© by PSP Volume 27 – No. 6/2018 pages 4212-4219 Fresenius Environmental Bulletin

RELATIONS BETWEEN CROP WATER STRESS INDEX AND STOMATAL CONDUCTANCE OF SOYBEAN DEPENDING ON CULTIVARS

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ABSTRACT

In order to use current water resources efficiently, plant based irrigation scheduling method among soil, climate and plant based methods is used widely. Infrared thermometers are well developed equipment to measure canopy temperatures for plant based irrigation scheduling. Soybean, which contains 40-45% protein, 18-24% fat and 26% carbohydrate, is important for both animal and human nutrition. The aim of this study is to investigate the relations between stomatal conductance (mmol/m^2/s) and crop water stress index in ATAEM-7 and SA-88 soybean cultivars registered officially by Batı Akdeniz Agricultural Research Institute and private sector, respectively. The study is conducted in the year of 2015 according to randomized complete block design to include two cultivars and six different irrigation treatments in three replications. Plots were irrigated using drip irrigation system based on the pan coefficient (K_{pc}) of 0, 0.25, 0.50, 0.75, 1.00, and 1.25 when the cumulative evaporation in Class A pan is 25±5 mm. According to the results, as crop water stress index is increased stomatal conductance decreased. Duncan test revealed that the differences in mean crop water stress index and stomatal conductance in terms of irrigation treatments were found to be statistically highly significant ($p<0.001$). It was concluded that differences between ATAEM-7 and SA-88 cultivars in terms of water stress is not statistically significant. Also, highly significant relationship between crop water stress index and stomatal conductance ($P<0.001$, $R^2=0.92$) was determined.

KEYWORDS:
CWSI, Deficit Irrigation, Antalya, Pan coefficient, *Glycine max (L.) Merr.*

INTRODUCTION

The soybean (*Glycine max (L.) Merr.*) is one of the most important crop species cultivated worldwide. It is a source of oil and protein and is used for livestock feed, human food, and for industrial purposes [1]. The world soybean production increased by 4.6% annually from 1961 to 2007 and reached average annual production of 217.6 million tons in 2005-2007 [2]. World production of soybeans is predicted to increase by 2.2% annually to 371.3 million tons by 2030 using an exponential smoothing model with a damped trend [2]. In Turkey, soybean plants were planted at 20 thousand hectares in the beginning of 1960s and 50 thousand tons were produced. In 2015, planting area reached 36 thousand hectares and production reached 161 thousand tons [3]. Today, Turkey can produce only 6 percent of 2 million tons of soybean that is imported.

Determining the water requirement and exact irrigation scheduling is important for agriculture. But they are affected by environmental and meteorological variables, crop characteristics and management practices. In order to use current water resources efficiently, plant based irrigation scheduling method among soil, climate and plant based methods is used widely. In recent years irrigation scheduling methods depending on the responses of the plants due to water stress are gaining importance. Infrared thermometers are well developed equipment to measure canopy temperatures for plant based irrigation scheduling. The use of canopy temperature as an indicator of crop water stress has been the subject of much research past 50 years [4-10]. According to Gardner et al. [7] crops that are extremely sensitive to water stress may not have irrigation adequately scheduled by crop water stress index (CWSI), while crops that tolerate mild to moderate water stress, or that benefit from water stress imposed at specific growth stages, can have irrigation very effectively scheduled by CWSI. Sezen et al. [9] conducted an experiment to determine the effect of water stress on yield and various physiological parameters including CWSI for drip and furrow irrigated processing red pepper in Mediterranean region. They also found significant relation between yield and CWSI. According to Candogan et al. [8] CWSI could be used to evaluate crop water stress and improve irrigation scheduling for soybeans under sub-humid climatic conditions.

Evapotranspiration (ET) estimation based on scaling up from leaf stomatal conductance (g_s) to canopy conductance (g_c) is important in improving effective use and evaluation of agricultural water resources [11]. Stomata play an essential role in the regulation of both water losses by transpiration and

CO_2 uptake for photosynthesis and plant growth [12]. Also, stomatal control is a major physiological factor for optimizing the use of water in drought conditions [13]. Liu et al. [14] investigated the involvement of root and shoot factors in controlling leaf gas exchange of soybean (*Glycine max (L.) Merr.*) during progressive soil drying and concluded that the g_s and evaporation (E) were the most sensitive processes to soil drying in soybeans. The similarity in the sensitivity of g_s and E in response to soil drying indicated that a decrease of E during soil drying was due mainly to a decrease of g_s, similar to earlier results in vegetable amaranths. Likewise, Makbul et al. [13] declared that g_s decreased during the drought period in leaves and exposure to drought stress resulted in decreasing in g_s as much as 42% in drought stressed leaves as compared to the unstressed leaves. Hattendorf et al. [15] expressed that higher canopy temperature for alfalfa was consistent with lower g_s. Zia et al. [16] reported a high correlation between g_s and CWSI, depending on the phonological stage of the wheat crop with R^2= 0.44 at pre-heading stage and R^2= 0.77 at post-heading stage. Similarly, Orta et al. [17] found statistically significant correlations between CWSI calculated from single leaf temperatures and stomatal resistance in sunflower. Decreasing transpiration may increase canopy temperature due to a reduction in evapotranspiration. An increase in canopy temperature as measured by CWSI occurred in response to water stress, but the effect was not as clear with CWSI as with g_s [18].

The aim of this study is to investigate the relations between g_s (mmol/m^2/s) and crop water stress index (CWSI) in ATAEM-7 and SA-88 soybean cultivars registered officially by Batı Akdeniz Agricultural Research Institute (BAARI) and private sector, respectively.

MATERIALS AND METHODS

The study was carried out in the summer of 2015 at the Bati Akdeniz Agricultural Research Institute (BAARI) in the city of Antalya located on the Mediterranean Sea coast line of Turkey, at the latitude of 36° 52' North and longitude of 30° 50' East, with an altitude of 15 m. The physical and chemical properties of the soil in the experiment area are given in Table 1.

The study is formed in randomized complete block design to include two cultivars and six different irrigation treatments in three replications. Plots were irrigated using drip irrigation system (2 L/h) based on the pan coefficient (K_{pc}) of 0, 0.25, 0.50, 0.75, 1.00, and 1.25 when the cumulative evaporation in Class A pan is 25±5 mm. At the beginning of the experiment, the salinity level of irrigation water was determined to be 0.56 dS/m and pH 7.7. Soybean cultivars of ATAEM-7 developed by BAARI and SA-88 developed by the private sector, were used in the experiment.

The soybean seeds were planted in all plots on 15 May 2015 at a depth of 5 cm, with row spacing of 0.70, intra-row spacing of 10 cm. Climatic parameters were taken from meteorology station which is located near the experiment area (about 250 m distance). The climatic data in the period during which the experiment was conducted are given in Table 2. Crop canopy temperatures were measured with a hand-held infrared thermometer (IR Crop Temperature Meter-Spectrum Technologies Inc.). Temperature readings were made in accordance with the manufacturer's manual [19].

TABLE 1
Physical and chemical properties of the soil in the experiment area

Depth (cm)	Texture class	Field capacity (%)	Permanent wilting point (%)	Bulk density (g cm^{-3})	pH	EC (dS m^{-1})	Organic matter (%)	$CaCO_3$ (%)
0-30	CL	24.0	12.8	1.35	8.0	0.18	1.7	29.9
30-60	CL	23.5	12.8	1.30	8.1	0.13	0.8	32.1
60-90	L	21.6	11.3	1.32	8.1	0.16	0.7	33.7

TABLE 2
Average climatic parameters during 2015 and long-term (1954-2013) for the experimental site

	Temperature (°C)		Total rainfall (mm)		Evaporation (mm)		Wind speed (ms^{-1})		Relative humidity (%)	
Months	1954-2013	2015	1954-2013	2015	1954-2013	2015	1954-2013	2015	1954-2013	2015
05	20.5	21.1	31.8	43.0	142.7	120.9	2.0	2.1	65	62
06	25.4	26.5	7.9	5.0	176.9	126.0	1.9	1.9	59	65
07	28.4	28.0	3.0	0.0	195.3	164.3	1.9	1.7	56	62
08	28.2	28.6	2.4	0.0	172.2	155.0	1.7	1.7	60	62
09	24.7	25.4	13.7	33.3	133.6	123.0	1.8	1.5	60	68
10	20.0	21.0	78.8	97.0	96.0	102.3	1.8	1.4	60	59

The Idso method [6], also known as the experimental approach, was used to calculate the crop water stress index (CWSI). The relevant formula is given in Equation 1.

$$CWSI = \left[\frac{(T_c - T_a) - (T_c - T_a)_l}{(T_c - T_a)_u - (T_c - T_a)_l}\right] \quad (1)$$

Where T_a is the air temperature (°C), T_c is the canopy temperature (°C), $(T_c\text{-}T_a)_l$ is the lower base line (°C), $(T_c\text{-}T_a)_u$ is the upper base line (°C).

g_s (mmol/m^2/s) measurements were made using the method given by Doubledee [18]. It was measured with an SC-1 Leaf Porometer (Decagon Devices Inc. Pullman, WA) with a range of 0 to 1000 mmol/m^2/s and a sample chamber aperture of 6.35 mm [20]. Measurements were made by clipping the sensor of the porometer onto a leaf at the top of the canopy just below the newest green leaf. g_s measurements were taken from two leaves per plot and the two readings were averaged. For accurate readings, g_s was measured when the sun is highest in the sky between the hours of 11:00 a.m. and 2:00 p.m. Statistical analyzes of the data were conducted using the SAS statistical software. Analysis of variance was performed in order to evaluate the influence of different irrigation level on CWSI and g_s measurement. The significance of differences between treatments was determined using Duncan's Multiple Range test. Also linear correlation was calculated for the relationship between CWSI and g_s.

RESULTS AND DISCUSSION

The variations of crop water stress index (CWSI) for ATAEM-7 and SA-88 soybean cultivars are shown in Figure 1 and Figure 2, respectively, as a function of different irrigation level and day of year (DOY).

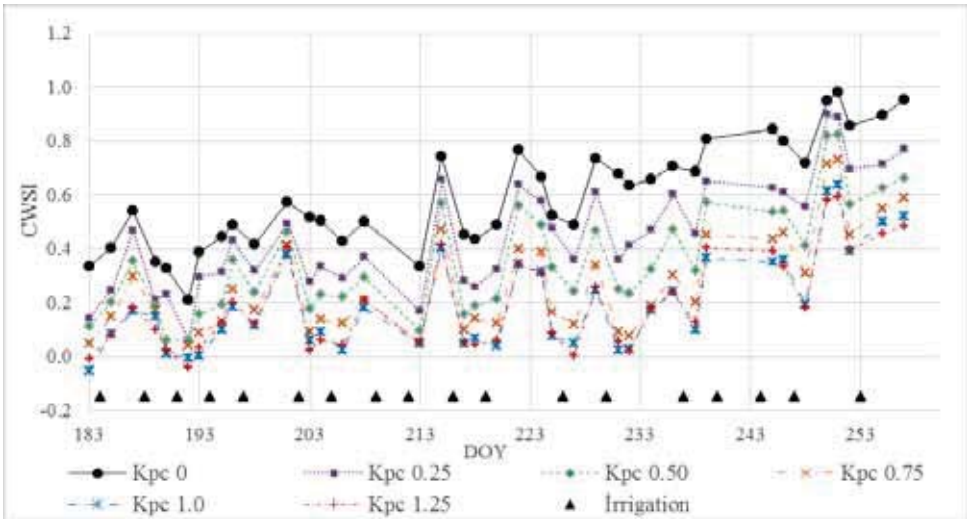


FIGURE 1
Seasonal variations of crop water stress index (CWSI) for ATAEM-7 soybean cultivar

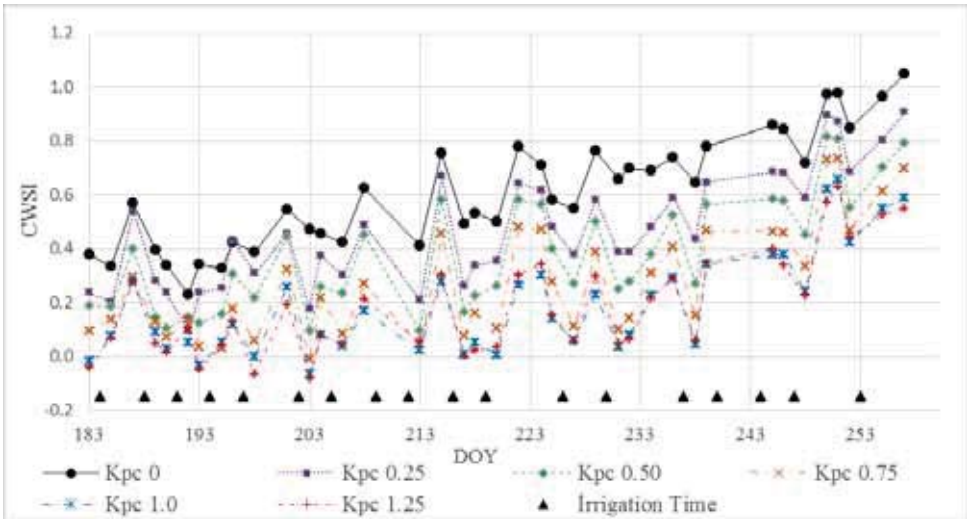


FIGURE 2
Seasonal variations of crop water stress index (CWSI) for SA-88 soybean cultivar

According to Figure 1 and 2, a similar CWSI trend was determined for each irrigation level and cultivar. CWSI values for soybean range from 0 to 0.4 at the beginning of the season and range from 0.5 to 1 at the end of the season depending on irrigation treatments. The highest CWSI values were determined at the end of the season for ATAEM-7 and SA-88 cultivar both in K_{pc}: 0 treatment as 0.95 and 1.05, respectively. Similar CWSI trends had been reported with deficit irrigation applied for maize by Taghvaeian et al. [21] and for pepper by Sezen et al. [9].

The variations of g_s (mmol/m^2/s) in ATAEM-7 and SA-88 soybean cultivars are shown in Figure 3 and Figure 4 as a function of different irrigation level and day of year (DOY).

According to Figure 3 and Figure 4, similar g_s trends determined for each irrigation level and cultivar. The lowest g_s values were measured in non-irrigated treatment (K_{pc}: 0). Mean g_s ranged from 231 to 569 mmol/m^2/s. Doubledee (2012) reported values of mean g_s varying between 175.5 and 718.6 mmol/m^2/s for soybean depending on different irrigation applications. In this context, the results obtained in this study were similar to the results of Doubledee [18]. As can be seen from Figures 3 and 4, as the water stress of the plants increases, the g_s decreases. Although not measured in this study, this could be attributed to the reduced stomatal area in the deficit irrigated treatments [22, 23]. Statistical analyzes regarding g_s and CWSI is shown in Table 3-4 respectively.

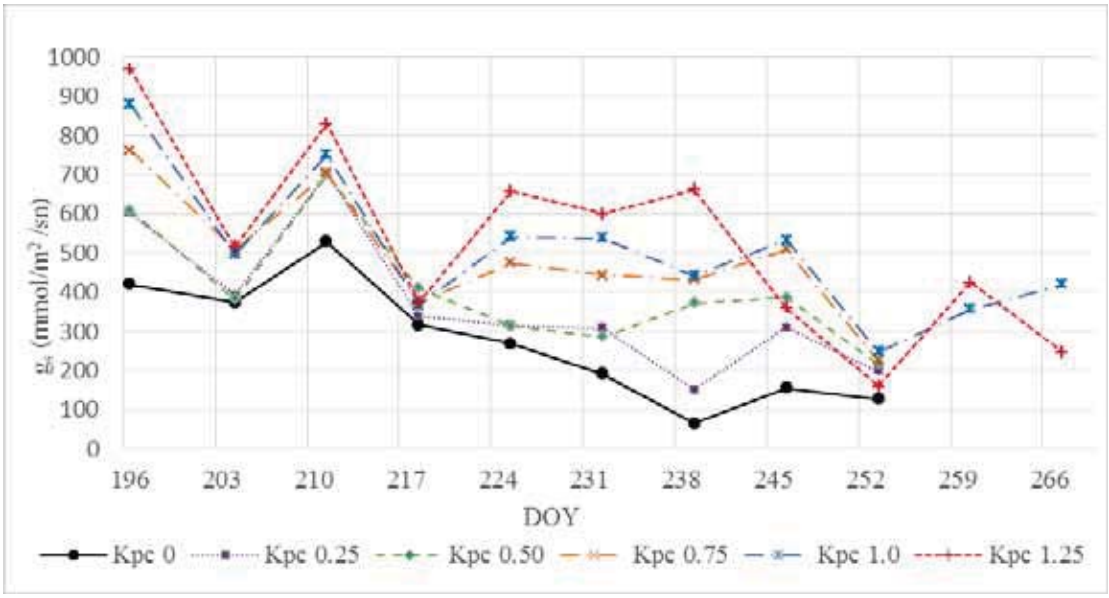


FIGURE 3
Seasonal variations of stomatal conductance (mmol/m^2/s) for ATAEM-7 soybean cultivar

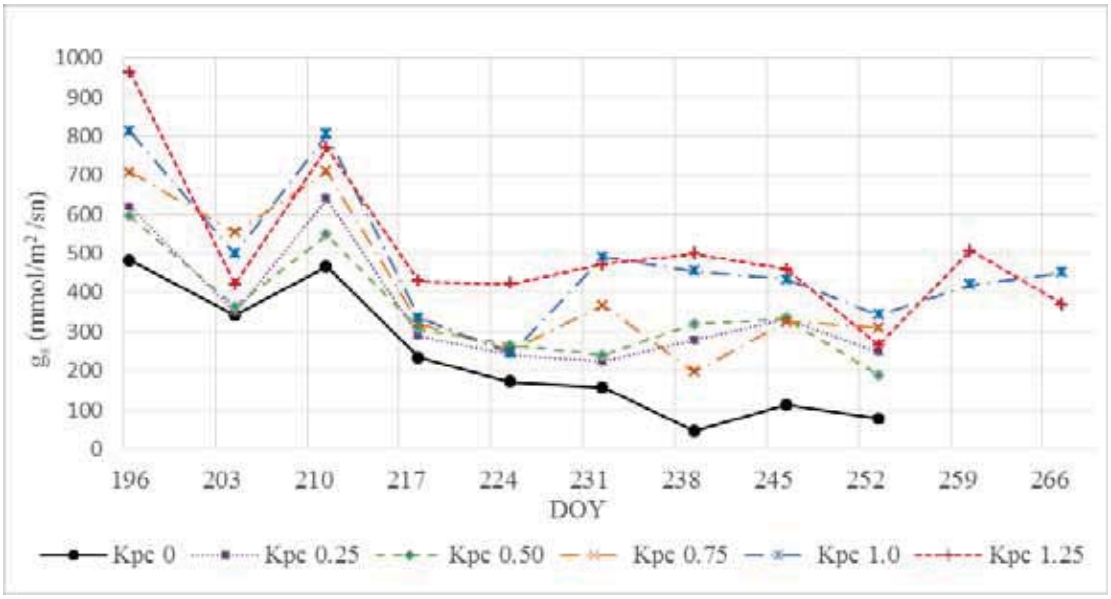


FIGURE 4
Seasonal variations of stomatal conductance (mmol/m^2/s) for SA-88 soybean cultivar

TABLE 3
Statistical comparison of g_s for cultivars and irrigation levels

	g_s (mmol/m²/s)							
Cultivar	**K_{pc}: 0**	**K_{pc}: 0.25**	**K_{pc}: 0.50**	**K_{pc}: 0.75**	**K_{pc}: 1.00**	**K_{pc}: 125**	**P > F**	**Mean of cultivar**
ATAEM-7	271.2 c	368.1	408.4 abc	492.5 ab	532.8 ab	569.4 a	*	440.4
SA-88	231.8 b	357.8 ab	351.1 ab	416.0 a	491.1 a	525.5 a	*	395.5
P > F	**ns**	**ns**	**ns**	**ns**	**ns**	**ns**		
Mean of irrigation level	**251.5 c**	**362.9 bc**	**379.8 b**	**454.2 ab**	**511.9 ab**	**547.5 a**		
Significance								
Cultivar (C)	: ns							
İrrigation level (I)	: ***							
C x I	: ns							

Means followed by the different letters in each row are significantly different at 5% level by Duncan test. Since there was no interaction between the irrigation level and the cultivars, all cultivars had been evaluated within themselves.
ns: non-significant; * P<0.05; ** P<0.01 *** P<0.001.

TABLE 4
Statistical comparison of CWSI for cultivars and irrigation levels

	CWSI							
Cultivar	Kpc: 0	Kpc: 0.25	Kpc: 0.50	Kpc: 0.75	Kpc: 1.00	Kpc: 125	P > F	Mean of cultivar
ATAEM-7	0.59 a	0.45 b	0.35 c	0.26 d	0.20 d	0.20 d	***	0.35
SA-88	0.61 a	0.47 b	0.38 b	0.27 c	0.19 c	0.19 c	***	0.34
P > F	ns	ns	ns	ns	ns	ns		
Mean of irrigation level	**0.60 a**	**0.46 b**	**0.36 c**	**0.27 d**	**0.19 e**	**0.19 e**		
Significance								
Cultivar (C)	: ns							
İrrigation level (I)	: ***							
C x I	: ns							

Means followed by the different letters in each row are significantly different at 5% level by Duncan test. Since there was no interaction between the irrigation level and the cultivars, all cultivars had been evaluated within themselves.
ns: non-significant; * P<0.05; ** P<0.01 *** P<0.001.

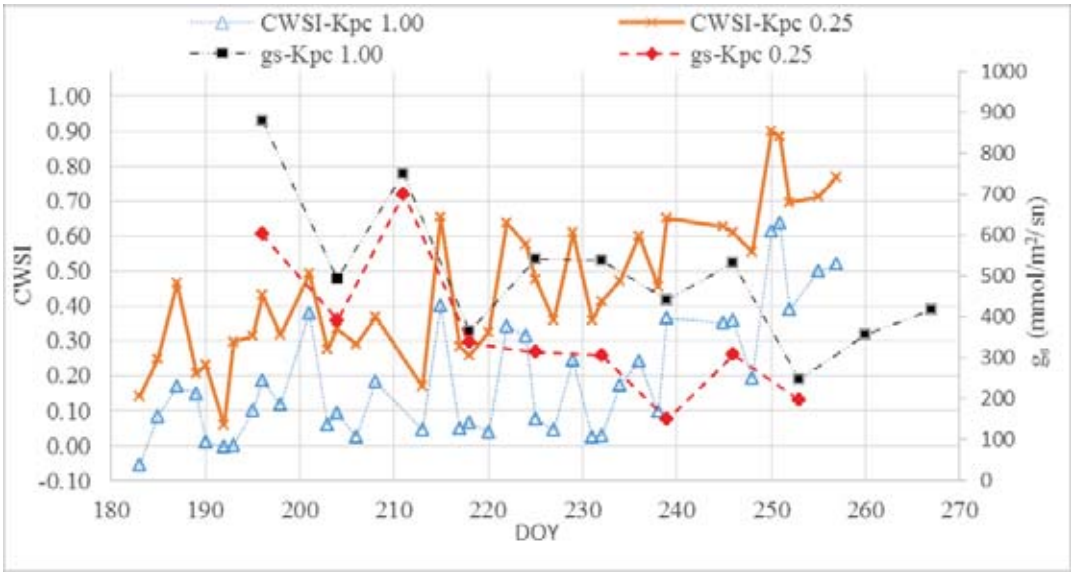


FIGURE 5
The relationship between stomatal conductance and CWSI for deficit (Kpc: 0.25) and well irrigated (Kpc: 1.00) treatments for ATAEM-7 cultivar

No significant differences for g_s and CWSI were found between cultivars as well as interaction of cultivars and irrigation levels. There was a highly significant difference (P<0.001) among irrigation treatments both g_s and CWSI. As expected, the highest CWSI value was determined for K_{pc}: 0. There was no significant difference between K_{pc}: 1.0 and K_{pc}: 1.25 treatments where the lowest mean CWSI values were obtained. It was determined that the soybean

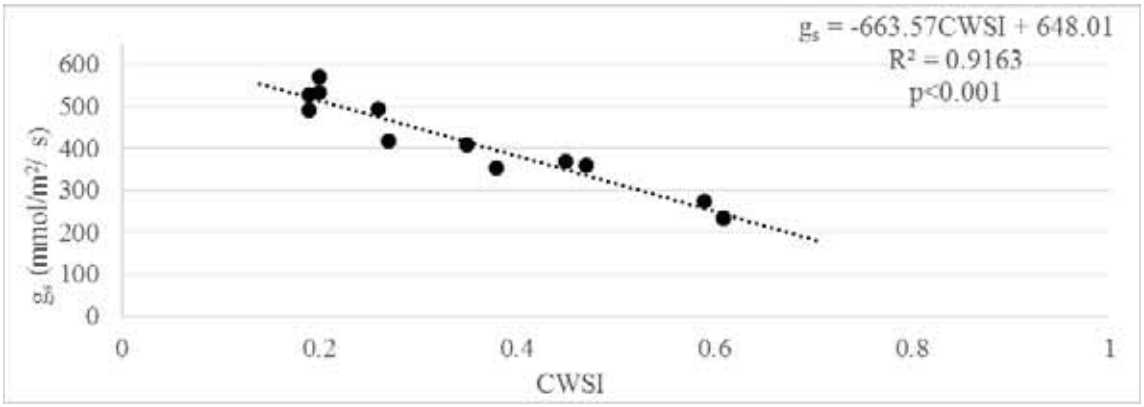


FIGURE 6
The relationship between seasonal averaged CWSI and gs (pooled data)

plants undergo stress because of the application of deficit irrigation. Nielsen [24] showed that irrigation scheduling could be done for soybeans using CWSI. For this reason, the results obtained in this study were in accord with Nielsen [24]. Similarly, Doubledee [18] found that cultivars and interaction between cultivars and irrigation level showed no significant effects on the g_s for soybean at 84 days after planting. The author also found that only irrigation level had significant effects on the g_s. According to Table 3, mean g_s for irrigation level is not significantly different for K_{pc}: 1.25, K_{pc}: 1.00 and K_{pc}: 0.75 irrigation levels, but significant differences were found between the other treatments. It was determined that the lowest mean g_s was in K_{pc}: 0 treatments (251.5 mmol/m^2/s). The relationship between g_s and CWSI for deficit (K_{pc}: 0.25) and well irrigated (K_{pc}: 1.00) treatments is presented in Figure 5.

As seen in Figure 5, there is an inverse relationship between g_s and CWSI for well irrigated (K_{pc}: 1.00) and deficit irrigated (K_{pc}: 0.25) treatments. The steady decline in g_s and the regular increase in CWSI can be evaluated as the response of the plant to water stress. Higher values in g_s and lower value in CWSI were observed in the later growth stage as a result of maturity. The relationship between CWSI and g_s is shown in Figure 6.

According to figure 6, it was found that highly significant relationship between CWSI and g_s ($P<0.001$, $R^2=0.92$) was found. Results showed as CWSI increased g_s decreased. Zia et al. [16] reported that CWSI and g_s are linearly correlated (R^2 =0.77) at the post-heading stage for wheat. Similarly, Orta et al. [17] stated that there was a strong relationship (R^2 =0.77) between CWSI and stomatal resistance ($1/g_s$) for sunflower.

CONCLUSION

Irrigations can be scheduled depending on the change in stomatal conductance and CWSI values of plants due to water stress. CWSI values for soybean range from 0 to 0.4 at the beginning of the season and range from 0.5 to 1 at the end of the season. At the end of the season, the highest CWSI for ATAEM-7 and SA-88 was found both in K_{pc}: 0 treatment as much as 0.95 and 1.05, respectively. Likewise, the lowest g_s values for ATAEM-7 and SA-88 were determined at the end of the season as much as 127 mmol/m^2/s and 77 mmol/m^2/s, respectively, in K_{pc}: 0 treatment.

According to the results, as CWSI increased stomatal conductance decreased. Duncan test revealed that the differences in mean CWSI and stomatal conductance in terms of cultivars and irrigation treatments were found to be statistically highly significant at $P<0.001$. Also it was found that highly significant relationship between CWSI and g_s ($P<0.001$, $R^2=0.92$). It was concluded that there were no significant differences between the soybean cultivars (ATAEM-7 and SA-88) for CWSI and stomatal conductance.

ACKNOWLEDGEMENTS

The authors would like to thank respectable authorities on Bati Akdeniz Agricultural Research Institute (BAARI) that helped us in carrying out this study.

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Received: **11.11.2017**
Accepted: **25.03.2018**

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