INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

Nr 1/III/2013, POLSKA AKADEMIA NAUK, Oddział w Krakowie, s. 85–98
Komisja Technicznej Infrastruktury Wsi

VARIATION OF LEAF AREA INDEX AND LEAF WATER POTENTIAL OF YOUNG DWARF APPLE TREES UNDER DIFFERENT IRRIGATION METHODS

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Summary

In this research which was carried out inSuleymanDemirel University Research and Application Farm during 2007 and 2008 years, apple leaf area index (LAI) and leaf water potential (LWP) were observed in Jersey Mac (V1) and Williams Pride (V2) young apple varieties budded on M9 rootstock irrigated with different irrigation methods. Drip (D), subsurface drip (SD), surface (S) and undertree micro sprinkler (M) irrigation methods were used in the research. The amount of applied irrigation water was as much as 100% of Class A Pan evaporation measured during five days irrigation intervals.

The amount of irrigation water was ranged between 348.3 (D, SD) – 1186 (S, M) mm depending on irrigation methods during the experimental years. Furthermore, maximum and minimum crop evapotranspiration values were determined as 426.1 (DV2) and 1334.7 (MV2) mm respectively.

LAI values □□related to treatments ranged from 0.32 to 0.52 in 2007, 0.73 to 1.12 in 2008. LAI values increased by approximately 126.3% for all treatments. In both years, generally, the highest LAI values were observed in drip irrigation (D) for both varieties. Linear correlation (r=0.99, n=16) was obtained between fruit yields and leaf area index (LAI) values of the apple trees.

Leaf water potential (LWP) measurements were repeated one day before and after irrigation during the irrigation period. The measurements were also conducted once along a day in the middle of the season. Changes in value of LWP were similar among the treatments.

Key words: Apple tree, irrigation methods, yield, leaf area index, leaf water potential

INTRODUCTION

Apple production in the world shows constant increase. During early 1960s, the production amount was 17 million tonnes, in 1970 this amount increased to 27 million, in 1990 to 41 million tonnes and as of 2010 it increased to 69.5 million tonnes. Turkey is the third biggest country after China and USA in apple production with 2.60 million tons [FAO, 2012]. Isparta region that provides almost 20% of total apple production of Turkey, has an important role in apple production for Turkey [TSI, 2009].

Recently, dense planting orchards using new varieties budded on dwarf (M9) rootstocks in the region have been started. Jersey Mac and Williams Pride varietiesbudded on M9 clonal rootstocks are commonly used in these orchards. The reasons of compatible apple varieties budded on M9 clonal rootstocks having been preferred recently by producers are in terms of both easy application of agricultural practices and yield, quality and early yield[Campbell, 1995; Mika andKrawiec, 1996; Buraket al., 1997; Costa et al., 1997; Weber, 2001].

Liu et al. [2001] determined that the leaf area changed according to the rootstocks but there was no change in leaf area index in their study related to water use and crown structure of apple trees budded on different rootstocks. Hopmans et al. [2000] emphasized that the decreasing of soil moisture in soil profile reduced the leaf area. Reduction of soil moisture in the soil profile decreases leaf area and also reduces the leaf water potential (LWP) [Punthakey et al., 1984]. Giulivo et al. [1985] stated that leaf water potential of Golden Delicious variety was higher in M9 rootstocks compared to MM106 and M7. Bergamini et al. [1988] found that effect of irrigation on leaf water potential and stoma resistance was insignificant in Golden Delicious trees budded on M9, M26, M7 and MM106 rootstocks irrigated by drip irrigation methods.Punthakey et al. [1984] investigated the relationship between leaf water potential, stoma resistance and transpiration in different soil moisture stress in peach trees and suggested that leaf water potential decreases in moisture stressed trees and critical LWP for well-watered trees was -18 bars for shaded leaves, and -21 bars for exposed leaves. In stressed trees, the critical was lowered to -25 bars. Aydin[2004], as a result of leaf water potential measurements carried out in pistachio trees irrigated by drip irrigation, during the day in the middle of irrigation period, has established that the LWP reaches negatively to -2.67 MPa in the afternoon due to temperature rise, while during the morning it is about -1.1 and -1.4 MPa and in the evening, due to temperature decrease, it falls to the value of -2.03 MPA.Kaynas[1994] analysed the effects of different irrigation levels on LWP in peach and nectarine varieties and determined that daily and seasonal changes occur in LWP values. Author concluded that decreases can occur with time in all plants in the seasonal LWP measurements carried out during mid-day and such decreases are risen as the water amount given to the plant is restricted.

With respect to daily LWP variations, Kaynas[1994] also indicated that the LWP which is the highest before sunrise shows increase again after reaching the lowest level during mid-day. Therefore, Kamal and Hwat[2001] have stated that the leaf water potential is a good indicator in the determination of the plant water content, thus continual measurement can be very beneficial for irrigation planning.

In this study, the variations of leaf water potential during the irrigation period and during the day and leaf area index according to year and relations between leaf area index and yield of Williams Pride (V1) and Jersey Mac (V2) apple varieties budded on M9 rootstocks irrigated with different irrigation methods, were investigated.

MATERIALS AND METHODS

Experimental site and plant material

The research was conducted on 2- and 3- year-old Jersey Mac (V1) and Williams Pride (V2) apple cultivar budded on M9 rootstock and planted at1x3 m spacing in the AgriculturalResearch and Application Centerat the Campus of SuleymanDemirelUniversity (lat. 37.83; N, long. 30.53; E,altitude 1,020 m) in Isparta, Turkey during the 2007 and 2008 growing seasons.

Climatic and soil characteristics

The research area has a transition characteristic between the Mediterranean climate (precipitation regime) and Middle Anatolian continental climate (summer season is hot and dry, winter season is cold and snowy). The average values of weather data in the research area belongs to 2007 and 2008 years (from May to October) were measured from meteorology station established close to the research area. Cumulative precipitations were45 mm and 80.6 mm,maximum and minimum temperature were 28.2^{o}C, 27.7^{o}C and 10.1^{o}C, 10.5^{o}C; maximum andminimum relative humidity were 78.3%, 78.0% and 25.5%, 27.0%respectively. Long-term average annual temperature, relative humidity and precipitation are 12°C, 61% and 520 mm, respectively [TSMS, 2008].

Steady infiltration rate was obtained according to test results of variable-level dual cylinder infiltrometer as 12 mm h^{-1}. The experimental soil was clay-loam, the dry soil bulk density average was 1.41 g cm^{-3} throughout the 1.2 m deep profile. The total available soil water content within top 1.2 m of soil profile was 270.81 mm and no ground water problem was found.

The orchard was received standard cultural practices including fertilization, pest management, weed control and winter pruning. During the growing season in 2007 and 2008, depending on the soil analysis, all plots were fertigatedwith fertilizers containing 40 kg ha^{-1} and 40 kg ha^{-1} phosphorus, 120 kg ha^{-1} and 150 kg ha^{-1}potassium and 80 kg ha^{-1} and 100 kg ha^{-1} nitrogen, respectively.

While the fertilizers were applied by venture as fertigation in D, SD and MS treatments, fertilizers were given by hand as granule in SF treatment.

Irrigation treatments and experimental design

Four different irrigation methods including Drip (D), subsurface drip (SD), surface (S) and under-tree micro sprinkler (M) irrigation methods were used in the research.Irrigation water amount was determined based on cumulative evaporation in daily values measured within each irrigation interval in the class a pan located in a meteorological station close to the orchard. Irrigation interval was 5 days. Irrigation was maintained identically within the period of last frost and the first one for experimental period (From May to October).

Irrigation water was obtained from the hydrants on the irrigation network near the research area. Discharge rate of the irrigation water taken from the irrigation network was 7 L s^{-1}. Water was class C_3S1 that can be used for irrigation. Treatments were irrigated up to field capacity at the beginning of the irrigated growth period in each year. Engineering characteristics and working principles of the irrigation methods were determined on the fundamentals given in Yildirim[2008].

Drip irrigation systems consisted of PE laterals of 16 (D) and 18 (SD) mm in diameter in-line type drippers with pressure regulators at 0.50 m distance. The drippers had a discharge rate of 4 L h^{-1} under an operational pressure of 1 atm. Two laterals were placed in each row and the percentage of the wetted area was determined as 33%. Laterals were placedat25 cm depth from soil surface in SD.In micro-sprinkler irrigation system, micro-sprinkler heads with a discharge rate of 40 L h^{-1} under an operational pressure of 2 atm and 5 m wetting diameter were placed at 2.5 m distance in PE laterals of 20 mm in diameter. Precipitation rate of the heads was measured as 5.3 mm h^{-1}.In surface irrigation, irrigation water were ponded in short borders created in 5×3 m dimensions which is included five trees.

Irrigation water volume was calculated with equation 1 described by Doorenbos and Pruitt [1984];

$$I = A \times kcp \times Ep \times P \qquad (1)$$

where:

- *I* – the volume of irrigation water applied (L),
- *A* – the plot area(m^2),
- *Kcp* – the plant-pan coefficient used in this study included pan coefficient and plant coefficient factors (*kc × kp=1.00*) as indicated in Senyigit and Kadayifci[2007],
- *Ep* – thecumulative evaporation at class a pan in the irrigation intervals(mm) and
- *P* – the wetted area percentage(%)(33 % for D and SD; 100 % for M and S).

Volumetric soil water content (m^3 m^{-3}) was measured by ΔT profile-probe before each an irrigation. ΔT probes were inserted between the tree trunks through the row in each plot. The probes were placed at soil depth of approximately 10, 20, 30, 40, 60, 100 cm to provide a depthwise profile of soil water content in each treatment. Evapotranspiration related to the treatments were calculated by the soil-water balance considering the soil water content readings and effective rainfall in equation 2 [James, 1988];

$$ET = I + P + C_p - D_p \pm R_f \pm \Delta S \tag{2}$$

where:

ET – the evapotranspiration (mm),
I – the depth of irrigation water(mm),
P – precipitation (mm),
Cp – the capillary rise (mm),
Dp – the water loss by deep percolation (mm),
Rf – runoff loss (mm) and
ΔS – the change in the soil water content (mm).

Total area of the research was 1890 m^2 (21 m ×90 m) and each plot area was established as 45 m^2 (3 m ×15 m). Each plot consisted of fifteen trees and five central trees being considered as experimental and all the others as guard trees. In the study, experiment was carried out according to the split plots in randomized complete block design with three replications. Statistical analyses were done applying the one way ANOVA analysis method. The Tukey test was used in determining the differences betweenthe averages of the groups and the differences of the treatments were indicated with the Latin letters in the test result.

Measurement of leaf area index (LAI) and leaf water potential (LWP)

LAI values related to the treatments were determined according to the basics given in Unlu[2000] and relationships between LAI and yield (kg $tree^{-1}$) obtained from the treatments were found. In addition, the leaf water potential has been determined by pressure chamber device in accordance with the principles given in Bastug and Kanber[1989]. The measurements were carried out one day before irrigation and one day after irrigation at high noon (12^{00}), in order to observe the variation during irrigation period. Moreover, the variation in leaf water potential during the day between sunrise and sunset has been observed at regular intervals of 2 hours during the time when water consumption level is the highest.

RESULTS AND DISCUSSIONS

Irrigation water amounts and evapotranspiration

Irrigation number, irrigation water and evapotranspirationvaluesof the treatments regarding to 2007 and 2008 years were presented in Table 1.

Table 1. Total irrigation water and evapotranspiration values related to years

Treatments	Irrigation interval (day)	2007			2008		
		Irrigation number	Total irrigation water (mm)	ET (mm)	Irrigation number	Total irrigation water (mm)	ET (mm)
DV1	5	29	391.2	432.5	27	348.3	428.5
SDV1	5	29	391.2	430.3	27	348.3	474.5
SV1	5	29	1186	1263.5	27	1056	1180.4
MV1	5	29	1186	1274.1	27	1056	1266.1
DV2	5	29	391.2	429.4	27	348.3	426.1
SDV2	5	29	391.2	433.1	27	348.3	479.5
SV2	5	29	1186	1243.8	27	1056	1198.5
MV2	5	29	1186	1334.7	27	1056	1231.4

Amount of open water surface evaporation occurring during irrigation period showed a change between 1056-1186 mm. The number of irrigation applied to the treatments did not show a significant change as per experiment years; in 2007 and 2008, irrigation was done 29 and 27 times respectively.Total amount of irrigation water applied to the treatments changed according to the evaporation amount and irrigation methods. The highest amount of irrigation water was applied to S and M (1186 and 1056 mm) treatments, while the lowest amount of irrigation water was applied to D and SD (391.2 and 348.3 mm) treatments according to years. The reason of lower irrigation water in drip irrigation methods (D, SD) was the fact that the percentage of wetted area (P=0.33) was lower than the percentage of other methods (P=1.00).

As it can be seen in Table 1, evapotranpiration values were changed according to years and treatments. In experiment years, the lowest evapotranpiration amounts were obtained in drip irrigation treatments as 426.1–487.9 mm; the highest evapotranpiration amounts were obtained in surface and under-tree micro sprinkler treatments as 1173–1334.7 mm.

Leaf area index(LAI)

LAI values were detected during periods closer to harvest (03.08.2007; 02.08.2008). As seen in Figure 1, measurements were carried out in 2007-2008 encompassing 2 and 3 ages of the trees. While LAI values changed between 0.32 and 0.52 in 2007, they changed between 0.73 and 1.12 in 2008.

According to the results obtained, the LAI values in all treatments increased by 126.3% in average. In general, while the highest LAI values in both apple varieties during such two years were observed in Dtreatment, the highest increase was observed in M treatment in V1 and V2 at the rates of 212.5 and 159.4% respectively.

Cohen and Naor[2002] measured the average leaf area index in Golden Delicious variety as 2.4 for M9 and as 2.7 for M109 and seedling. Lakatos[2004] established the total leaf area as 4.4-19.5 m^2. Liu et al. [2001] determined that the leaf area changed according to the rootstocks but there was no change in leaf area index.

In the study, the obtained values were lower than findings of previous studies mentioned above, because apple varieties budded on M9 rootstocks irrigated by different irrigation methods could not reach exact ripening period and continued to grow due to 2 and 3 ages. Both character of the plant variety and early age of such variety resulted in this manner.

Relationships between leaf area index (LAI) and yieldper tree

During 2007 and 2008 years of the experiment, the obtained amounts of yield per tree related to the treatmentswereshown in Table 2 and their relations with measured leaf area index were shown in Figure 1.

Table2. Yield per tree for all treatments, kg $tree^{-1}$ (2007, 2008)

Year - Variety		Irrigation methods				
		D	SD	S	M	Average $\bar{x}$ ±S $\bar{x}$
		$\bar{x}$ ± S $\bar{x}$	$\bar{x}$ ± S $\bar{x}$	$\bar{x}$ ± S $\bar{x}$	$\bar{x}$ ± S $\bar{x}$	
2007	V1	1.54±0.24Aa	1.49±0.07Aa	1.71±0.26Aa	0.31±0.10Bb	1.26±0.19
	V2	1.62±0.21Aa	1.19±0.09ABa	1.02±0.13Bb	0.85±0.18Ba	1.17±0.11
Average $\bar{x}$ ±S $\bar{x}$		1.58±0.14	1.34±0.08	1.36±0.20	0.58±0.15	
2008	V1	6.00±0.16Ab	4.26±0.55Bb	3.96±0.25Bb	4.45±0.04Ba	4.67±0.27
	V2	7.22±0.35Aa	6.59±0.09Aa	5.77±0.27Ba	4.80±0.10Ca	6.09±0.29
Average $\bar{x}$ ±S $\bar{x}$		6.62±0.32	5.43±0.58	4.86±0.44	4.62±0.09	

LAI values of young apple trees for all treatments increased in 3 age (2008) when compared to 2 age [2007], and a similar increase was also observed in yield amounts.

In both varieties, the highest leaf area index value and yield per tree in 2008 were observed in D treatment for V2 as 1.12 and 7.22 and V1 as 1.03 and 6.01 and followed by SD treatment with values of 1.10, 6.59 and 0.85, 4.26. Besides, LAI and yield values in the same treatment displayed differences among the varieties and V2 apple variety which had a higher values with 0.71 and 3.63 than V1 (0.62; 2.97) according to average of years and treatments.As is seen in Figure 1 related to 2007 and 2008 years, a linear relationships (r=0.99, n=16) were found between the yield and LAI values in all treatments. Together with the increase in leaf area index, a significant increase was obtained in yield.

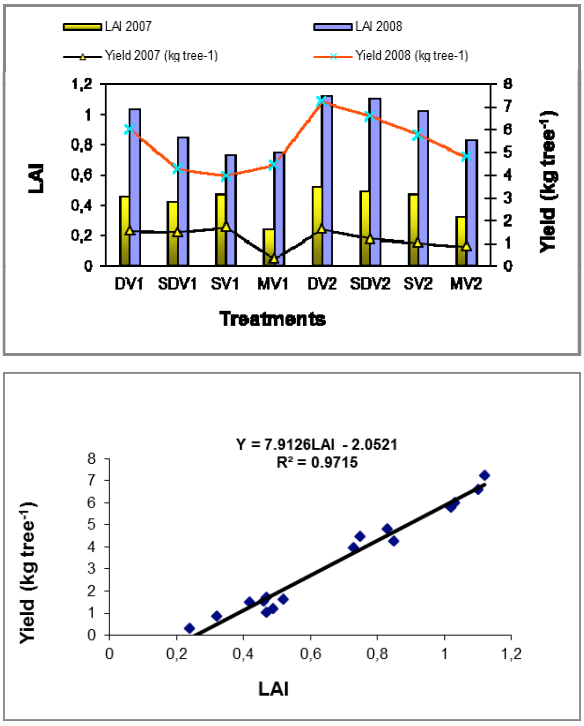

Figure 1. LAI and yield values in 2007 and 2008 years related to treatmentsand relationships between leaf area index (LAI) and yield per tree

Leaf water potantial (LWP)

Leaf water potential (LWP) measurements, made at noon (12^{00}) one day before and after irrigation in 2007 and 2008 for treatments of different irrigation methods in V1 and V2 apple varieties included in the experiment, were shown in Figure 2.

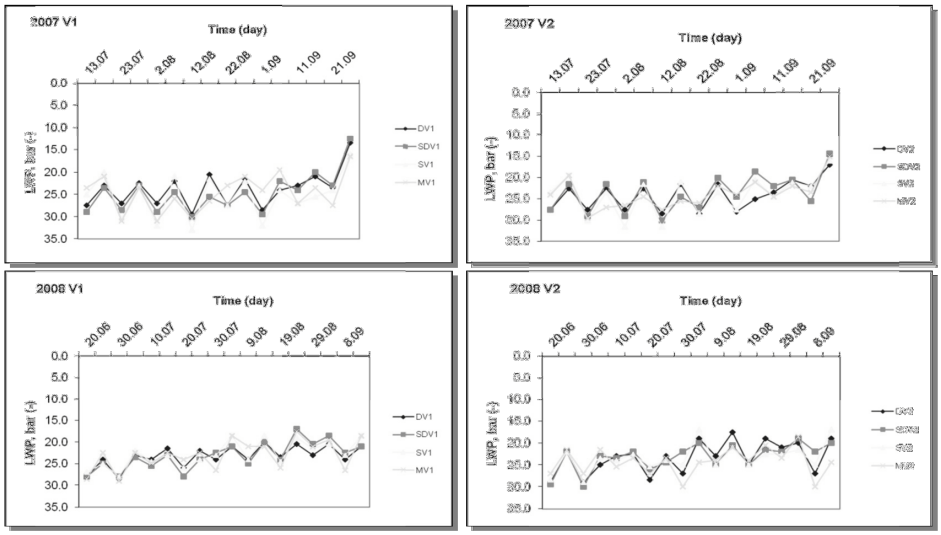

Figure 2. The variation in LWP values measured at noon (12^{00}) one day before and after irrigation in different irrigation methods treatments during 2007-2008 irrigation periods in V1 and V2 apple varieties

The variations in LWP values were shown similarities in V1 apple variety during the irrigation period of 2007. In July, while LWP values changed between -25 and -31 bars before irrigation, they ranged between -20 and -23.5 bars after irrigation. In August, a negative increase in LWP values was observed and especially in S treatment the values reached to -33 bars before irrigation. In September, a rapid negative decrease was occurred in LWP values, in SD treatment, the values of -23 and -12.5 bars were obtained before and after irrigation respectively.

Similar results were also observed in V2 apple variety. In July, the highest negative LWP value after irrigation was observed in S treatment with a value of -30 bars and the lowest LWP value before irrigation was observed in the same irrigation method treatment with a value of -19.5 bars. In August, an increase was observed in LWP values as in V1 variety; the highest LWP value before irrigation and the lowest LWP value after irrigation were observed in S (-31.5 bars) and SD (-20 bars) treatments respectively. In September, a negative decrease was observed in LWP values of all treatments. The lowest LWP values before and after irrigation were observed in SD treatment with values of -18.5 and -14.5 bars respectively.

During 2008 period of the experiment, the LWP values of treatments before and after irrigation were observed similar to the ones in 2007. However, unlike 2007, measurements were made in June in 2008, and LWP values were

obtained as between -27 and -30 bars which were considered negatively higher compared to July and August. As of September, a decrease was observed in LWP values up to -17 bars especially after irrigation.

According to the results, pre-irrigation LWP values increased negatively in all treatments due to reduction in soil water, increase in air temperature and decrease in relative humidity level in air. In addition, LWP values measured after irrigation increased with the increasing of soil water content. Together with increasing of soil moisture content after irrigation, LWP values showed a tendency to decrease compared to pre-irrigation values. Such values can be considered as an index point to start irrigation in apple irrigation planning.

In the middle of irrigation period, LWP measurements were carried out at intervals of 2 hours during the day. The results obtained were shown in Figure 3. As a result of LWP measurements carried out all day long, in the middle of irrigation period of 2007 (06 August 2007), consecutive measurements were carried out at intervals of 2 hours during day, LWP values showed similar variation in all irrigation method treatments in V1 apple variety. In all four irrigation methods, especially in the afternoon when temperature increased and relative humidity decreased, the LWP values dropped up to -24 and -27 bars.

Due to decrease in temperature and increase in relative humidity during sunrise and sunset hours, the LWP values increased again and reached up to -7 and -12 bars in sunrise and -13 and -18 bars in sunset. However, especially in the measurement carried out just after sunrise (8^{00}), a high decrease of about 10 bars was observed in all treatments due to increase in air temperature. While the highest negative LWP value among the treatments was observed in S, with respect to M, the lowest negative LWP value was determined during sunrise and sunset, on the contrary, the highest negative LWP value was observed as -27 bars.

Results of V2 apple variety showed similarities with V1 variety. While similar LWP values were observed in all irrigation treatments especially at noon (10^{00}-14^{00}), the lowest negative LWP value was measured in SD treatment with -15 bars during sunset.

With respect to V1 apple variety, in the middle of irrigation period (July 23, 2008), consecutive measurements were made all day long at intervals of 2 hours, and LWP values showed similar change in all irrigation treatments. However, in comparison with 2007, lower LWP values were observed at noon (-25 and -29 bars); and LWP values were obtained higher as -9 and -11 bars during sunset. In measurements made from sunrise until noon, a rapid decrease in LWP values of 2008 were observed, and a increase in similar rate were observed from noon to sunset. While the lowest negative values in sunrise were measured in D and SD treatments as -8 bars, and it was measured as -9 bars in sunset in D treatment.

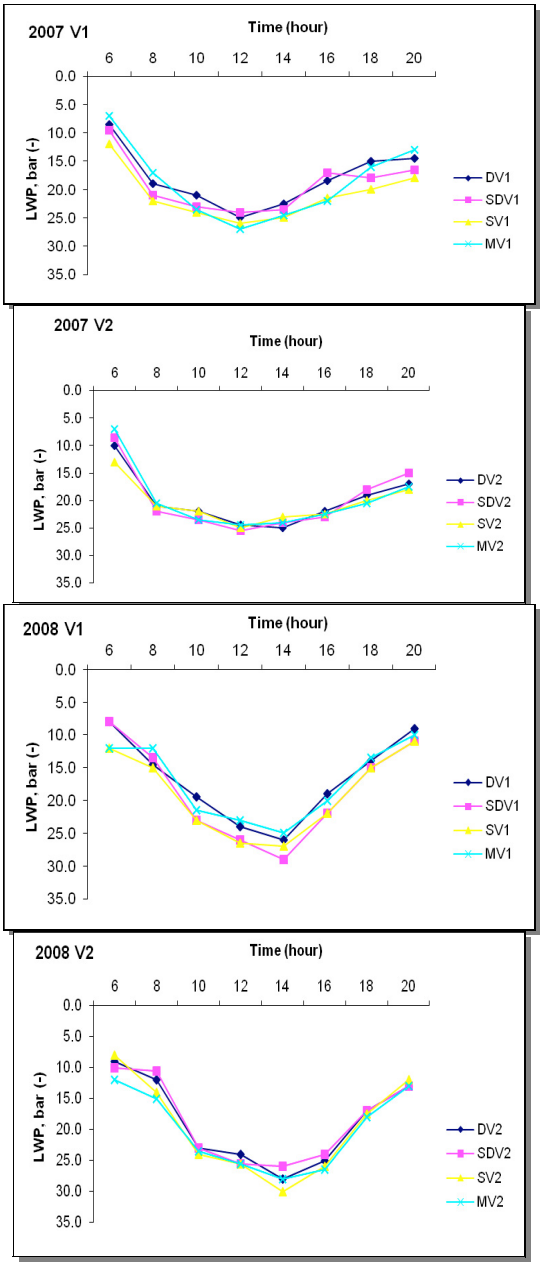

Figure 3. Daily variation in LWP values related to different treatments in V1 and V2 apple varieties during 2007-2008 irrigation periods.

Although rapid decreases or increases in LWP values of V1 variety during the day was not observed in V2 variety, similar changes were also observed in this variety. Among the treatments, the lowest negative LWP values during sunrise and sunset were measured in S as -8 and -12 bars, and the lowest value at noon was observed as -26 bars in SD. Similar to our findings, a decrease in the leaf water potential due to higher air temperature, lower relative humidity and soil moisture was reported previously in peach trees [Punthakey et al., 1984; Kaynas, 1994], pistachio trees [Aydin, 2004] and nectarine [Kaynas, 1994].

CONCLUSIONS

1. LAI values of young apple trees increased in all treatments during growing period and a similar increase was also observed in yield amount. A linear relation was determined between yield and LAI values at a significant level (r=0.99).

2. The leaf water potential in apple trees depends upon both the irrigation conditions under different irrigation methods and the soil moisture and climatic changes. Increasing air temperature and decreasing relative humidity values along the periods of measurement caused a decrease in the leaf water potential, in other words, decreasing air temperature and increasing relative humidity values caused a increase in the leaf water potential along the periods of measurement. Non-significant differences observed between leaf water potentials of treatments in this study can be interpreted that water requirement of apple trees wasmet adequately and there was no a significant stress for trees resulted from the lack of moisture in the soil.

3. According to the findings of present study, while yield potential of young apple trees can be observed with LAI level, leaf water potential also represents a good indicator of thewater status of plants, and continuous monitoring of leaf water potentialcanbe useful in research and field applications such as irrigation scheduling.

ACKNOWLEDGEMENT

The authors would like to thank the Scientific Research Projects Coordinatorship of Suleyman Demirel University for its financial support to the project of 1371 D-06.

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