International Journal of
Agriculture, Environment and Food Sciences

JAEFS

e-ISSN : 2618-5946 DOI: 10.31015/jaefs.2020.3.2 www.jaefs.com

Research Article Int J Agric Environ Food Sci 4 (3): 244-254 (2020)

Response of some physiological components of cotton to surface and subsurface drip irrigation using different irrigation water levels

Oner Cetin[1,*]

[1]Dicle University, Agriculture of Faculty, Dept. of Agricultural Structures and Irrigation, Diyarbakir, Turkey

*Corresponding Author: oner_cetin@yahoo.co0m

Abstract

This study was carried out to determine the leaf water potential (LWP), stomatal conductance (SC) and leaf area index (LAI) of cotton crop using subsurface drip irrigation (SSDI) and surface drip irrigation (SDI) and different irrigation water levels based on the FAO-56 Penman-Monteith (PM) during the 2016 and 2017 growing seasons. The critical LWPs in vegetative period, flowering stage and boll formation stage in SDI for irigation time were -24, -23 and -24 bar, respectively. Considering the same putting in order for the crop development stages in SSDI-40 cm, those were -23, -23 and -24 bar, respectively. The values of LWP in SSDI-30 cm were the same levels in SSD-40 cm. LWP in the boll formation stage were, in general, lower (bigger in minus numerical number) compared to the first two development stages of the crop. The critical SCs in vegetative period, flowering stage and boll formation stage in SDI were 312.8, 201.8 and 198.9 mmol m^{-2} s^{-1}, respectively. The values of SC in the same putting in order for the crop development stages in SSDI-30 cm and SSDI-40 cm were 368.8, 182.6 and 221.8 mmol m^{-2} s-1; and 371.7, 185.9 and 186.8 mmol m^{-2} s^{-1}, respectively. SC decreased from the vegetative period through generative period of the crop. The SCs increased together with increasing amount of irrigation water and it decreased with increasing water stress conditions. The LAIs were 2.99, 3.11 and 3.45 in SDI, SSDI-30 cm and SSDI-40 cm, respectively. The values of LAI increased from the surface drip irrigation and lower irrigation water level applied through subsurface drip irrigation and highest level of amount of irrigation water. Although some plant physiological indicators such as LWP and SC might be used for irrigation scheduling and irrigation time, these indicators are highly affected by soil water status, temperature, light, air humidity and calibration of the devices used.

Keywords: Cotton, Leaf water potential, Stomatal conductance, Leaf area index, Drip irrigation

Introductıon

Cotton is the major industrial crop produced in Turkey and it is crucial to the wider economy since it provides the fiber for textiles. Cotton is primarily grown in the Southeast Anatolia Region which is in the study area of Turkey. Cotton requires a large amount of water (about 1000 mm) using surface irrigation methods since climatological and farmer conditions (Kanber et al., 1991; Cetin and Bilgel, 2002).

In the last decade, use of drip irrigation for cotton increased enormously by means of subsidizing of Turkish Government and awareness of farmers considering water saving. However, use of modern technology, surface and subsurface drip irrigation, need more attention and high experience to accurate and to precise irrigation water. Thus use of irrigation water considering water saving and/or higher irrigation water productivity will be essential if farmers are to minimize risks associated with deficit water while also minimizing the negative outcomes of overirrigating (Chastain et al., 2016).

On the other hand, some data and parameters pertaining to the soil or plant water status for crop irrigation scheduling must be known for an accurate irrigation. However, this is not always reliable, as different physiological behaviours of

Cite this article as:
Cetin, O. (2020). Response of some physiological components of cotton to surface and subsurface drip irrigation using different irrigation water levels. Int. J. Agric. Environ. Food Sci., 4(2), 244-254
DOI: https://doi.org/10.31015/jaefs.2020.3.2
ORCID: Oner Cetin 0000-0002-4450-0811
Received: 24 April 2020 **Accepted:** 22 June 2020 **Published Online:** 13 July 2020
Year: 2020 **Volume:** 4 **Issue:** 3 (September) **Pages:** 244-254
Available online at : http://www.jaefs.com - http://dergipark.gov.tr/jaefs

plants might correspond to the same soil water content. In addition, it is sometimes difficult to know where to measure soil water content because of variation in the soil water content in soil volume surrounding the roots (Patane, 2011). Thus, some physiological criteria such as leaf water potential (LWP) and stomal conductance (SC) might be usefull for irrigation scheduling and/or to show the water stress conditions for plants.

LWP could be defined as a measurement of the negative hydrostatic pressure that occurs in the xylem tissue of a plant. LWP can have been, thus, estimated as the negative pressure value required to obtain liquid on the surface of the xylem exposed to atmospheric pressure (Scholander et al., 1965; Campbell, 1985; Busso, 2008). LWP can be used as an effective irrigation measure and/or scheduling to maximize water productivity for cotton irrigation with considerably differences in water availability (Chastain et al., 2016). However, some environmental factors can limit the use of indirect measurements of water status in the plant. This can potentially be accounted for by a calibration pertaining to the specific region using a direct measure of plant water status (Jones, 2004). Concerning measurement of water potential in the midday is highly indicative for the physiological state of the plant (Turner et al., 1986; Pettigrew, 2004; Ennahli and Earl, 2005; Chastain et al., 2016) and a strong indicative of water-induced variation in productivity (Grimes and Yamada, 1982).

Stomatal conductance (SC) is a measurement of the degree of stomatal opening and can be used as an indicator of plant water status. The SC can show the stress conditions of plants through use of a porometer device. Some evidence indicates that the SC and photosynthetic rate of leaves are correlated across diverse environments. The correlation between SC and photosynthetic rate has led to the postulation of a "messenger" from the mesophyll that directs stomatal behavior (Radin et al., 1988).

On the other hand, leaf area index (LAI) directly specify canopy structure, and can be used to estimate primary productivity and growth of crops. LAI is commonly used in ecosystem and crop. Thus many ecosystem and crop models require LAI as an input variable.

The main purpose of this study is to evaluate some crop physiological stress indicators such as leaf water potential and stomatal conductance and leaf area index associated with yield and different irrigation water levels using surface and subsurface drip irrigation for cotton.

Materials and Methods

Study area

This study was carried out at the Research and Experimental Station, Faculty of Agriculture, Dicle University (Diyarbakir, Turkey) during the 2016 and 2017 cotton growing seasons. The experimental site is located at 37° 54' N, 40° 14' E, at an elevation of 660 m above sea level. The soil texture is heavy texture, clay content is about 65%. The climate in the study area fall into terrestrial climatological properties. The average annual rainfall of 490 mm is concentrated in winter season and there is no almost precipitation during the cotton irrigation season. The bulk density of soil ranged from 1.19 to 1.27 g cm^{-3} in the soil profile. The infiltration rate was 8 mm h^{-1}. There were no any risk in terms of water table, salinity and irrigation water used.

Experimental design and treatments

The field trials were performed using a split plots in randomize blocks with three replications (Yurtsever, 2011). Main plots are surface and subsurface drip irrigation systems, and sub-plots are different amount of water based on FAO-56 Penman-Monteith method (PM) and Kc approach (Allen et al., 1998). The experimental treatments are given in Table 1.

The irrigation amount of water was applied according to the estimated crop evapotranspiration (ETc) based on FAO-56 Penman-Monteith method and using actual climatological data pertaining to experimental site (Allen et al., 1998). For this, the reference evapotranspiration (ETo) was daily calculated using the meteorological data pertaining to the study site according to the FAO-56 Penman-Monteith method equation. Then, amount of irrigation water was computed using Kc coefficients in the crop development stages of cotton. Irrigation cycle was at each 5 days. The last irrigation was ended at the approximately 10% of boll opening (Bilgel, 1994).

The equations (1 and 2) given below were used to calculate amount of irrigation water applied (Allen et al., 1998).

$$ETc = Kc\ ETo \quad (1)$$

$$I = A\ .\ ETc\ .\ K.\ Pc \quad (2)$$

Where ETc is estimated crop evapotranspiration (mm d^{-1}), Kc crop coefficient (dimensionless) and ETo reference crop evapotranspiration for grass (mm d^{-1}). I is amount of irrigation water applied to the experimental plot (Liters), A is plot area (m^2), K is different rates of ETc, Pc is canopy cover (%).

The plot size is 4.20 m x 8.00 m (33.60 m^2). One lateral has irrigated two cotton rows, thus, the lateral spacing is 1.40 m. The sowing date was at the beginning of May and the harvest date was at the beginning of October for two experimental years.

Measurement of LWP and SC

The physiological indicators, LWP and SC were measured in five cotton plants for each treatments and plots under different irrigation treatments and irrigation systems (SDI and SSDI) for three critical stages of cotton, vegetative period (I), flowering stage (II) and boll formation (III) before irrigation (Kara and Gunduz, 1998). LWP and SC were measured by a pressure chamber as bar and a diffusion porometer as mmol H_2O m^{-2} s^{-1}, respectively. To measure SC was used a portable porometer. The instruments were calibrated according to the manufacturer's instructions before each measurement cycle.

The measurements were carried out at noon (13.00–14.00) on the lower surface of the last fully expanded leaf on five samples per plot (Martinez et al., 2013; Koksal et al., 2010).

Leaf area index (LAI)

LAI is the ratio of all leaves' area on the plant to the certain and cropped ground area. For this, all leaves on the five plants in each plot were collected and they were scanned and computed all area of the leaves using a computer programme (software). Then, this area of the leaves were divided to the total area of certain cropped in the field.

Table 1. Experimental treatments according to the split plots design

Main plots (Drip irrigation systems)	Sub-plots (Irrigation water)
I_1 : Surface drip irrigation **I_2:** Subsurface drip irrigation (depth of 30 cm) **I_3:** Subsurface drip irrigation (depth of 40 cm)	**K_1**: I=1.25 × ETc (crop evapotranspiration based on FAO-56 Penman-Monteith **K_2**: I=1.0 × ETc **K_3**: I=0.75 × ETc

Results and Discussion

Leaf water potential (LWP)

The values of LWP ranged from -20.7 to -26.3 in 2016 and from -16.6 to -26.3 depending on crop stages, irrigation water levels, surface and subsurface drip irrigation systems and experimental years. However, the average values for 2 experimental years are given in Figure 1a. In addition, Figure 1a shows the values of LWP in both different drip irrigation systems (SDI and SSDI) and different amount of irrigation water according to the different development stages of cotton. Thus, LWPs in the first two stages of the crop, vegetative development and flowering, were higher compared (smaller in minus numerical number) to those in boll formation stage. In general, the values of LWP in the boll formation stage, generative stage of crop, were, thus, lower (bigger in minus numerical number) compared to the first two development stages of the crop. This result clarified that boll formation stage was more consumptive water use because of generative stage of the crop (Kara and Gündüz, 1998). On the other hand, considering the different development stages of crop , the range and/or treshold of LWPs for flowering stage were same for all drip irrigation systems (Figure 1a).

According to the variance analysis, the treatments in the main plots, surface and subsurface drip irrigation, significantly affected ($P \leq 0.01$) LWPs in the vegetative stage of crop. It is understood from these results that the plants in the subsurface drip irrigation at 40 cm depth has got less water stress compared to the surface and the other subsurface drip (30 cm) irrigation. There were significantly effects ($P \leq 0.05$) of different amount of irrigation water on LWPs in the boll formation of crop. LWPs increased (smaller in minus numerical number) as long as increased amount of irrigation water applied (Figure 1b). Different amount of irrigation water applied in the boll formation of crop which has got more stress affected the LWP. For instance, the treatment of I=ETc x 1.25 (K_1, more irrigation water) showed lower LWP (bigger minus numerical number) however the treatment of I=ETc x 0.75 (K_3, less irrigation water) showed higher LWP (smaller minus numerical number) in both SDI and SSDI depending on amount of irrigation water applied (Figure 1b and Figure 2). Thus, LWP dependent on amount of irrigation water rather than different drip irrigation systems. Kaufman (1981) stated that the critical treshold value of cotton on LWP for irrigation is between -17 and -18 bar. Maya (2017) reported that the values of LWP of cotton for full irrigation, deficit irrigation and severe stress conditions were about -15.5, (-16)-(-18) and (-22)-(-23) bars, respectively. Yazdıç and Değirmenci (2018) measured the LWP to be (-23.4)-(-26.9) for cotton under the Mediterranean conditions. Although there have been some similar results taking into acoount the previous studies, the values of LWP at the crtical development stages of cotton were more or less different. The values of LWP in our study were lower (bigger minus numerical number) compared to these values. The reasons of these differences might be probably the lower available water in the soil since very heavy soil texture (clay content of soil is about 65%) and compaction, in another word, water retention energy by clay particules is very high thus water moving from soil into the plants are not easy. Thus, the values of LWP could be different considering environmental, soil and agronomic conditions. These could be considered such as soil water availability, soil temperature, absolute humidity and wind spead (Kaufman and Hall, 1974; Hake and Grimes, 2010). Considering some extreme climatic and soil conditions such as maximum temperatures (up to 45 ^{o}C), some extra advection to the study area, soil texture (very high clay content) and soil structure in the study region, obtaing different values of LWPs is expected results.

According to the previous studies, LWP is an using way in terms of internal dynamic for the plants (Jones et al., 1991), and LWP shows inverse correlation with relative water content of leaves, stoma dimension and numbers, and agronomic applications (Saleem et al., 2016). In addition, relative water content in the leaves and photosynthesis rate decreased as long as decreasing (increasing negative number) LWP (Lawlor and Cornic, 2002). Stomal and non-stomal irregularity under the deficit irrigation conditions for cotton caused in decrease of photosynthesis rate (Leidi et al., 1999).

On the other hand, LWP is a physiological criteria frequently used in irrigation scheduling. LWP shows energy status of water in the leaves, in another word it is described as a collimator power of water moving. LWP might be varied according to the transpirational flow and water content in the soil, thus it is an important criteria for the assessment of plant water relationships (Camacho et al., 1974).

Stomatal conductance (SC)

The SC could not measure in only vegetative period in 2016 since the porometer was out of order. In addition, although there has been a special calibration for porometer before reading and this was made, some readings (base or treshold values) might show deviation from readings from each stage of crop. Because, rapid stomatal closure in the porometer cuvette is another problem that can limit porometer accuracy in certain cases. There is substantial variation in sensitivity to leaf surface humidity among plants (McDermitt, 1990).

In the study, the SC were ranged 82.6-312.5 mmol m^{-2} s^{-1} and 143.4-437.3 mmol m^{-2} s^{-1} for all treatments in 2016 and

2017, respectively. However, the average values of SC pertaining to the experimental treatments and years are shown in Figure 3a and 3b.). According to the results of variance analysis, there were significantly differences (P≤0.01) between SDI and SSDI, and different amount of irrigation water applied in flowering stage in 2016. The maximum SC reached in the treatment that the maximum amount of irrigation water applied in K_1: I=1.25x ETc (Figure 3b). As expected, the SC increased together with increasing amount of irrigation water and decreased with increasing water stress conditions (decreasing amount of irrigation water) (Figure 4.). That the values of SC have been showed difference might be attributed to the development crop stage, different application of irrigation water, climatic conditions and variations in the porometer device.

On the other hand, SC increased for the crops on the plots in which grown under the subsurface drip irrigation at 40 cm compared to the other treatments during the vegetative development stage (Figure 3a). Considering the stage of boll formation, there were significantly difference (P≤0.01) between SC under the applications of different amount of irrigation water. In this stage, there was no any effect on SC under surface and subsurface drip irrigation. For this, the lowest SC was obtained under the lowest level of irrigation water (Figure 3b and 4). However, there were no significantly difference on SC during the boll formation. This might be attributed that the irrigation was ended different period considering the different treatments and the plants consumed more water.

According to the results in 2017, there were significantly differences (P≤0.05) between SCs on the SDI and SSDI during the flowering stage, however there were significantly differences (P≤0.01) between SCs on different amount of irrigation water during the boll formation. The SCs increased as long as amount of irrigation water increased (Figure 4).

Considering the treatment in which subsurface drip irrigation at 40 cm and irrigation water application based on crop evapotranspiration using FAO-PM (I=1.0xETc), the values of SC were 369, 183 and 222 mmol $m^{-2} s^{-1}$ for the stages of vegetative development, flowering and boll formation stage, respectively. The values of SC during the vegetative stage were higher compared to those in the the other stages because this stage is rapidly development stage. In another word, during the vegetative growth stage, roots develop rapidly (Hake and Grimes, 2010). The values of SCs decreased in the next stages of crop (Figure 4). One of the factors indirectly affecting on SC might be soil compaction because of soil texture (very high clay content up to 65%) and clay type in the experimental site. For that reason, this condition affects soil water availability for crops.

Similarly, Ephrath et al. (1990) reported that SC decreased with increasing water stress conditions, the correlation between radiation and SC decreased as long as the plants exposed to water stress and there was a asymptotic relationship between photosynthesis rate and SC. All these findings show similar results from this study. Meidner and Mansfield (1968) stated that SC is also depending on CO_2 concentration in the surrounding environment and difference on leaf-air vapor pressure. Cell growth in cotton is, thus, more sensitive than stoma closure during the limited water conditions. For this, sensitivity to cell gowth and increase on plants height and leaf area are more responsive than the results related to stoma closure on transpiration and photosynthesis (Turner et al., 1986; Puech-Suanez et al., 1989).

On the other hand, photosynthesis and stomal conductance become discrete under the higher temperatures. Because, the higher temperature decrease absisic acid level, thus transpiration become maximum, thus this cause cool of leaves. Biological water use efficiency and water saving become maximum (Radin, 1992). Connecting this, in this study region has very hot climate regime during the growing season up to 45 ^oC. Thus, the effects of higher temperatures on stomal conductance are effective as reported by Radin (1992). In addition, the main effects of deficit water on cotton production occur on decreasing of stoma closure and C fixation in the leaves and leaf growth (Patterson et al., 1978; Inamullah and Isoda, 2005). The plants adapts differently to water stress. Cotton adapts to water stress by maintaining higher transpiration compared to the other crops such as soybean. The higher transpiration in cotton was due to a higher SC, which was supported by a higher flow rate of stem sap, larger stomatal area, and probably the diaheliotropism (Inamullah and Isoda, 2005).

Leaf area index (LAI)

LAI was only computed in 2017 and it was measured at the generative stage of crop (boll formation). Accoroding to the results, the LAIs ranged from 1.60 through 4.09 depending on the treatments and experimental years. However, the average values of LAI are given in Figure 5. The lowest LAI was obtained from the treatment in which the lowest amount of irrigation water was applied and the maximum amount of irrigation water resulted in the maximum LAI. The values of LAI increased from the surface drip irrigation and lower amount of irrigation water applied through subsurface drip irrigation and highest level of amount of irrigation water (Figure 5).

According to the results of variance analysis, increasing amount of irrigation water applied significantly ((P≤0.05) increased the values of LAI. Although there were no significantly difference on the values of LAI between surface and subsurface drip irrigation systems, the subsurface drip irrigation system at 40 cm resulted in the maximum LAI (Figure 5).

Considering the average seed cotton yields, there was a linear relationships between seed cotton yield and LAI (for SDI: y = 1093+873.7X, R^2 = 0.97**, P ≤ 0.01; for SSDI-30 cm: y = -8664+4113.5X, R^2 = 0.70*, P ≤ 0.01; and for SSDI-40 cm: y = 905.9+1045.4X, R^2 = 0.99**, P ≤ 0.01), and the regression curves with regard to each drip irrigation system are shown in Figure 6.

Ashley et al. (1964) reported that LAI reaches to 1.0 at 6 or 8 weeks after emergency of the plants. Considering the relationship between boll formation and LAI, LAI rises up to 5.0 during the boll formation. In addition the evaporation from the soil surface decreases as long as LAI and canopy cover increase (Luo et al., 2011). In the previous studies, the values of LAI ranged from 3.62 through 3.71 depending on different cotton varieties (Ekinci et al., 2008), the maximum LAI was obtained to be 4.0-5.8 at the treatment in the maximum crop evapotranpiration (Kanber et al., 1991) and LAI was 3.37 for cotton grown at the Lower Seyhan Plain of Turkey (Baydar, 2010). Ödemiş et al. (2018) determined LAI to be 3.59 for full irrigation conditions. In addition, Ertek and Kanber (2001) reported that the values of LAI ranged from 3.24 through 4.40. LAI were found between 3.10 and 5.54 depending on amount of irrigation water applied and cottton variety and LAI increased as long as increasing irrigation water (Keten, 2016). The valus of LAI in this study are, in general, similiar to the results of previous studies. However, LAI might be different as it is in this study depending on cotton varieties, irrigation systems and/or methods and amount of irrigation water and climatological conditions. On the other hand, ageing of leaves accelerate under the deficit irrigation, LAI continue to increase during the crop development stages under the full irrigation conditions but it decrease under the deficit irrigation (Saleem et al., 2016; Noreen et al., 2013). In addition, LAI is one of the criteria on measurement of photosynthesis capacity. Thus LAI might be used to determine the variation rate of CO_2 in the plants regardless the shape and dimension of (Pegelow et al., 1977).

On the other hand, there were significantly relationships (P≤0.01) between LAI and amount of irrigation water using regression analysis in both surface and subsurface drip irrigation systems (Figure 7). For this, seed cotton yield increased with increasing of LAI. As a result irrigation water applied increased directly cotton yield and LAI (Chen et al., 2017).

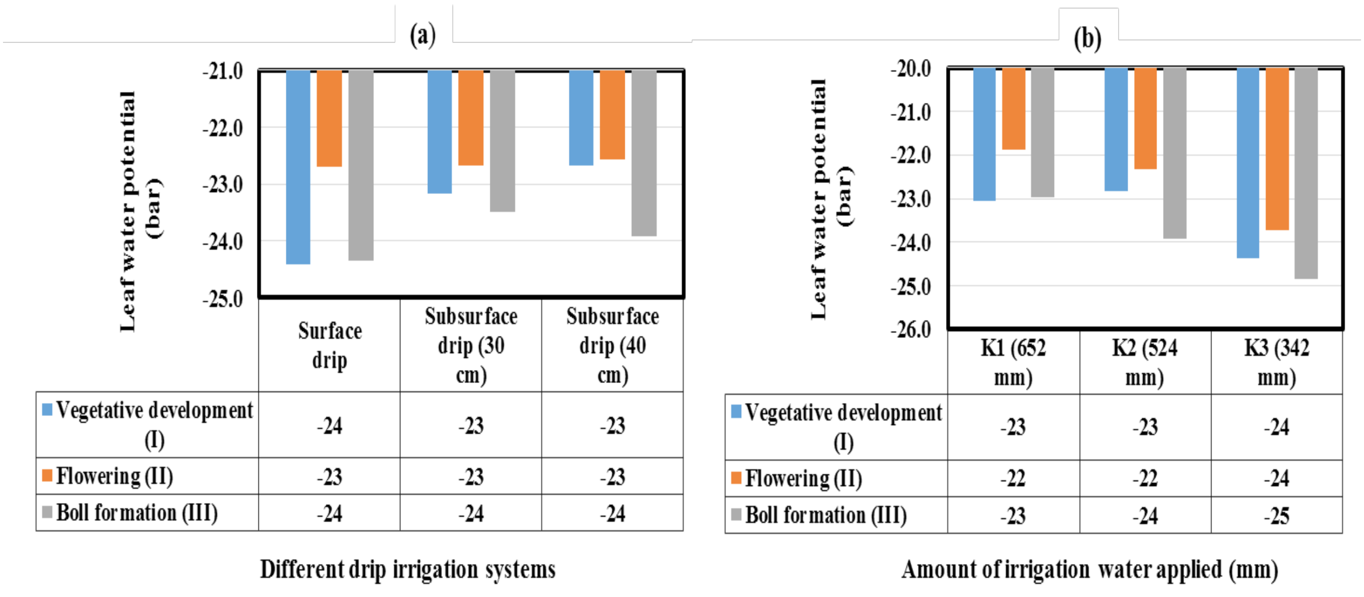

Figure 1. The effects of different drip irrigation systems (a) and different amount of irrigation water (b) on leaf water potential according to the crop development stages for the average of two experimental year.

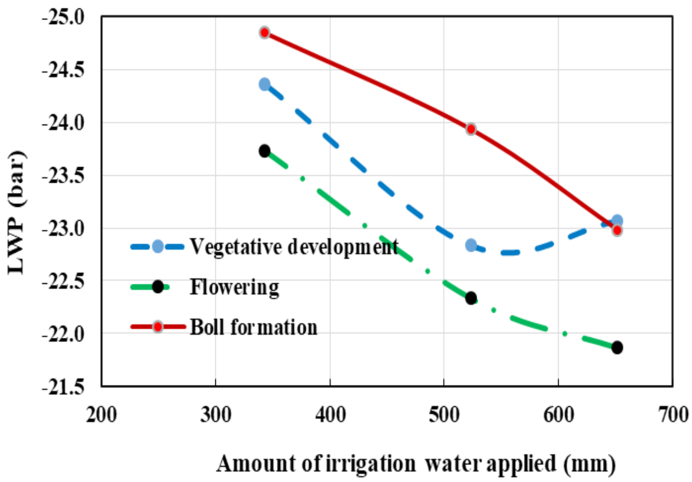

Figure 2. Relationship between amount of irrigation water and LWP

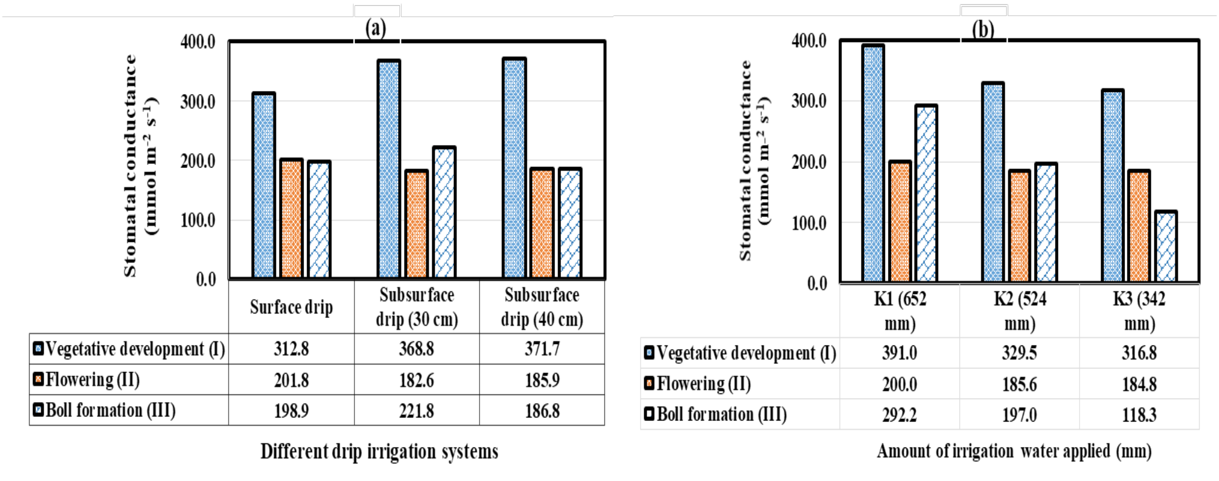

Figure 3. The effects of different drip irrigation systems (a) and different amount of irrigation water (b) on stomatal conductance according to the crop development stages for the average of two experimental years

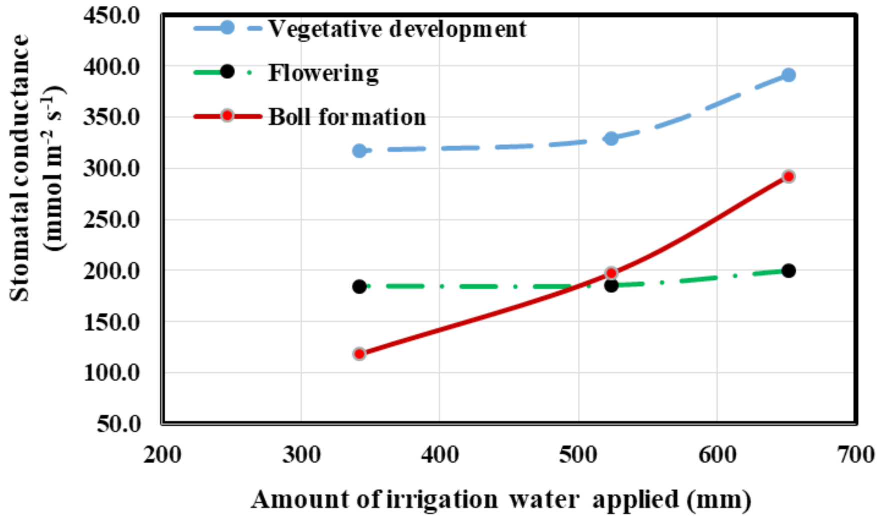

Figure 4. Relationship between stomatal conductance and amount of irrigation water applied regardless SDI and SSDI

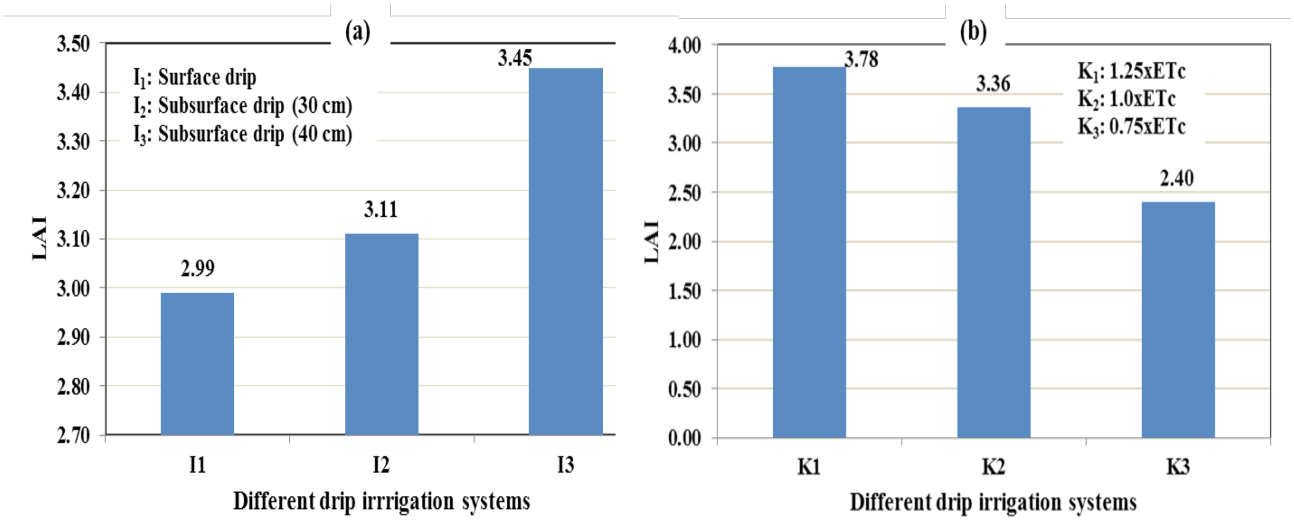

Figure 5. The values of leaf area index according to the different drip irrigation systems (a) and different amount of irrigation water (b)

DOI: https://doi.org/10.31015/jaefs.2020.3.2

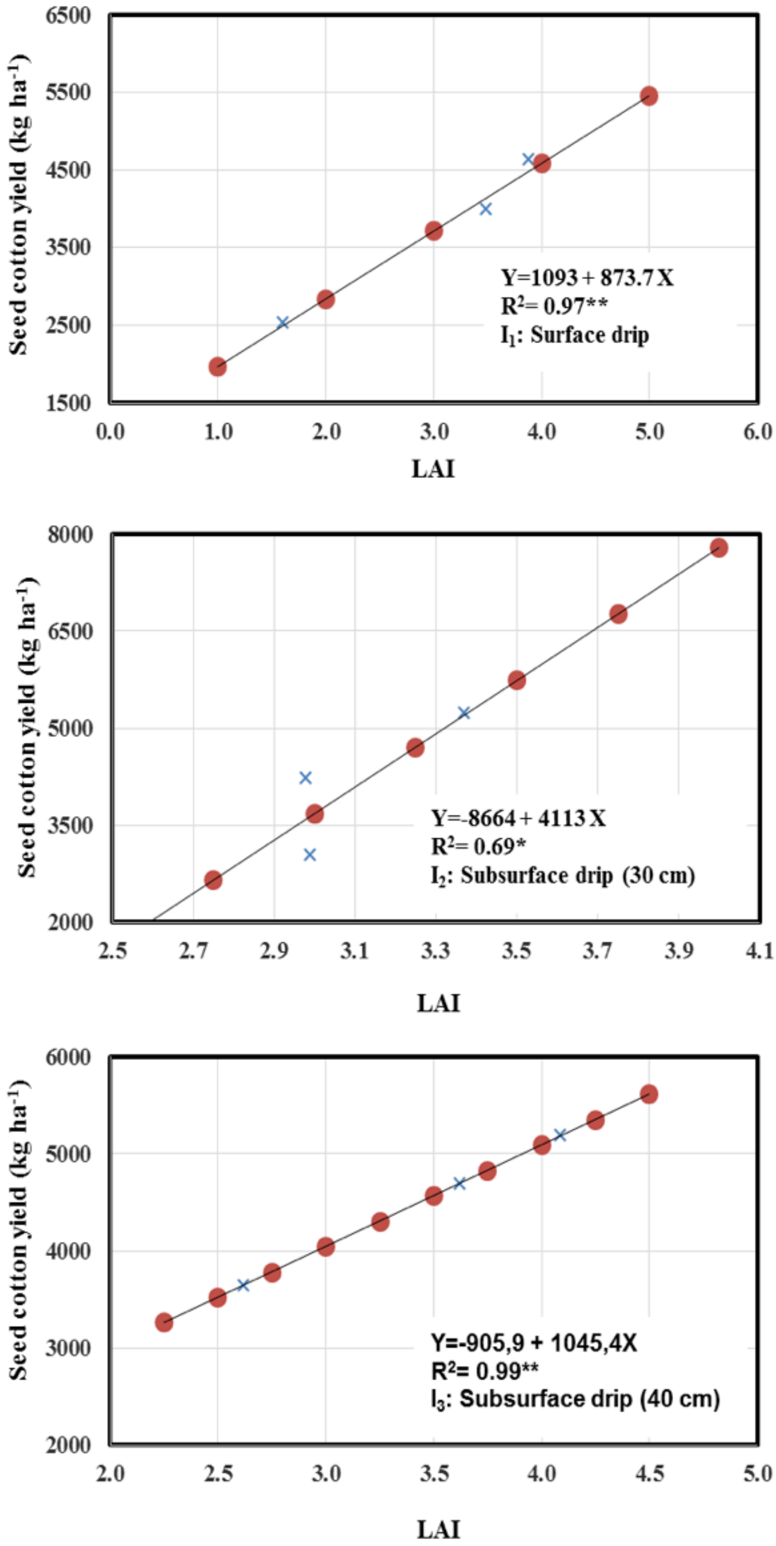

Figure 6. Relationship between LAI and seed cotton yield according to the drip irrigation systems

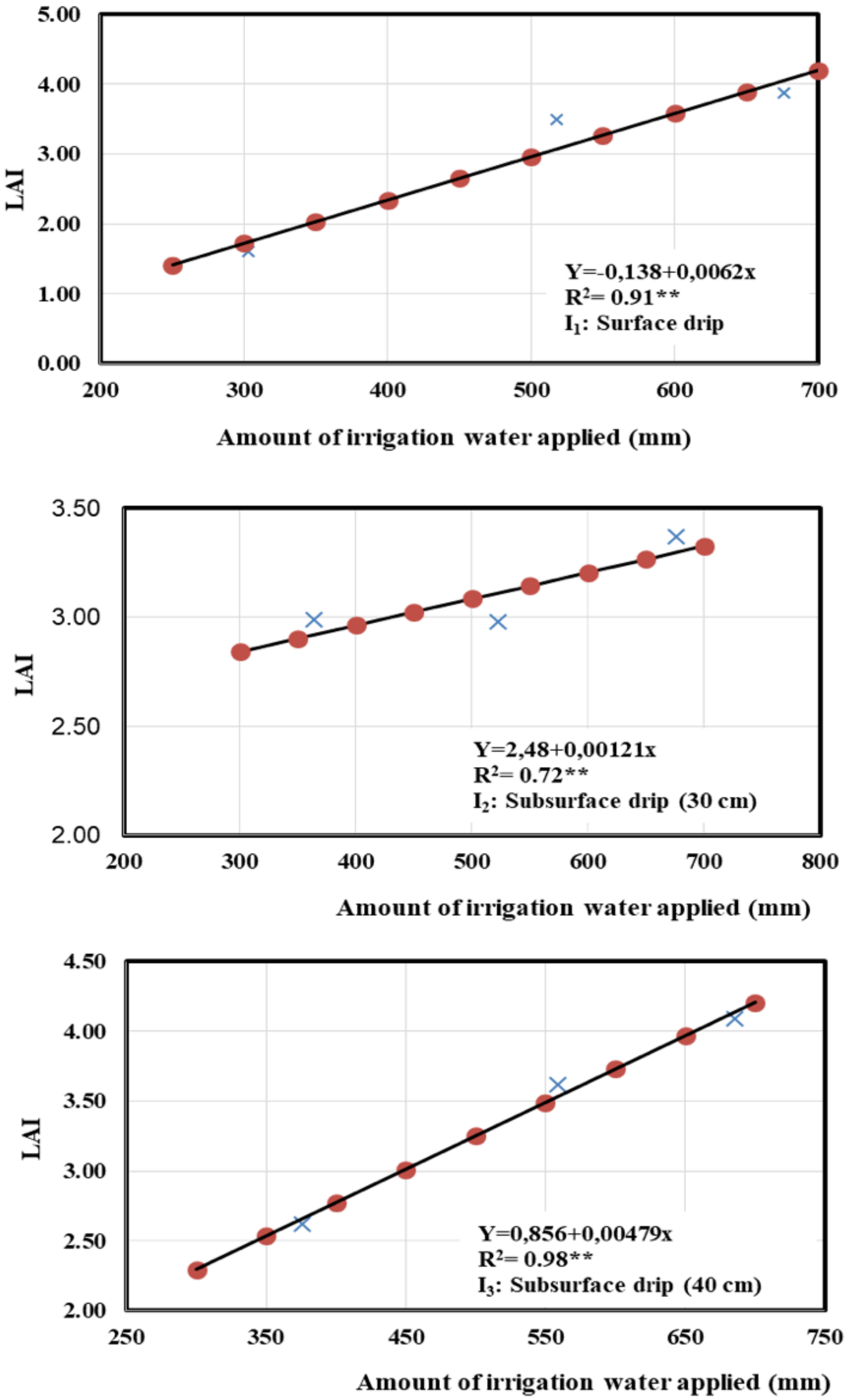

Figure 7. Relationship between amount of irrigation water applied and LAI according to different drip irrigation systems

Conclusion

In this study, the critical LWPs in vegetative period, flowering stage and boll formation stage of cotton in SDI for irrigation time were -24, -23 and -24 bar, respectively. Considering the same putting in order for the crop development stages in SSDI-40 cm, those were -23, -23 and -24 bar, respectively. The values of LWP in SSDI-30 cm were the same levels in SSD-40 cm. LWP in the boll formation stage were, in general, lower (bigger in minus numerical number) compared to the first two development stages, vegetative and flowering stages of the crop.

The critical SCs in vegetative period, flowering stage and boll formation stage in SDI were 312.8, 201.8 and 198.9 mmol m^{-2} s^{-1}, respectively. The values of SC in the same putting in order for the crop development stages in SSDI-30 cm and SSDI-40 cm were 368.8, 182.6 and 221.8 mmol m^{-2} $s^{-}1$; and 371.7, 185.9 and 186.8 mmol m^{-2} s^{-1}, respectively. SC decreased from the vegetative period through generative period of the crop. The SCs increased together with increasing amount of irrigation water and it decreased with increasing water stress conditions. The LAIs were 2.99, 3.11 and 3.45 in SDI, SSDI-30 cm and SSDI-40 cm, respectively. The values of LAI increased from the surface drip irrigation and lower amount of irrigation water applied through subsurface drip irrigation and highest level of amount of irrigation water. Although some plant physiological indicators such as LWP and SC might be used for irrigation scheduling and irrigation time, these indicators are highly affected by soil water status, light, air humidity, temperature and calibration of the devices used.

As a result, useful parameters for crop irrigation scheduling are provided by measurements of the soil or plant water status. Some physiological criteria such as leaf water potential (LWP) and stomal conductance (SC) might be usefull for irrigation scheduling and/or to show the water stress conditions for plants. LWP is reference measuring of water status of cotton leaves and have enabled solid reference thresholds of cotton plant water status. This data is obtained by measuring the leaf water potential by means of a pressure chamber. The LWP could be used to manage cotton irrigation. It is a useful method for precision irrigation which could help to save water. However, these indicators are highly affected by soil water status, light, air humidity, temperature, atmospheric CO_2 and calibration of the devices used. Thus, the measurement time and the threshold values for critical consideration such as irrigation scheduling might vary depending all these conditions.

Compliance with Ethical Standards

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contribution

The author read and approved the final manuscript. The author verifies that the Text, Figures, and Tables are original and that they have not been published before.

Ethical approval

Not applicable.

Funding

This study was financially supported by The Scientific and Technological Research Council of Turkey (TUBITAK) (Grant number: 115O600).

Data availability

Not applicable.

Consent for publication

Not applicable.

Acknowledgement

I would like to thank to The Scientific and Technological Research Council of Turkey (TUBITAK) for supporting this study. It is declared that only some parts of “Material and Method” in this article are similar to those in the different paper(s) produced from “Project Final Report using different data, parameters and evaluations. In addition, the author would like to thank to Neşe Üzen, Erhan Akalp, Hilal Altunten, Bayram Önen and Seniha Pirinçioğlu for their supports during the field works.

References

Allen, R. G., Pereira L.S., Raes, D., Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements”. United Nations Food and Agriculture Organization, Irrigation and Drainage Paper 56, Rome.

Ashley, D.A., Doss, B.D., Bennett O.L. (1964). Relation of cotton leaf area ındex to plant growth and fruiting. Agronomy Journal, 57(1), 61-64.

Baydar, A. (2010). Effects of climate change on cotton under the Seyhan Plain conditions. Çukurova University, Applied Science Institute, Agricultural Structures and Irrigation, M.Sci. Thesis. Adana, p. 57.

Bilgel, L. (1994). The first and last irrigtion time of cotton in Harran Plain. Şanlıurfa Research Institute of Rural Affairs, Publication No: 88/61, Şanlıurfa, Turkey

Busso, C.A. (2008). Use of the pressure chamber and thermocouple psychrometers to determine the water relations of plant tissues. Phyton - International Journal of Experimental Botany, 77 (12), 327-350

Camacho, B., Kaufmann, M., Hall, A. (1974). Leaf water potential response to transpiration by citrus. Physiologia Plantarum, 31, 101-105.

Campbell, G.S. (1985). Soil physics with basictransport models for soil-plant systems, Amsterdam: Elsevier.

Cetin, Ö., Bilgel, L. (2002). Effects of different irrigation methods on shedding and yield of cotton. Agricultural Water Management, 54, 1-15

Chastain, D.R., Snider, J.L., Collins, G.D., Perry, C.D., Whitaker, J., Byrd, S.A., Oosterhuis, D.M., Porter, W.M.(2016). Irrigation scheduling using predawn leaf water potential improves water productivity in drip-irrigated cotton. Crop Science, 56, 3185–3195, Doi: 10.2135/cropsci2016.01.0009

Chen, Z., Ma, H., Xia, J., Hou, F., Shi, X., Hao, X, Hafeez, A., Han, H., Luo, H. (2017). Optimal pre-plant irrigation and fertilization can improve biomass accumulation by maintaining the root and leaf productive capacity of cotton crop. Scientific Reports, 7, Article number: 17168, Doi:10.1038/s41598-017-17428-5

Ekinci, R., Gencer, O., Başbağ, S. (2008). Correlations between some physio-morphological formations and yield on okra and normal leaf cotton cottons. Ankara University, Agricultural Sciences, 14 (3), 217-221

Ennahli, S., and H. Earl. 2005. Physiological limitations to photosynthetic carbon assimilation in cotton under water stress. Crop Science 45:2374–2382. Doi: 10.2135/cropsci2005.0147

Ephrath, J.E., Marani, A., Bravdo, B.A. (1990). Effects of moisture stress on stomatal resistance and photosynthetic rate in cotton (Gossypium hirsutum) 1. Controlled levels of stress". Field Crops Research, 23(2), 117-131.

Ertek, A., Kanber, R. (2001). Effects of different irrigation schedules on drip-irrigated cottonTurkish Journal of Agriculture and Foresty, 25, 415-425

Grimes, D., Yamada, H. (1982). Relation of cotton growth and yield to minimum leaf water potential. Crop Science 22, 34–139. Doi: 10.2135/cropsci1982.0011183X002200010031x

Hake, K.D., Grimes, D.W. (2010). Crop water management to opitimizing growth and yield. In: Physiology of Cotton (Eds: J.Mc.D. Stewart, D.M. Ooesterhius, J.J. Heitholt, J.R. Mauney). ISBN: 978-90-481-3194-5, Doi: 10.1007/978-90-481-3195-2, Springer, Lonad and New York

Inamullah, Isoda, A. (2005) Adaptive responses of soybean and cotton to water stress: I. Transpiration changes in relation to stomatal area and stomatal conductance, Plant Production Science, 8(1), 16-26, Doi: 10.1626/pps.8.131

Jones, H. (2004). Irrigation scheduling: Advantages and pitfalls of plant-based methods. Journal of Experimental Botany, 55:2427–2436. Doi:10.1093/jxb/erh213

Jones, H.G., Flowers T.J., Jones. M.B. (1991). Plants under stress: biochemistry, physiology and ecology and their application for plant improvement. Cambridge University Press, New York.

Kanber, R., Tekinel, O., Baytorun, N., Kumova, Y., Alagöz, T. (1991). Use of evaporation from open water on determination of irrigation interval and water consumptive use of cotton under Harran Plain conditions. Head of GAP Development Administration Adana, 44, 15-25.

Kara, C., Gündüz, M. (1998). Effects of deficit irrigations on cotton yield under GAP Region conditions. General Directorate of Rural Affairs, Publication No: 106, 285-301.

Kaufman, M.R. (1981). The physiology and biochemistry of drought resistant in plants. Acedemic Press, New York, 55-56.

Kaufman, M.R., Hall, A.E. (1974). Plant water blance-its relationships to atmospheric and edaptic conditions, Agricultural Meteorlogy, 14, 85-98

Keten, M. (2016). Effects of different deficit irrigation levels on different cotton genotypes. Kahramanmaraş Sütçü İmam University, Applied Science Institute, M.Sc. Thesis, Biosystem Engineering, Kahramanmaraş, p. 48

Köksal, E.S., Üstün, H., İlbeyi, A. (2010). Leaf water potential and stomal, conductance and water stress index of dwarf green beans on irrigation time. The Journal of Uludağ University, Agricultural Faculty, 24 (1), 25-36

Lawlor, D.W., Cornic, G. (2002). Photosynthetic carbon assimilation and associate metabolism in relation to water deficits in higher plants. Plant Cell Environment, 25, 275-294.

Leidi, E.O., Lopez, M., Gorham, J., Gutierrez, J.C. (1999). Variation in carbon isotope discrimination and other traits related to drought tolerance in upland cotton cultivars under dryland conditions. Field Crops Research, 61, 109-123.

Luo, Y., OuYang, Z., Zhao, Q., Yu, Q. (2011). Modelling maximal evapotranspiration and crop coefficient. www.klter.or/EVENTS/Conference00/html, Access date: 15.07.2011.

Martínez, E.M., Rey, B.J., Fandiño, M., Cancela, J.J. (2013). Comparison of two techniques for measuring leaf water potential in Vitis Vinifera var. Albariño. Ciência Téc. Vitiv. 28(1), 29-41.

Maya, F. (2017). The effects of different irrigation and fertilizer regimes on leaf water potential of cotton. Çukurova University, Applied Scince Institute, Agricultural Structures and Irrigation, M.Sci. Thesis, Adana, p. 44

McDermitt, D.K. (1990). Sources of error in the estimation of stomatal conductance and transpiration from porometer data. Hortscience, 25(12), 1538-1548.

Meidner, H., Mansfield, T.A. (1968). Physiology of stomata. London: McGraw-Hill.

Noreen, S., Athar, H.R. Ashraf, M. (2013). Interactive effects of watering regimes and exogenously applied osmoprotectants on earliness indices and leaf area index. In: cotton (*Gossypium hirsutum* L.) crop. Pakistan Journal of Botany, 45, 1873-1881.

Ödemiş, B., Candemir, D.K., Delice, H., Karazincir, K. (2018). Determination of the effects of different water stress levels on yield and vegetative properties of cotton (*Gossypium Hirsutum* L.) in Hatay conditions. Journal of Agricultural Faculty of Mustafa Kemal University, 23(1), 58-75

Patane, C. (2011). Leaf area index, leaf transpiration and stomatal conductance as affected by soil water deficit and VPD in processing tomato in semi arid Mediterranean climate. Journal of Agronomy & Crop Science, 197, 165–176, Doi: 10.1111/j.1439-037X.2010.00454.x

Patterson, L.L., Buxton, D.R., Briggs. R.E. (1978). Fruiting in cotton as affected by controlled boll set. Agronomy Journal, 70, 118-122.

Pegelow, E.J., Buxton, D.R., Briggs, R.E., Muramoto, H., Gensler. W.G. (1977). Canof1i photosynthesis and transpiration of cotton as affected by leaf type. Crop Science, 17, 1-4

Pettigrew, W. (2004). Physiological consequences of moisture deficit stress in cotton. Crop Science, 44, 1265–1272, Doi:10.2135/cropsci2004.1265

Puech-Suanez, J., Hsiao, T.C., Fereres, E., Henderson, D.W. (1989). Water-stress effects on the carbon exchange rates of three upland cotton (Gossypium hirsutum) cultivars in the field. Field Crops Research, 21, 239-255.

Radin, J.W. (1992). “Reconciling water-use efficiency of cotton in field and laboratory”. Crop Science 32, 13-18.

Radin, J.W., Hartung, W., Kimball, B.A., Mauney, J.R. (1988). Correlation of stomatal conductance with photosynthetic capacity of cotton only in a CO_2-enriched atmosphere: Mediation by abscisic acid. Plant Physiology, 88(4), 1058-62.

Saleem, M.F., Raza, M.A.S, Ahmad, S., Khan,I.H., Shahid, A.M. (2016). Understanding and mitigating the impacts of drought stress in cotton- A Review, Pakistan Journal of Agricultural Sciences, 53(3), 609-623

Scholander, P.F., Hammel, H.J., Bradstreet, A., Hwemmingsen, E.A. (1965). Sap pressure in vascular plants. Science, 148, 339-346.

Turner, N., A. Hearn, J. Begg, Constable, G. (1986). Cotton (Gossypium hirsutum L.), physiological and morphological responses to water deficits and their relationship to yield. Field Crops Research, 14, 153-170, Doi:10.1016/0378-4290(86)90054-7

Yazdıç, M., Değirmenci, H. (2018). Effect on leaf water potential and chlorophyll value of different irrigation levels in cotton. Kahramanmaraş Sütçü İmam University, Journal of Agricultural Sceinces, 21(4), 511-519, DOI:10.18016/ ksudobil.369337

Yurtsever, N. (2011). Applied statistical methods. Research Institute of Soil-Fertilizer and Water Resources, Publication No: 56/121, Ankara, Turkey.