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Responses to Irrigation onto Apple Tree Grown under the Farmer Condition: A Case Study of Düzce Region

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This study aimed to investigate response of "Granny Smith" apple (*Malus domestica Borkh.*) tree to irrigation under farmer condition in Düzce Region. In this study, some physiological measurements, such as leaf water potential (LWP), stomatal conductance (g_s) and photosynthetic active radiation (PAR) on the apple trees, were performed weekly before irrigation in the selected period during the irrigation season. Concurrently, in irrigation season, soil water content (SWC) in the different soil layers (0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm) was also monitored at the apple orchard. Study results showed that SWC was fluctuated between field capacity (FC) and permanent wilting point (PWP) during irrigation season. The value of SWC didn't reach up to 50%, which is the allowable depletion value at the soil of apple orchard, except some high rainy days. LWP, g_s and PAR were increased by increasing of SWC in all soil layers. The strongest relationship for all correlations in all soil layers was obtained in 30-60 cm soil layers. It was found that LWP had strong relationships with PAR (R^2=0.84) while LWP~g_s relationships were weak (R^2=0.53). Finally, by considering the all results in this study, it may be concluded that a proper irrigation scheduling was needed for such as apple orchards even though precipitation was frequently and unevenly happened in the summer.

Keywords: Leaf water potential (LWP), Stomatal conductance (g_s), Photosynthetic active radiation (PAR), Soil moisture, Apple tree, Düzce Region

Çiftçi Koşulunda Yetiştirilen Elma Ağacının Sulamaya Tepkileri: Düzce Yöresi Örneği

Bu çalışma, Düzce yöresi ikliminde "Granny Smith" elma ağacının (*Malus domestica Borkh.*) çiftçi koşulları altındaki sulamaya tepkilerinin araştırılmasını amaçlamıştır. Bu çalışmada, sulama sezonu içerisinde elma ağaçlarında yaprak su potansiyeli (LWP), stoma iletkenliği (g_s) ve fotosentetik aktif radyasyon (PAR) gibi bazı fizyolojik gözlemler ele alınan dönem içerisinde her sulamadan önce bir hafta aralıklar ile yapılmıştır. Eşzamanlı olarak, tüm sulama sezonu boyunca, elma bahçesinde farklı toprak katmanlarındaki (0-30 cm, 30-60 cm, 60-90 cm, 90-120 cm) toprak su içeriği (SWC) de izlenmiştir. Hasat sonrasında tüm gözlemler kendi arasında değerlendirilmiştir. Araştırma sonuçları, sulama sezonu içerisinde, SWC değerlerinin tarla kapasitesi (FC) ile solma noktası (PWP) arasında değiştiğini ortaya koymuştur. SWC değeri, aşırı yağışlı bazı günler hariç, elma bahçesi toprak profilinde tüketilmesine izin verilebilir %50'lik miktarına ulaşılamamıştır. LWP, g_s ve PAR, tüm toprak katmanlarında, SWC'nin artışı ile artmıştır. Ele alınan tüm karşılaştırmalara ait en güçlü ilişki, elma bahçesinde tüm toprak katmanları içerisinde, 30-60 cm toprak katmanından elde edilmiştir. LWP~g_s arasındaki ilişkiler (R^2=0,53) hafif iken LWP~PAR arasındaki ilişkilerin (R^2=0,84) güçlü olduğu saptanmıştır. Sonuçta, ele alınan tüm gözlemler doğrultusunda, yaz döneminde yağışın sık ve düzensiz olmasına rağmen, uygun bir sulama programına ihtiyaç olduğu anlaşılmıştır.

Anahtar kelimeler: Yaprak su potansiyeli (LWP), Stoma iletkenliği (g_s), Fotosentetik aktif radyasyon (PAR), Toprak su içeriği, Elma ağacı, Düzce yöresi

Introduction

Apple, which is a pome fruit and a member of the Rosaceae family, is one of the important fruit in Turkey (Kaşka and Küden, 1992). Apple production in Turkey has been estimating 3.3% of the world annual production (FAO, 2015). Düzce Region has many types of fruit trees in which apple production is second one with 5% of all fruit tree production after hazelnut (DPDA, 2014). These productions would have been impossible without irrigation in the way of conscious even though this region had 800 mm annually precipitation (Özmen, 2013).

It is very critical that apple trees are irrigated well and managed correctly for having higher production in Düzce Region. However, most of crops have been irrigated wisely based on farmer decision that is about to irrigate the crops according to their appearance in Düzce Region and as well as other regions in Turkey. This is one of the techniques, which is used in irrigation scheduling (Kanber, 1999). However, it is not practicable technique in decision of irrigation water applies to many crops. Kanber (1999) pointed out that the other important technique is monitoring of the soil moisture and plant canopy. This technique is very applicable to decisions of irrigation water apply and quite convenience to understand plant water stress (PWS) in irrigation scheduling for any crops. Jones (2004) expressed that plant's response to water stress was a better indicator of PWS. Leeuwen et al. (2009) mentioned that irrigation scheduling techniques based on PWS were ideally suited for regulated deficit irrigation (RDI) management to improve the quality of fruits.

In quantifying PWS, pressure chamber (or bomb) and leaf porometers are considered as the standard method to measure mid-day (12:00-14:00 PM) leaf water potential (LWP) and stomatal conductance (g_s), respectively (Lampinen et al., 2001). On the other hand, Lampinen et. al. (2009) indicated photosynthetically active radiation (PAR), which exposed plant canopy resistance to light, was one of the very valuable components to implement canopy management.

Ebel et al. (1993) found out that LWP values of apple trees were directly changed with soil moisture content. Researcher stated that LWP values for RDI and full irrigation were changed 10 to 25 bar and 7 to 13 bar, respectively. Greer (2015) indicated that the value of g_s was strongly affected by the leaf temperatures across the growing season of apple trees. Decreasing in the value of g_s was observed by increasing the temperature in the leaf, which results the stress for crops (Greer, 2015). Li et al. (2010) expressed that PWS could be estimated by using PAR observations. Forrester et al. (2010) stated that LWP, PAR and g_s measurements on the crops during irrigation season could be used to understand PWS.

Previous studies revealed that plant-soil-atmosphere relationships should be understood by applying the irrigation water in the correct way. These relationships are also very important to choose the appropriate irrigation scheduling for any crops. However, until now, there has been no study concerning to plant, soil and water relationships on apple trees in Düzce Region. Farmers have mostly applied water according to appearance of plant if crops would need to be applied water or not during the summer. In this study, the relationships between soil water and apple trees' status under the farmer condition was determined by the response of apple tree to irrigation water given by farmer in Düzce Region.

Materials and Methods

Experimental Site

This study was performed at the apple orchard in Sarımeşe village of Çilimli town in Düzce city between 10th June and 2nd September in 2013. The experimental orchard located at latitude 40°53' N, longitude 31°02' E had the region of about 0.22 hectares with the altitude of 185 m. Annual average precipitation and temperature for last 40 years in Düzce city were 814 mm and 13.2 °C, respectively. The maximum temperature and minimum precipitation occurred in July during a year when the data were considered for last 40 years (Özmen, 2013). Daily reference evapotranspiration (ETo) was calculated by Penman-Monteith (PM) equation using the program of California Irrigation Management Information System (CIMIS). Daily precipitation (P) and reference evapotranspiration (ETo) were plotted based on data from Meteorological Station in the center of Düzce city and shown in Figure 1. During studied year, in a month, average daily values of ETo with 5.4 mm per day was obtained in July.

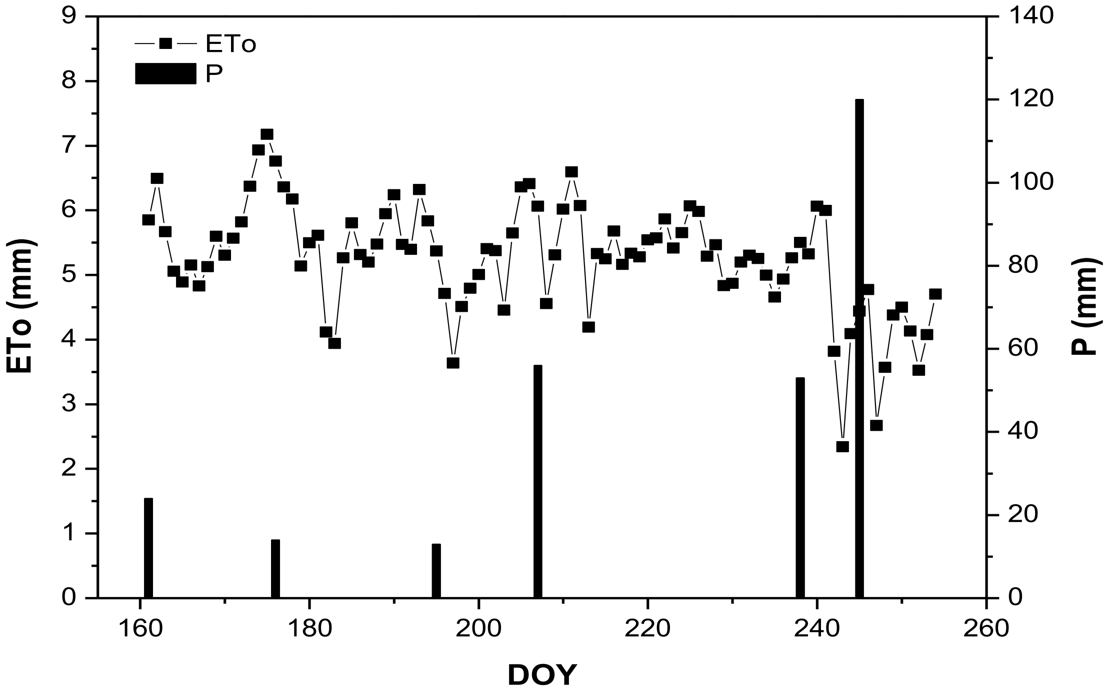

Figure 1. Daily precipitation (P) and reference evapotranspiration (ETo) during the experimental period in Düzce Region.

Physical and chemical characteristics of the soil at the apple orchard were analyzed and given in the Table 1. Soil properties of orchard had clay-loam containing 37% sand, 32% clay and 31% silt in the upper 120 cm profile. Soil bulk density of the orchard ranged from 1.27 to 1.30 g*cm^{-3}. The orchard with deeper soil had an average depth of 1.2 m and 241 mm of total water available at field capacity (FC). The topography of apple orchard was non-problematic. Richards' method (1954) was used for all analyses as shown in Table 1.

In this study, Granny Smith variety of apple trees (*Malus domestica Borkh.)* was used at the experimental orchard. A 4x3-m planting distance was designed at apple orchard. In the given study, experimental apple orchard was 3 years old, and apple trees were irrigated by applying furrow irrigation under farmer condition during the study in the summer season. Canopy properties of the apple trees were similar with each other. Additionally, it should be noticed that the nutrient management and the other cultural practices for the studied experimental apple orchard were managed by Provincial Agriculture Directorship of Düzce.

Table 1. Soil characteristics of the experimental field.

	Soil depth, cm			
	0-30	30-60	60-90	90-120
Saturation Point, %	57.00	66.00	53.00	46.00
Sand, %	37.00	37.00	46.00	43.00
Clay, %	32.00	34.00	28.00	27.00
Silt, %	31.00	29.00	26.00	30.00
Texture	CL	CL	SCL	L-CL
Total Salt (%)	0.021	0.023	0.016	0.013
pH	6.41	6.61	6.70	6.74
As (g cm^{-1})	1.27	1.28	1.27	1.30
FC (%)	36.15	34.99	31.59	20.67
PWP (%)	19.87	19.18	16.36	5.31

Soil Moisture, Irrigation and Evapotranspiration (ET)

During the study, soil moisture content at the depth of 0-120 cm (in 30-cm increments) was measured gravimetrically (105 °C, 24 h) one week interval before or after irrigation events. Soil samples were taken with a hand-driven auger under the tree canopy during the study year. All irrigation amounts which were given by farmer were applied by farmer using furrow irrigation method, and each amounts of irrigation application were measured on the site in the period of study. Irrigation applications of trees were decided by farmer according to tree canopy appearance. ET values (mm) for apple trees were calculated using Equation (1):

$$ET=P+IR+Cr-Dp-Rf\pm\Delta W \qquad (1)$$

where P and IR are rainfall and total irrigation water depth (mm), respectively, and ΔW is the change in soil water content (final minus initial). P was determined by pluviometer, which was installed on the experimental site, while IR was measured on the site for each irrigation interval. Cr, Dp and Rf are capillary rise, deep percolations and runoff, respectively. As there was no water table or runoff in the experimental region, Cr and Rf were set to 0, and Dp was assumed to be negligible (Dağdelen et al., 2009). Data presented that the soil moisture content was consistently less than field capacity at the lower boundary of the root zone. To exhibit the relationship of soil-plant-atmosphere for apple tree during studied year, one period was selected in the experiment period (Wang et al., 2012). Hence, this period was between 13th July 2013 (DOY 194) and 5th August 2013 (DOY 217).

Plant Observations

LWP was measured on five leaves per tree for five trees with a pressure chamber which was given method of Garnier and Berger (1985). Leaf porometer (Decagon Devices, Inc., Pullman, Washington) was used to determine the values of g_s on five leaves per tree. Sunlit and healthy leaves around tree canopy were selected for LWP and g_s measurements. Additionally, PAR under tree canopy was quantified according to method given by Rosati et al. (2007) (Decagon Devices, Inc., Pullman, Washington). All measurements of LWP, g_s and PAR were performed weekly between 12th July and 5th August in 2013 during noon time (12:00-14:00) before or after irrigation events while soil samples were taking at the same time. This period was selected due to the highest ETo values just before harvesting. At the end of study, harvests were done by hand. Yield per tree, which was to compare with the observed values of LWP, g_s and PAR, was weighed using portable scale and elevated per tree.

Results and Discussion

Irrigation, SWC, ET and Fruit Yield

In the present study, the changes of SWC, amount of irrigation water applied and precipitation were plotted according to day of year (DOY) as given in Figure 2. Irrigation was started at the DOY 171 (20th June 2013) and ended at the DOY 238 (26th August 2013). Hereby, SWC was fluctuated between field capacity (FC) and permanent wilting point (PWP). The highest and lowest values of SWC were observed in DOY 245 with 463.8 mm and DOY 210 with 243.7 mm, respectively. SWC was more affected by precipitation than irrigation during irrigation season because SWC was increased quickly after each precipitation event. Black and Cardon (2008) emphasized that the amount of allowable depletion for apple trees could be until 50% of the total available water in the soil. Thereby, it can be concluded that irrigation applications were not enough for water needs of apple trees since the value of SWC didn't reach up to 50%, which is the allowable depletion value at the soil of apple orchard except some high rainy days such as DOY 207 with 438 mm and DOY 245 with 464 mm.

The values of applied IR, ET, and fruit yield for apple trees during the irrigation season were presented in Table 2. Minus value was obtained for soil water content difference (ΔS) between the beginning and ending of irrigation season since higher precipitation occurred at the end of irrigation season. The results of this study showed up similarity with literature (Nielsen et al., 2003; Aslantas et al., 2007). However, the differences between findings from the literature could be attributed to age of trees with non-correct irrigation scheduling without any program, and frequently and unevenly precipitations at experimental orchard in Düzce Region.

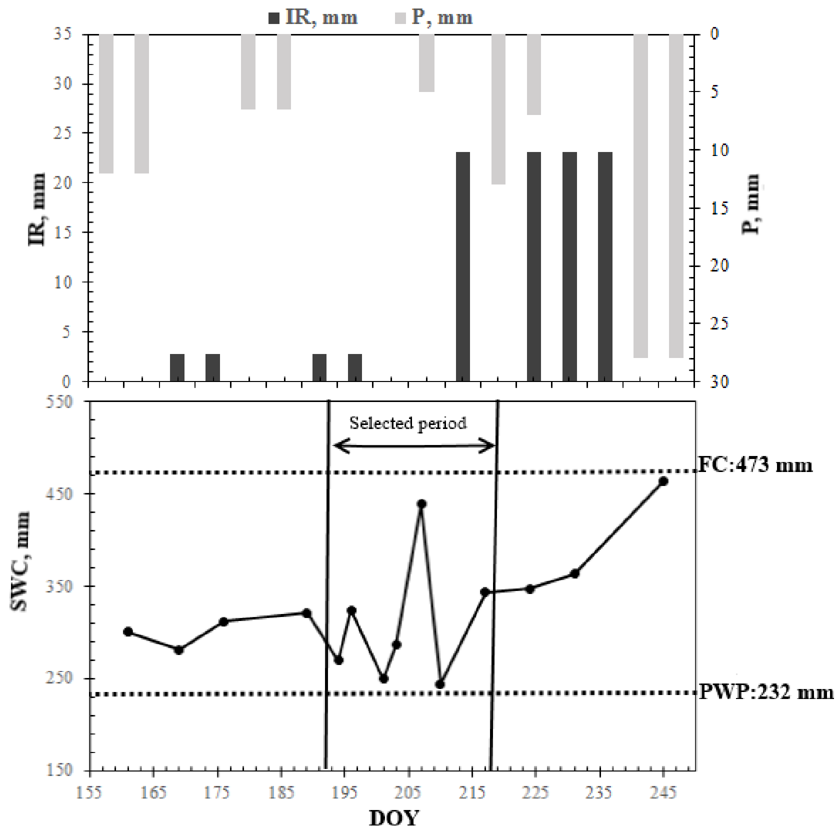

Figure 2. Soil water content (SWC) at between 0-120 cm soil profiles, precipitation (P) irrigation water (IR) at apple orchard in the irrigation season in Düzce Region.

Table 2. IR, ET and fruit yield of apple trees in Düzce Region.

Treatments	ΔS	P	IR	ET	Yield
	mm	mm	mm	mm	kg.tree^{-1}
Apple	-164	132	92.8	60.8	1.0

The Variation of LWP, g_s and PAR Response to SWC Changing

LWP, g_s and PAR measurements were able to be applied for any crops to understand plant water status and how crops were grow well (Wu et al., 2014). In this study, to understand how LWP, g_s and PAR are changed by SWC and which one of them are more affected by SWC for different soil layer in the selected period at apple orchard, the variation of LWP, g_s and PAR response to SWC changing were plotted for total soil layer (0-120 cm) and different soil layers (0-30 cm, 30-60 cm, 60-90 cm, 90 120 cm) according to DOY (Figure 3-8). LWP, g_s and PAR values were ranged -1.2 to -2.7 MPa, 77.8 to 201.6 mmol/(m²·s) and 838.4 to 1928.4 µmmol/(m²·s), respectively. All values of LWP, g_s and PAR were increased by higher values of SWC in total soil layers during the irrigation season as anticipated. In each soil layer, findings showed up that LWP, g_s and PAR were increased while SWC was increasing as well. LWP values obtained from this study showed up similarity with study reported by Ebel et al. (1993). Therefore, in the regions where have such higher and unevenly precipitation, it may be stated that -1.4 MPa of LWP value is used as threshold for starting of irrigation water apply if the amount of allowable depletion for apple trees is until 50% of the total available water in the soil as reported by Black and Cardon (2008).

A variation was happened between the FC and the PWP due to frequent precipitation. Figures 3-8 presented that there is a relationship between the responses of LWP, PAR and g_s values to SWC changing for apple orchard grown by the conditions of this study. For total soil layer (0-120 cm), g_s (R^2=0.89) response to SWC changing was higher than LWP (R^2=0.87) and PAR (R^2=0.83) response to SWC changing at the apple orchard. For 30-60 cm soil layer, g_s (R^2=0.98), LWP (R^2=0.97) and PAR (R^2=0.95) response to SWC changing had stronger relationship than those of other soil layers. The stronger relations of parameters response to SWC changing for 30-60 cm soil layer can be due to higher SWC and lower root density with less ET for shallow soil layers as reported in the study of Özmen et al. (2015). Additionally, it should be remarked that the results of this study concerning LWP, g_s and PAR responses to SWP changing for apple orchard were matched up with the findings of the other works in the literature (Ebel et al., 1993; Wu et al., 2014; Greer, 2015).

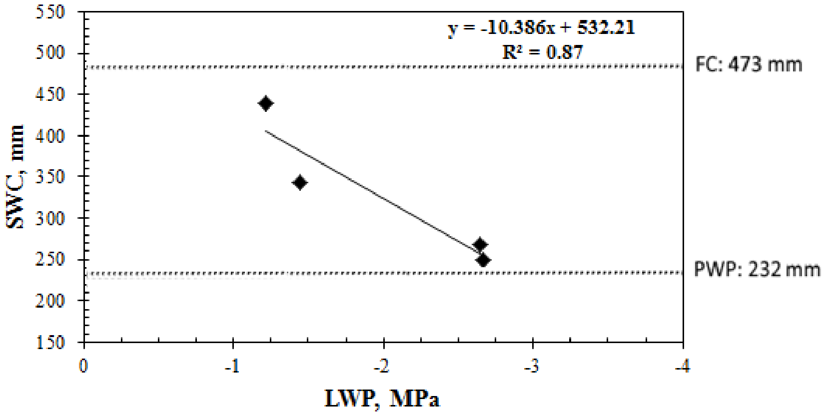

Figure 3. The relationships between LWP and total soil profile of SWC (0-120 cm) during the selected period at apple orchard in Düzce Region.

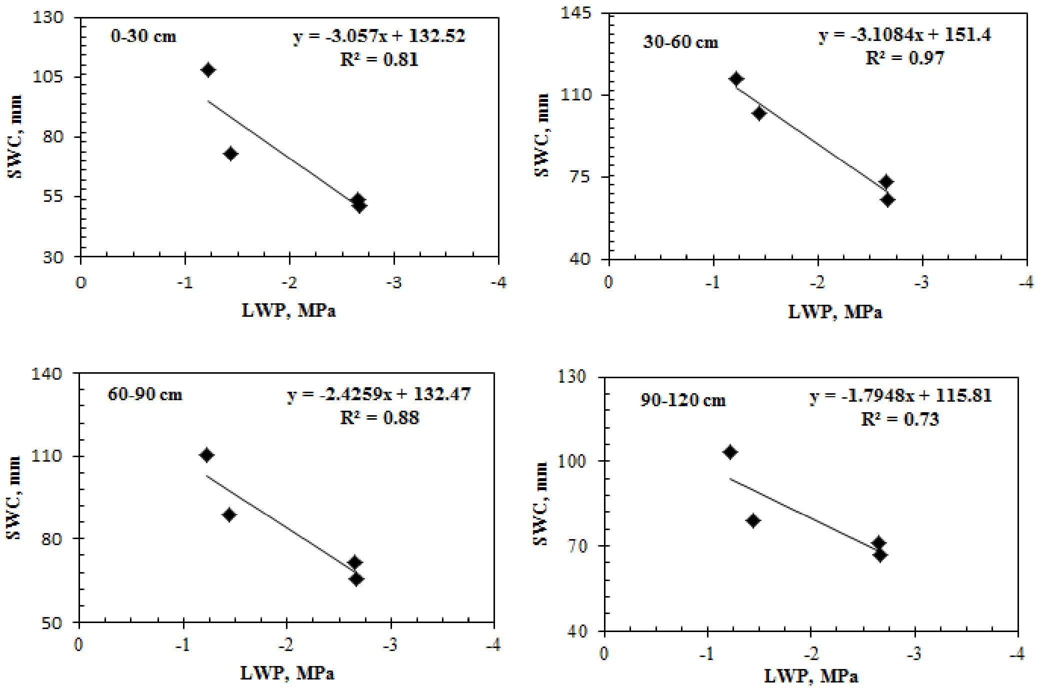

Figure 4. The relationships between LWP and different soil layers (0-30 cm 30-60 cm 60-90 cm, and 90-120 cm) of SWC during the selected period at the apple orchard in Düzce Region.

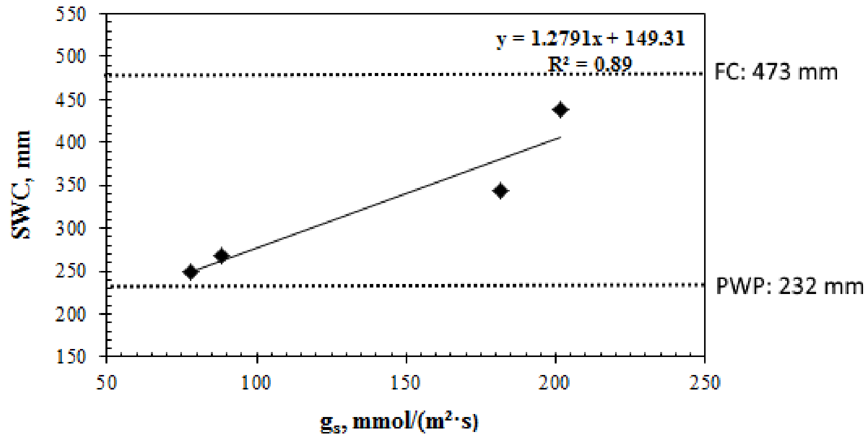

Figure 5. The relationships between g_s and total soil profile of SWC (0-120 cm) during the selected period at the apple orchard in Düzce Region.

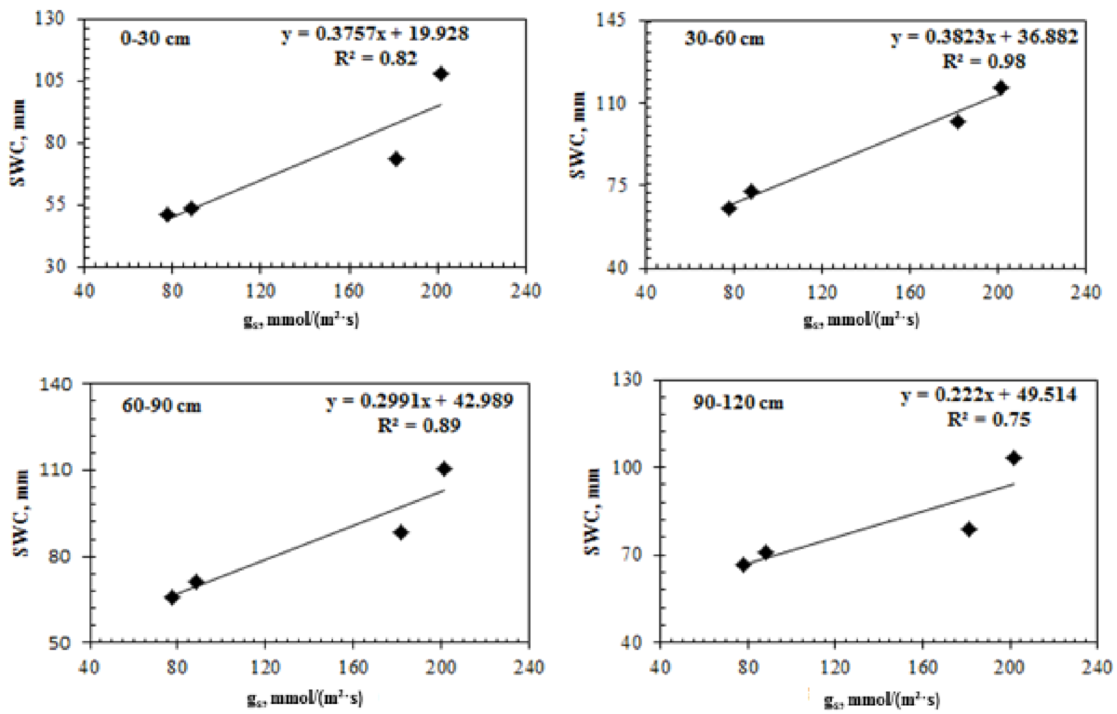

Figure 6. The relationships between g_s and different soil layers (0-30 cm, 30-60 cm, 60-90 cm, and 90-120 cm) of SWC during the selected period at the apple orchard in Düzce Region.

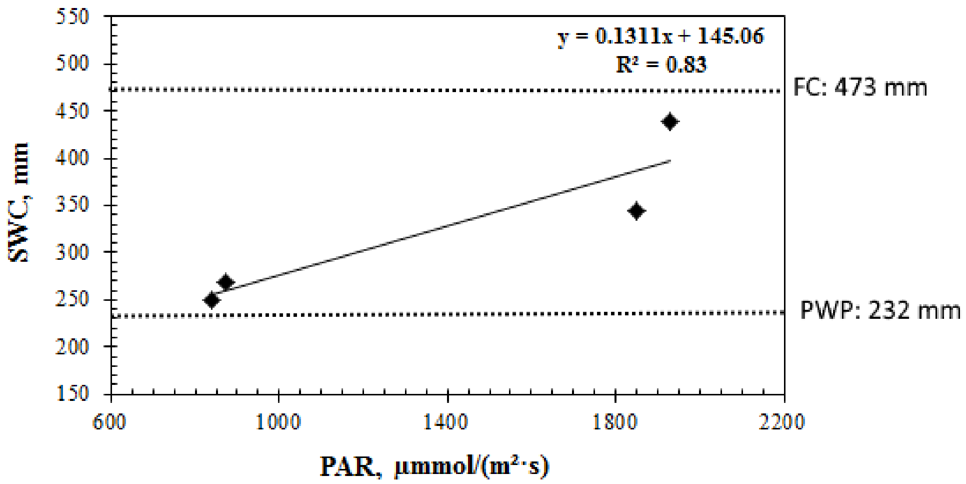

Figure 7. The relationships between PAR and total soil profile of SWC (0-120 cm) during the selected period at apple orchard.

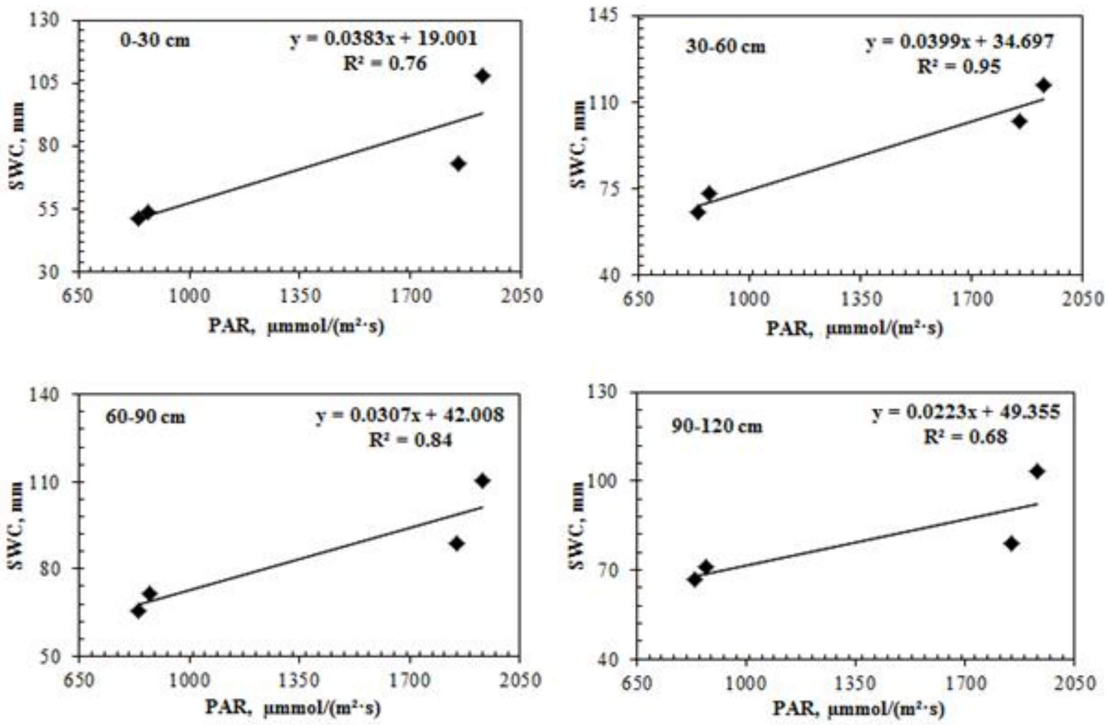

Figure 8. The relationships between PAR and different soil layers (0-30 cm 30-60 cm 60-90 cm, and 90-120 cm) of SWC during the selected period at the apple orchard in Düzce Region.

The Relationships of LWP, g_s and PAR

Leaf gas exchanges such as LWP, g_s, photosynthetic rate and CO_2 assimilation are valuable criteria to understand situation of PWS (Da Silva et al., 2014). PAR is also related to understand PWS as much as it is used for yield prediction (Cieslak et al., 2008). To analyses the water status of apple trees, LWP~g_s, LWP~PAR and PAR~g_s were plotted in Figure 9 for selected period in the irrigation season.

The results showed that there was a linear relationship between LWP~PAR, LWP~g_s and g_s~PAR for apple trees investigated in this study. It means that the value of PAR was increased with the increase in g_s while either g_s or PAR values have the enhancement with increasing the value of LWP. Findings showed up that the relationship between LWP and PAR (R^2=0.84) was stronger than LWP~g_s (R^2=0.53) and g_s~PAR (R^2=0.78) relations (Figure 9). Reported studies exhibited that LWP, g_s and PAR values for this type of fruit depended on the environmental conditions, such as solar irradiance and soil and plant water status content, and had linear relationships between each other (Schulze, 1986; Francesconi et al., 1997). Therefore, the results of this study were in good agreement with the studies in literature.

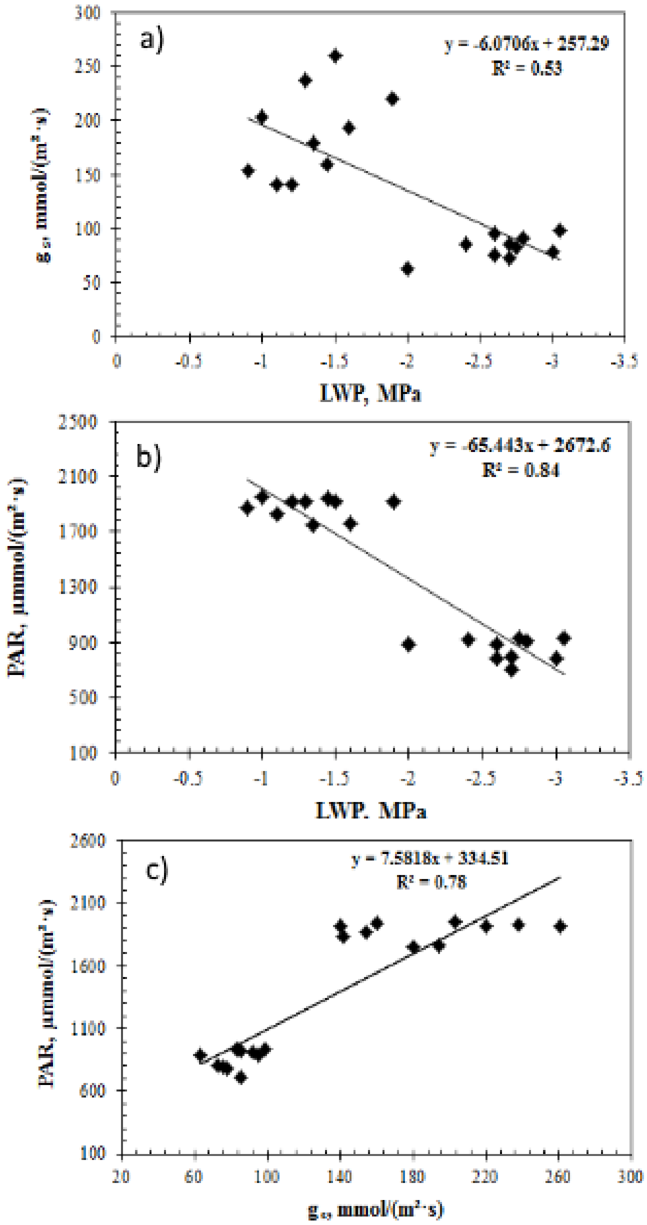

Figure 9. The relationships of (a) LWP~g_s, (b) LWP~PAR and (c) g_s~PAR during the selected period at the apple orchard in Düzce Region.

Conclusion

In this study, apple tree responses to irrigation under farmer condition in Düzce Region were investigated. SWC was changed between FC and PWP during irrigation season. However, this has not fulfilled until 50% of amount of allowable depletion in the soil profile for apple orchard except rainy day. LWP, g_s and PAR were increased as increased of SWC in all soil layers (0-30 cm, 30-60 cm, 60-90 cm and 90-120 cm). It was deduced that there are quite strong relationships between LWP, g_s and PAR responses to SWC changing for all soil layers. Among all soil layers, soil layer of 30-60 cm have the strongest relationships for all correlations. It was obtained that LWP~PAR had the stronger relationships with R^2=0.84 while LWP~g_s had slight relationships with R^2=0.53 in this study. As a result, a proper irrigation scheduling may be needed for such as apple orchards even though precipitation was frequently happened in the summer.

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