planta correlacionaron positivamente con el contenido de proteína de las semillas y negativamente con el contenido de aceite.

Palabras clave adicionales: aceite y proteínas de la semilla; condiciones climáticas semi-áridas; estrés por sequía; nivel de riego.

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Abbreviations used: DM (dry mass), EC (electrical conductivity), ET (evapotranspiration), FM (fresh mass), GAP (southeastern Anatolia project), IWUE (irrigation water use efficiency), LAI (leaf area index), LRWC (leaf relative water content), TM (turgid mass), WUE (water use efficiency).

Introduction

Soybean (*Glycine max* L.) is an economical and valuable agricultural commodity due to its unique chemical composition. It is one of the world's most important leguminous plants. It is considered as a good source of high quality plant protein and vegetable oil. Given its high concentration of protein (36-48%), oil (18-24%), and carbohydrate (20%), soybean is grown in almost all parts of the world for human consumption, industry and animal feed (Arıoglu, 1989; Boydak *et al.,* 2002). Besides, diets including soybean have been proposed to reduce risk of major diseases such as breast cancer, cardiovascular disease, osteoporosis, diabetes and obesity. The biochemical composition of soybean seeds affect the quality of various soy foods such as soy milk, soy flour, tofu, soy sprouts, soy concentrates and soy isolates. Higher protein content and low oil content are generally desirable characteristics for food users (Kumar *et al.,* 2006).

Southeastern Anatolia Project (locally called GAP) is Turkey's biggest multisectoral development project based on improvement of water resources. About 1.7 million ha of agricultural land will be irrigated when project is completed. The Sanliurfa-Harran plain, part of the GAP, has been open to irrigation in 1995. Sanlıurfa-Harran plain covers about 150,000 ha agricultural land of which currently about 95% is irrigated. Cotton (*Gossypium hirsutum*) has been dominant crop for over 10 years in the region. Lately there has been a shift to some other field crops such as soybean, particularly with the start of irrigation. Total soybean production in Sanlıurfa is about 900 ton per year and has been increasing. Traditionally, furrow irrigation has been the technique of choice in the region. However, drip irrigation use has been increasing with the governmental subsidizes especially in recent years. Since average annual precipitation in the region is about 380 mm and most of the precipitation falls in the winter months, irrigation is necessary for summer crops.

Soybean crops need to be irrigated frequently in order to avoid yield and quality losses (Constable and Hearn, 1980). Sutherland and Danileson (1980) found that full irrigation after water stress during flowering increased growth and quality. Water stress has also been known to reduce oil and protein contents in soybean (Aparicio *et al.,* 1994; Kumuwat *et al.,* 2000; Rotundo *et al.*, 2009).

Rotundo *et al.* (2009) observed that high seed protein content was linked to greater leaf area index. They also found that there was a negative correlation between seed protein concentration and yield. Rose (1988) indicated that oil and protein are key constituents of soybean seed. Synthesis and deposition of oil and protein in the seed occurs during pod filling stage. Therefore, semi-arid environmental conditions, deficit irrigation and moisture stress affect the deposition of these two key constituents. Moisture stress occurred early in pod filling resulted in a low protein and high oil percentage. Increases in irrigation interval throughout the whole growing season maintained protein contents constant while increased oil content.

The concentration of polyunsaturated fatty acids such as linoleic and linolenic acid can be reduced by hydrogenation. Hydrogenation of these unsaturated fatty acid leads to heart disease. Monounsaturated fatty acids such as oleic acid are less susceptible to oxidative changes. Hence, the food industry is becoming increasingly interested in producing soybean seed with a high content of oleic acid, low linoleic and linolenic acids. Besides, decreasing palmitic acid content in soybean oil is a desirable trait for human consumption and seed oil industry because of its oxidative stability. The polyunsaturated fatty acids decrease shelf life of soy products but improve human health conditions (Kumar *et al.*, 2006; Bellaloui and Mengistu, 2007). According to Henry (2010), optimal soybean protein and oil contents are 35% and 20%, respectively, while optimal palmitinic acid, stearic acid, oleic acid, linoleic acid and linolenic acid levels are 8-13.5, 2.5-5.4, 17.7-28.0, 49.8-59.0, and 5.0-11.0, respectively.

Dornbos and Mullen (1992) have observed little effects of drought on the fatty acid composition of the oil, while high air temperature reduced the proportion of the polyunsaturated components. Linolenic acid content is reduced by high air temperature during seed filling stages. Similarly, Piper and Boote (1999) have observed oil concentration increments with increasing temperature (approaching a maximum at a mean temperature of 28°C) and a negative correlation between oil and protein content attributed to environmental and genotypic variations.

Although many studies involving soybean as a main crop have been conducted, irrigation studies with soybean as a second crop (grown right after wheat or barley) under semi-arid climatic conditions, the analysis of the effects of irrigation levels on seed composition of soybean under hot climate are limited. Therefore, the objectives of this study were (1) to determine the possible effect of seasonal water stress on second crop soybean growth,

Table 1. Some properties of the study area soil

Depth (cm)	FC[1] (%)	PWP[2] (%)	BD[3] ($g\ cm^{-3}$)	pH	OM[4] (%)	N ($kg\ ha^{-1}$)	P_2O_5 ($kg\ ha^{-1}$)	K_2O ($kg\ ha^{-1}$)	Soil particle distribution (%)		
									Sand	Silt	Clay
0-30	31.5	22.2	1.37	7.3	1.2	25	27	1,280	7	34	59
30-60	31.8	22.6	1.40	7.2	0.8	12	20	900	17	25	58
60-90	32.3	21.5	1.43	7.2	0.6	6	17	810	20	21	59
90-120	32.5	21.5	1.43	7.2	0.5	—	—	—	19	20	61

[1] FC: field capacity. [2] PWP: permanent wilting point. [3] BD: bulk density. [4] OM: organic matter.

physiology and yield, (2) to evaluate effect of water stress on oil and protein content and fatty acid composition of second crop soybean seed.

Material and methods

Experiments were conducted on a clay textured soil (vertic calciorthid aridisol) during 2003 and 2004 production seasons at Faculty of Agricultural Engineering, Harran University research station, Sanliurfa-Turkey. The altitude, latitude and longitude of the experimental site were 460 m, 36° 42' N and 38° 58' E, respectively. Relevant physical properties and climatic data of the study area are presented in Tables 1 and 2, respectively.

A hybrid cultivar 'A-3935' of soybean widely cultivated in the Southeast Turkey was selected as crop material. Plots were 5 m long and consisted of 5 rows of soybean sown 4-5 cm apart in 0.75 m wide rows with each treatment having 3 replications. Soybean seeds were hand sown at 3 to 4 cm depth and right after sowing all plots were irrigated with a drip irrigation system. The middle 3 rows of soybean plots were hand harvested for yield and seed quality analysis. There was a 3.0 m empty buffer area between all plots in order to eliminate any effect from one plot to another.

Irrigation water was supplied from a deep well with pH 7 and EC 0.31 dS m^{-1}. Each row of soybean had a drip lateral established for irrigation. Laterals had 20 cm-spaced emitters with 4 L h^{-1} discharge rate.

Sowing dates were June 26th and 20th in 2003 and 2004, respectively. All treatment plots received the same amount of irrigation water (total of 50 mm, starting from sowing to 30% crop field coverage) at 4 days interval in order to establish homogenous stands. All treatments received 100 kg ha^{-1} pure N as ammonium nitrate injected through drip irrigation system in 4 equal amounts starting with planting to full bloom

Table 2. Climatic data of the study area during soybean crop growing season for the years of 2003 and 2004

	June	July	August	September	October
2003					
Min. air temperature (°C)	21.4	25.8	26.0	20.2	16.0
Max. air temperature (°C)	35.5	39.7	40.3	34.0	28.4
Average air temperature (°C)	28.6	32.5	32.7	26.4	21.5
Relative humidity (%)	35.1	28.5	32.2	42.4	51.5
Wind speed ($m\ s^{-1}$)	2.6	2.9	2.3	2.5	1.8
Rainfall (mm)	0	0	0	0	0
Solar radiation ($Cal\ cm^{-2}$)	623.7	636.8	545.5	470.3	332.8
2004					
Min. air temperature (°C)	21.8	25.6	23.6	20.7	16.5
Max. air temperature (°C)	35.7	39.7	38.1	35.3	28.7
Average air temperature (°C)	29.0	32.8	30.8	27.3	21.7
Relative humidity (%)	33.5	27	40.7	34.8	48.7
Wind speed ($m\ s^{-1}$)	3.0	2.5	2.5	2.0	1.7
Rainfall (mm)	0	0	0	0	0
Solar radiation ($Cal\ cm^{-2}$)	642.0	621.5	561.9	463.9	314.9

stage, 2003 and 2004, respectively. Additionally, 50 kg ha^{-1} pure P as a diammonium phosphate was applied to treatment plots at the time of planting.

Irrigation water treatments included 0 (I_0), 25 (I_{25}), 50 (I_{50}), 75 (I_{75}), and 100% (I_{100}) of full irrigation amounts with a 4 day irrigation interval. Evaporation data were obtained from a standard Class-A-Pan located near the experimental field and collected on a daily basis. Irrigation treatments were initiated when crop canopy reached 30% field coverage (July 21st and July 18th for 2003 and 2004, respectively). Irrigation amounts were calculated with the following equation (Doorenbos and Pruitt, 1992):

$$I = Epan \times Kcp \times CP \times A \quad [1]$$

where I = applied irrigation (mm), Epan = cumulative evaporation amount in the period of irrigation interval (mm), Kcp = crop-pan coefficient (0.0, 0.25, 0.50, 0.75, and 1.0), CP = crop percentage of soil cover, and A = area (m^2).

Evapotranspiration (ET, mm) for each treatment was calculated according to the water-balance approach (Doorenbos and Kassam, 1979):

$$ET = I + P - Dr - Rf \pm \Delta s \quad [2]$$

where I = irrigation water applied during the growth period (mm), P = effective rainfall during the growth period plus capillary rise (mm), Dr = amount of drainage water (mm), Rf = amount of runoff (mm), and Δs = change in the soil moisture content (mm) determined by gravimetric sampling. Since there was no runoff during irrigations and the water table was at 4 m depth, capillary flow to the root zone and runoff flow were assumed to be negligible in the calculation of ET. Based on a number of soil-water content measurements, drainage below 90 cm was considered to be negligible. Thus the above equation was reduced at:

$$ET = I + P \pm \Delta s \quad [3]$$

At the end of the full seed stage, the number of branch per plant, number of nodes per plant and plant stem diameter were determined from randomly chosen 5 plants per replicate in order to determine the effect of water stress on crop vegetative growth. Total leaf area was determined with a portable leaf area meter (LI-3100, LI-COR, Lincoln, Nebraska, USA) from 3 randomly selected plants per replicate. Leaf area index (LAI) was computed as the ratio between total upper leaf surface and the corresponding land area.

Irrigation water use efficiency (IWUE) was calculated from the seed yield and amount of water applied to each treatment plots. Water use efficiency (WUE) was computed as the ratio of seed yield to seasonal crop evapotranspiration.

Leaf relative water content

Leaf relative water content (LRWC) was determined for fully grown leaves collected just before irrigation events with three replications. After taking fresh weights, samples were soaked into distilled water for 4 h to determine turgid weights. Then the same samples were dried at 85°C for 24-48 h using Yamasaki and Dillenburg (1999) method. Leaves of three randomly chosen plants per replicate were collected from middle section of plant in order to minimize age effects. Individual leaves were first removed from stem and then weighed to obtain fresh mass (FM). The leaves were then floated in distilled water inside a closed petri dish. During the imbibitions period, leaf samples were weighed periodically to determine turgid mass (TM), (after gently wiping the water from the leaf surface with tissue paper). After the imbibitions period, leaf samples were dried in a pre-heated oven at 80°C for 48 h, to obtain the dry mass (DM). All mass measurements were made using an analytical balance, with precision of 0.0001 g. Values of FM, TM and DM were used to calculate LRWC using the equation below:

$$LRWC\ (\%) = [(FM - DM) / (TM - DM)] \times 100 \quad [4]$$

Chlorophyll concentration

Chlorophyll concentration was determined in three plants per replicate at early fruit stage. Fresh leaf samples (1 g) were taken from the youngest, fully expanded leaves. Chlorophyll was extracted with 90% acetone. The absorption of the extracts at 663, 645 and 750 nm were read using UV/visible light spectrophotometer absorbance at 750 nm was subtracted from absorbance of the other two wavelengths to correct for any turbidity in solution. Chlorophyll concentrations were calculated using the formula below from Strain and Svec (1996):

$$Chl.\ a\ (mg\ mL^{-1}) = 11.64\ (A_{663}) - 2.16\ (A_{645}) \quad [5]$$

$$Chl.\ b\ (mg\ mL^{-1}) = 20.97\ (A_{645}) - 3.94\ (A_{663}) \quad [6]$$

where (A_{663}) and (A_{645}) represent absorbance values read at 663 and 645 nm wavelengths respectively.

Seed compositional analyses

Soybean seeds were ground with a lab mill (M20 model, IKA®-WERKE, Staufen, Germany). The oil content of seeds was determined by a Soxhlet extraction method using n-hexane as solvent at 70°C for 6 h (IUPAC, 1987). Protein content of soybean samples was determined according to the Kjeldahl procedure (AOAC, 1984) using a Tecator Kjeltech Auto Analyzer, model 1030. Fatty acid methyl esters were prepared according to AOCS (1989), method Ce 2-66 and analyzed with HP 6890 Series II Gas Chromatograph (GC) (Hewlett-Packard Company, Wilmington, DE, USA) equipped with a flame ionization detector and auto sampler. A fused silica capillary column SP 2340 (60 m × 0.25 mm *i.d.*) with a film thickness of 0.25 μm (Supelco, Taufkirchen, Germany) was used. Injection, detector, and oven temperatures were 250, 260, and 190°C, respectively. Nitrogen was used as a carrier gas at a flow rate of 1.0 mL min^{-1}. Individual peaks were identified by comparing the retention times with grain fatty acid methyl esters.

Statistical analysis

The experimental design was a randomized block design with 3 replications. MSTAT program was used to carry out statistical analysis. Treatment means were separated by Duncan's multiple range test.

Results

Yield, ET, growth and physiological variables

Seasonal applied irrigation water amounts in 2003 and 2004 ranged from 72 (I_0) to 550 mm (I_{100}) and from 74 (I_0) to 596 mm (I_{100}), respectively. Seasonal ET rates were between 83 to 575 mm in 2003 and 74 and 596 mm in 2004. ET rates were increased with increasing applied irrigation water. The highest ET rates in both of the years were obtained from I_{100} treatment.

Yields in 2003 ranged from 322 (I_0) to 3,684 kg ha^{-1} (I_{100}), while in 2004 those values varied from 267 (I_0) to 3,952 kg ha^{-1} (I_{100}). In both years, any water stress imposed on soybean plants resulted in a significant yield reduction compared to I_{100}. In 2003 and 2004, average yield reductions from I_0, I_{25}, I_{50} and I_{75} treatments were 92, 76, 50 and 24%, respectively, compared to I_{100}. A statistically significant ($p < 0.01$) linear relationship between ET and yield was observed (Fig. 1a).

The IWUE for drip-irrigated soybean ranged from 4.5 to 6.8 kg ha^{-1} mm^{-1} in 2003 and from 3.6 to 6.6 kg ha^{-1} mm^{-1} in 2004. In general, WUE values decreased with decreasing water use. In both years, IWUE values were higher than WUE values. The WUE for soybean were between 3.9 and 6.6 kg ha^{-1} mm^{-1} in 2003 and from 3.1 to 6.4 kg ha^{-1} mm^{-1} in 2004. There were 9 and 14% reduction between I_{50} and I_{100} treatments in 2003 and 2004, respectively. In 2003, I_{75} and I_{100} treatments were in the same statistical group for both WUE and IWUE, while in 2004, I_{50} and I_{75} were in the same group (Table 3).

Table 3. Effects of deficit irrigation on water use efficiency, number of branches per plant and plant diameter of drip irrigated soybean

	I_0	I_{25}	I_{50}	I_{75}	I_{100}
2003					
Applied water (mm)	72	196	311	434	550
IWUE[1] (kg ha^{-1} mm^{-1})	4.5[c]	4.2[c]	6.1[b]	6.8[a]	6.7[a]
WUE[2] (kg ha^{-1} mm^{-1})	3.9[c]	4.0[c]	5.8[b]	6.6[a]	6.4[a]
Number of branches per plant	0.53[d]	1.13[c]	1.40[c]	1.90[b]	3.43[a]
Plant diameter (mm)	6.5[d]	7.0[c]	7.7[b]	7.8[b]	8.5[a]
2004					
Applied water (mm)	74	205	318	456	596
IWUE (kg ha^{-1} mm^{-1})	3.6[d]	5.0[c]	6.1[b]	6.1[b]	6.6[a]
WUE (kg ha^{-1} mm^{-1})	3.1[d]	4.7[c]	5.5[b]	5.7[b]	6.4[a]
Number of branches per plant	0.55[d]	1.20[c]	1.44[c]	1.95[b]	3.58[a]
Plant diameter (mm)	6.6[d]	7.1[c]	7.6[b]	7.8[b]	8.6[a]

[1] IWUE: irrigation water use efficiency. [2] WUE: water use efficiency. Mean values in the same row followed by different letters are significantly different ($p < 0.05$).

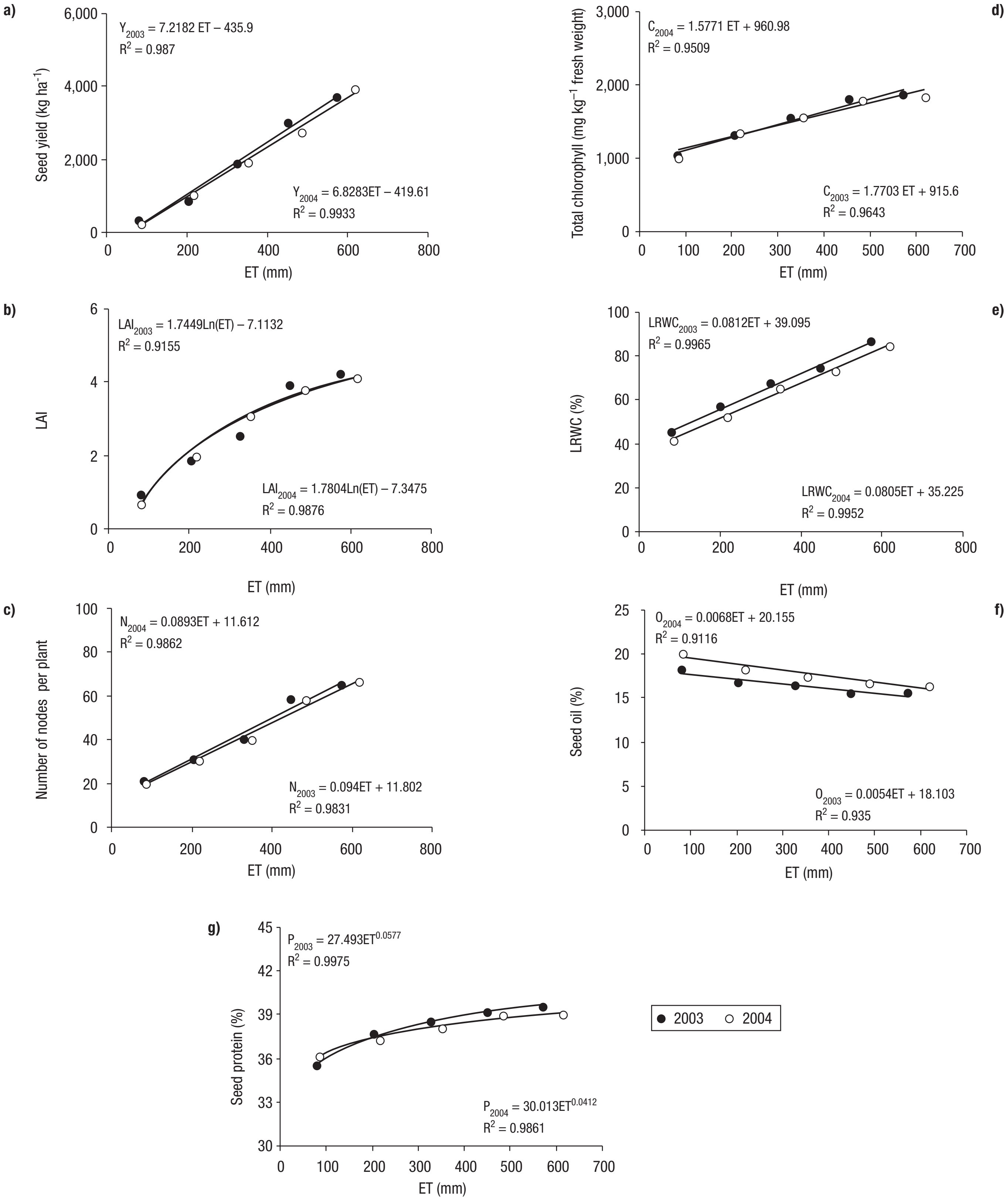

Figure 1. Effects of ET on seed yield (a), LAI (b) and number of nodes per plant (c), chlorophyll content (d), LRWC (e), seed oil (f) and protein content (g) for drip irrigated soybean.

LAI values ranged from 0.9 (I_0) to 4.2 (I_{100}) in 2003 and 0.7(I_0) to 4.1(I_{100}) in 2004 while protein content varied from 35.41(I_0) to 39.60% (I_{100}) in 2003 and 36.11(I_0) to 39.00% (I_{100}) in 2004. In both of the years any water stress imposed on soybean plants resulted in LAI reduction compared to fully irrigated treatment. A statistically significant ($p < 0.01$) linear relationship between ET and LAI was observed (Fig. 1b).

The lowest stem diameter was obtained from I_0 (6.5 mm in 2003 and 6.6 mm in 2004). Tthe highest stem diameters were obtained for I_{100} (8.5 mm in 2003 and 8.6 mm in 2005). There was no statistical difference in plant diameter between I_{50} and I_{75} in both years.

Other growth variables such as number of branch per plant and number of nodes per plant were significantly decreased by deficit irrigation in both years. In 2003 and 2004, the lowest number of nodes per plant was obtained from I_0 as 20.13 and 20.21, respectively. I_{75} and I_{100} treatments were in the same statistical group in terms of number of the nodes per plant. A statistically significant ($p < 0.01$) linear relationship between ET and number of nodes per plant was observed (Fig. 1c).

The highest values of total chlorophyll and LRWC were obtained from unstressed I_{100} treatment as 1,851.67 mg kg^{-1} fresh weight and 86.1% in 2003 and 1,850.11 mg kg^{-1} fresh weight and 84.7% in 2004, respectively. The total chlorophyll values obtained from I_{75} treatment were almost the same as those for the control treatment. Total chlorophyll content and LRWC in I_{50} decreased 17% and 23% in 2003 and 18% and 22% in 2004, respectively, compared to C treatment. A statistically significant ($p < 0.01$) linear relationship between ET and total chlorophyll content (Fig. 1d) was found.

The higher LRWC values are indication of enough soil water in root zone. Observed LRWC values in 2003 varied from 45.1 to 86.1% and similarly, in 2004 LRWC values ranged from 41.5 to 84.7%. As water deficit increases in the root zone, LRWC decreases. Regression analysis showed that there was a significant linear relationship between ET and LRWC (Fig. 1e).

Seed composition of soybean

Oil content varied from 15.30 to 17.96% and from 16.40 to 20.10% in 2003 and 2004, respectively. Statistical analysis in 2003 and 2004 indicated that I_{75} and I_{100} treatments produced similar oil content since they were in the same statistical group. Regression analysis showed that there was an inverse linear relationship between ET and seed oil content (Fig. 1f). Overall, the protein and oil contents were significantly different among treatments at $p < 0.05$ level. Significant differences were found in protein and oil contents of soybean seeds between years, likely due to the differences in weather conditions (especially, average, minimum and maximum air temperature).

Irrigation treatments and the interaction between irrigation treatments and year affected soybean seed protein content. Protein content varied from 35.41 to 39.60% and from 36.11 to 39.00% in 2003 and 2004, respectively. The highest protein content was obtained from I_{75} and I_{100} while I_0 produced the lowest protein content in both of the years. There was a power function between ET and seed protein content (Fig. 1g).

Table 4 shows that palmitic (C16:0), stearic (C18:0), oleic (C18:1), linoleic (C18:2) and linolenic (C18:3)

Table 4. Effect of deficit irrigation on fatty acid content (%) of drip irrigated soybeans

Fatty acid (%)	Year	I_0	I_{25}	I_{50}	I_{75}	I_{100}
C16:0	2003	10.61^{ns}	10.07	9.95	10.49	10.17
	2004	10.00^{ns}	9.88	9.96	10.07	10.06
C18:0	2003	5.85^{a}	5.90^{a}	4.60^{b}	4.50^{bc}	4.66^{b}
	2004	6.20^{a}	6.05^{a}	5.23^{bc}	5.50^{b}	5.23^{bc}
C18:1	2003	30.01^{a}	30.21^{a}	26.79^{b}	27.03^{b}	26.90^{b}
	2004	28.93^{a}	29.00^{a}	28.13^{b}	28.31^{b}	28.47^{b}
C18:2	2003	46.51^{b}	46.55^{b}	47.93^{a}	47.85^{a}	47.96^{a}
	2004	46.23^{bc}	46.84^{b}	48.11^{a}	48.05^{a}	48.21^{a}
C18:3	2003	5.44^{b}	5.49^{b}	6.11^{a}	5.98^{a}	6.05^{a}
	2004	5.33^{b}	5.39^{b}	6.22^{a}	5.28^{b}	6.17^{a}

C16:0, palmitic acid; C18:0, stearic acid; C18:1, oleic acid; C18:2, linoleic acid; C18:3, linolenic acid. ns: non significant. Mean values in the same column followed by different letters are significantly different ($p < 0.05$).

acids determined as principal fatty acids of soybean oil. Also arachidic (C20:0) and behenic (C22:0) acids concentrations of the seed oil were determined lower than 0.4%. The average values of palmitic, stearic, oleic, linoleic, and linolenic acids were 10.38, 5.10, 28.19, 47.36 and 5.81% in 2003 and 11.98, 5.64, 28.58, 47.49, and 5.68% in 2004, respectively. Irrigation treatments had non significant effects on palmitic acid. Overall, I_0 had the highest stearic and oleic concentrations and the lowest concentrations of linelonic and linolenic fatty acids. There were significant positive correlations between; C18:1-C18:0 and C18:2-C18:3, however significant negative correlation between C18:1-C18:2, C18:1-C18:3, C18:2-C18:0 and C18:3-C18:0.

Discussion

Soybean crops were grown as a second crop under the semi-arid climatic conditions of Harran plain, Sanlıurfa, Turkey with different degrees of irrigation. Seasonal crop water use in this study was in agreement with reported values of 450-700 mm (Doorenbos and Kassam, 1979). Visual observations indicated that all treatments showed water stress during application of treatments except $I_{100,}$ which received full water calculated with Class-A Pan values. Since the only source of water for the soybean was irrigation (no precipitation), any seasonal irrigation water reduction resulted in substantial loss of yield. In general, for every 25% reduction in irrigation water amount resulted in severe yield loss such as 49% and 52% between I_{50} and I_{100} treatment in 2003 and 2004, respectively. These findings were in line with reported studies conducted on different crops (Lamm *et al.,* 1994; Costa and Shanmugathasan, 2002; Karam *et al.,* 2005). ET increased with the intensity of irrigation and this resulted in a significant correlation between ET and yield. Similar results were also obtained by Constable and Hearn (1980), Costa and Shanmugathasan (2002) and Karam *et al.* (2005).

Since there was no rainfall during the growing season, the differences between IWUE and WUE values can be attributed to water used from soil storage. As water stress increased, both WUE and IWUE values decreased. According to Pandey *et al.* (2000), since water use efficiency can be improved by either increasing yield or decreasing water use and applied irrigation water, any of these factors might be used by growers to decrease water use of crops, while maintaining yield and quality. However, our data show that yield and quality were not maintained under deficit irrigation. Our results show that I_{75} could be recommended to growers to save water under limited water conditions, while taking the risk of lowered yield.

The magnitude of irrigation affected several physiological traits with potential impact on yield. The number of branches per plant, the number of nodes per plant and plant diameter increased with increased irrigation amounts of particular importance are the increased LAI with irrigation. The leaves play a key role in the production of photosynthetic assimilates for seed growth and the are primary source of carbon and nitrogen accumulated by the seed at maturity Rotundo *et al.* (2009).

The chlorophyll reductions in this study were lower than those reported for brinjal (Prakash and Ramachandran, 2000). Total chlorophyll values especially under full irrigation were similar to previous reported study with wheat (Sarker *et al.,* 1999). Zhang *et al.* (2007) reported that water deficit decreased chlorophyll content of soybean leaves by 10% and 24% compared to full irrigated control treatment. In our experiment, the chlorophyll content in I_{25}, I_{50} and I_{75} treatments reduced 30, 17 and 3% respectively, compared to I_{100} treatment in 2003 while these deduction for the same treatments were 27, 16 and 3% respectively in 2004. The low chlorophyll concentration may be associated with leaf senescence as a result of water deficit. The highest leaf chlorophyll content and LRWC was obtained from the unstressed treatment similar to previous studies in different crops (*e.g.* Sarker *et al.,* 1999; Prakash and Ramachandran, 2000).

Severe water stress (I_0) treatment produced the highest oil content in both years. A negative correlation between oil and protein contents was observed for both years. A similar negative correlation has also been reported by Hymowitz *et al.* (1972), Liu *et al.* (1995) and Kumar *et al.* (2006). In this study minimum, maximum and average air temperatures during seed filling stage were higher (Table 2) in 2004 than those of 2003 resulted in higher oil and protein content in 2004. Dornbos and Mullen (1992) have shown that seeds from plants exposed to 35°C during seed fill contained 4% more protein and 2.6% less oil than those exposed to 29°C. Similarly, Kumar *et al.* (2006) also found that the mean air temperature during bean development showed a significant positive correlation with protein and a negative correlation with oil and lenolenic acid.

Regarding seed protein levels, our data agree with the results of Celik (1995), who emphasized that protein content is moisture sensitive. In midsouth USA, Bellaloui and Mengistu (2007) observed a high protein percentage under full season irrigation compared to non-irrigation treatments. Specht *et al.* (2001) have also observed that severe drought can lead to a decrease in protein content. However, Dornbos and Mullen (1992) obtained the opposite result, *i.e.* severe drought increased protein content by 4.4% while oil content decreased by 2.9%, likely due to the differences in temperature, natural day length, humidity among seasons, management practices and the sensitivity of the genotypes to the treatments.

The level of linoleic acid found in the current study was higher than previous reported values (Boydak *et al.,* 2002), oleic acid level, however, was lower. Conversely, the results are consistent with the findings of Celik (1995), except for palmitic acid. May *et al.* (1993) have noted that the fatty acid composition of vegetable oils varies depending on seed genealogy, planting date and meteorological factors during the growing season. Differences in fatty acid content were likely due to the different weather patterns between years and locations. Air temperature plays a vital role in the synthesis of fatty acids, especially unsaturated fatty acids, in soybean oil. Studies conducted with common cultivars under extreme temperature conditions have also indicated that soybean plants exposed to high daily temperatures have reduced linoleic and linolenic acids and increased oleic acid contents (Dornbos and Mullen, 1992). However, our results were opposite to these results. It could be due to differences in cultivar type and/or strategies in soil and irrigation management.

In average, optimum protein and oil content of soybean seed should be 20% and 35%, respectively (Henry, 2010). In our experiments all treatments showed protein values above the 35% level and oil contents lower than 20% level, except I_0 in 2004. Fatty acid contents except lineolenic acid were within the expected values (Henry, 2010). In general, seed protein contents in this study were higher than those reported values of previous researchers. Previous researchers mostly grew the soybean as a main crop not as a second crop. However, since soybean was grown as a second crop in this study and the seed filling stage coincided with period of high air temperature, the seed protein values in this study were higher than those reported values.

In conclusion, water stress imposed on soybean crops resulted in reduction both growth and seed quality. Therefore, deficit irrigation should be avoided in order to obtain a high quality seed composition and growth. Our results suggest that I_{75} could be recommended in order to save water under limited water conditions, while taking the risk of lowered yield. Higher seed yield together with higher seed protein could be achieved under I_{75} (22% less applied water compared to full irrigation) and I_{100} treatments.

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