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Interaction of Water Salinity and Different Irrigation Levels on Physiological Growth of Olive (*Olea europaea* L.)

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ABSTRACT

During the last few years, due to inadequate rainfall, Iran has faced water scarcity. This made the fertile zones including the Fars Province and especially the Marvdasht District to face many problems. Salt concentrations increase and the groundwater resources reduction in the central part of this district are currently occurring. Recently, the farmers have attempted to change the cultivation pattern by cultivation of salt-resistant plants including olive and pistachio. Therefore, in this study, interaction between salinity of the irrigation water and the water deficit on physiological growth of the olive plant (*Olea europaea* L.) was investigated. The experiment was conducted as a completely randomized block design for three years (2013-2015) in a 7-years-old olive grove (Roghani-Fishomi cultivar) grown in a sandy soil with planting density of 5.5×5.5 meters. Treatments included five Irrigation levels (I_1= 25%, I_2= 50%, I_3= 75%, I_4= 100%, and I_5= 125 percent of olive water requirements) and three Salinity levels of 2.2 to 7.7 dS m^{-1} (S_1), incorporation of 50% well water with 50% drinking water from the local region (*S_2*), and pure drinking water from the region (S_3= Salinity of 0.4 to 0.85 dS m^{-1}) of irrigation water. Treatments were applied in a factorial arrangement, with three replications. Daily irrigation of trees was performed by drip irrigation. The results showed that in all of the three consecutive years, the highest Intrinsic Water Use Efficiency (IWUE) values were obtained in I_3S_1 (131.94, 114.14 and 96.95 by years, respectively). Also, the highest transpiration efficiency was achieved in I_3S_3 (1.24, 1.06 and 0.88 respectively). In high salinity, due to the stress applied to the olive trees, leaf water potential decreased and, consequently, the water in the leaves could not meet the existing *$VPD_{l.a}$* (saturation Vapor Pressure Deficit near leaf area), thus causing stomatal closure and reduction in stomatal conductance (gs). Generally, for I_1 to I_4 irrigation levels, the highest salinity effect on Transpiration Efficiency (TE) happened in S_3 salinity level.

Keywords: Intrinsic Water Use Efficiency, Olive physiological growth, Salinity and water stress interaction, Transpiration efficiency.

INTRODUCTION

Olive tree has moderate resistance to salinity (Connor and Fereres 2005). Hence, it can be irrigated using saline water (Simkeshzadeh *et al*., 2015). Resistance of olive trees to salinity is not the same in different varieties. Depending on the salinity level of the irrigation water, the yield and the plant growth are affected differently and, in some cases, due to the high salinity level, the plant confronts the risk of dying. Olive plant’s resistance to salinity depends highly on the salt excretion mechanism around the roots (Melgar *et al*., 2012). High salinity reduces pollination, fruit size (Ben-Gal, 2011) and thus reduces fruit crop yields of the olive

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tree, but it will have no effects on the amount of the fruit oil (Ben-Ahmed *et al*. 2009). On the other hand, it increases the ratio of linoleic to linolenic acids and decreases the ratio of oleic acid to linolenic acid (Cresti *et al*., 1994). It also decreases the concentration of phenols in the olive fruit oils (Ben-Ahmed *et al*., 2009) and significantly causes a reduction in the growth of the shoots, leaf area, and the dry weight of the chlorophyll (Alaei *et al*., 2015). Moreover, olive is a drought-resistant plant, which is able to grow in shallow soils with minimal supplemental irrigation and with winter rainwater. Based on table olive production, fruit production and its economical return do not depend solely on its durability, but the fruit size, yield, oil yield and quality are important factors that determine whether olive production is economical or not (University of California, 2014). By applying deficit irrigation in some circumstances, the quality of the produced oil is increased. The best deficit irrigation range for a high oil quality is between 33 and 40% of water requirement, and for optimal olive oil production, it is between 70 and 75% of water requirement. By reducing irrigation up to 30 percent of the water requirement, not only fruit production is reduced heavily, but also the oil percentage and its quality are reduced, as well. By an increase in the percentage of the consumed water, the fruit yield increased by a reduction in oil production (Vossen *et al*., 2008; Grattan *et al*., 2006).

Asik *et al*. (2014) showed that irrigation scheduling using deficit irrigation allowed considerable water savings in Memecik olive trees (*Olea europaea* L.), with minimal effects on yield. Different irrigation levels had no significant effect on the yield, while significant differences between treatments were detected in some morphological features such as shoot length, shoot diameter, canopy volume, and fruit set ratio. Results indicated that irrigation of Memecik olive trees should be scheduled based on the amount of water equivalent to 25% ($S_{0.25}$) of the five-day cumulative evaporation from a Class A pan. Kaya *et al*. (2017) demonstrated that an increase in the amount of irrigation water applied to an olive orchard was accompanied by a fall in ripeness index values, a rise in moisture content, and a reduction in the oil content of the fruit.

The most efficient olive fruit production has been reported at the irrigation level of 100% (Talozi and Al Waked 2016). Salt resistance in plants depends on the interaction between salinity and other environmental parameters including dryness (Jouyban, 2012). Not many cases of researches exist on the interaction between different levels of irrigation and salinity in garden plants so far. Lots studies have generally referred to crop yield. (Melgar *et al*., 2012). For instance, in the interaction between three salinity levels (0.5, 5, and 10 dS m^{-1}) and three irrigation levels, it was demonstrated that the water salinity had no substantial effects on the fruit size, fruit mantle, and olive fruit core; but the amount of oil available in the fruit was increased linearly by an increase in the salinity (Serrano Castillo *et al*., 2008).

The aim of this study was to investigate the interaction between the salinity of the irrigation water and the water deficit on physiological growth (by examining the relationship between photosynthesis and transpiration) of the olive plant in the Marvdasht District, Fars Province, Iran.

MATERIALS AND METHODS

The study area is located in the central part of the Marvdasht District with longitude of longitude of 52° 59' 43" E, latitude of 29° 50' 22" N, and altitude of 1,620 m (Figure 1).

The experiment was conducted for three years (2013 to 2015) in a 7-years-old olive garden planted (Roghani-Fishomi variety) at a cultivation density of 5.5×5.5 meters. Treatments included different irrigation levels (I_1, I_2, I_3, I_4 and I_5 for 25, 50, 75, 100, and 125% of water requirements). Three

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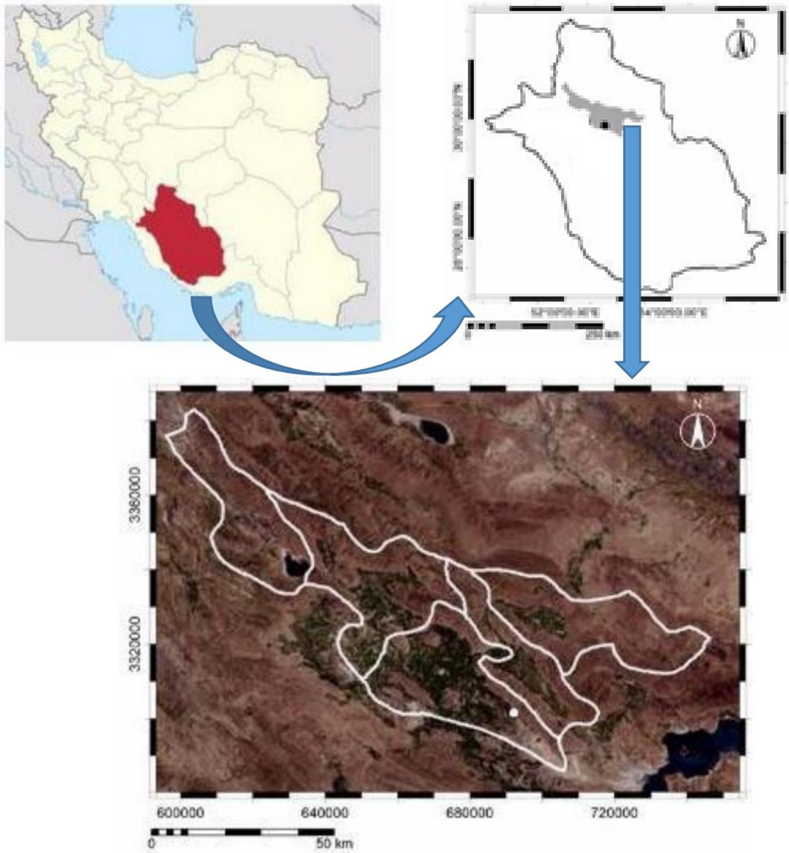

Figure 1. Location of the studied area in Fars Province, Iran**.**

replications were used in the form of a factorial layout within a completely randomized blocks design. Plant water requirement was calculated by FAO Penman-Monteith method modified for the Kooshkak Area of the Marvdasht County (Razzaghi and Sepaskhah, 2012) and meteorological data of the Persepolis synoptic station. The irrigation water salinity levels were salinity of 2.2 to 7.7 dS m^{-1} (S_1), incorporation of 50% well water (S_1) with 50% drinking water from the local region (S_2), and finally pure drinking water from the region (S_3= salinity of 0.4 to 0.85 dS m^{-1}). Different levels of applied irrigation were maintained from the beginning of the treatments until the end of the experiment. The method of irrigation was loop drip irrigation and eight emitters with discharge of 4 liters per hour for each tree. Irrigation was done on daily basis and by three electronic pumps.

To assess the interaction of water salinity and different irrigation levels on physiological growth of olive, the relationship between stomatal conductance (gs, mol m^{-2} s^{-1}), saturation Capor Pressure Deficit near leaf area ($VPD_{l.a}$, kPa), stem water potential (ψ_{stem}), and photosynthesis rate (A, µmol m^{-2} s^{-1}), was investigated. Parameters of gs, $VPD_{l.a}$, *A*, and Transpiration (Tr, mmol m^{-2} s^{-1}) were extracted through the data recorded by the photosynthesis meter device (ADC BioScientific LCi Analyser Serial No. 30784). The measurement was conducted on sunny days and between 11 to 14 o'clock. In addition, ψ_{stem} was measured using pressure bomb (model 5100A, Santa Barbara, CA, USA).

In this study, using the relevant information, the Intrinsic Water Use Efficiency (IWUE) (Equation 1) (Farquhar *et al*., 2001; Jones, 2004) and Transpiration Efficiency (TE) (Equation 2) (Jones, 2004) were calculated:

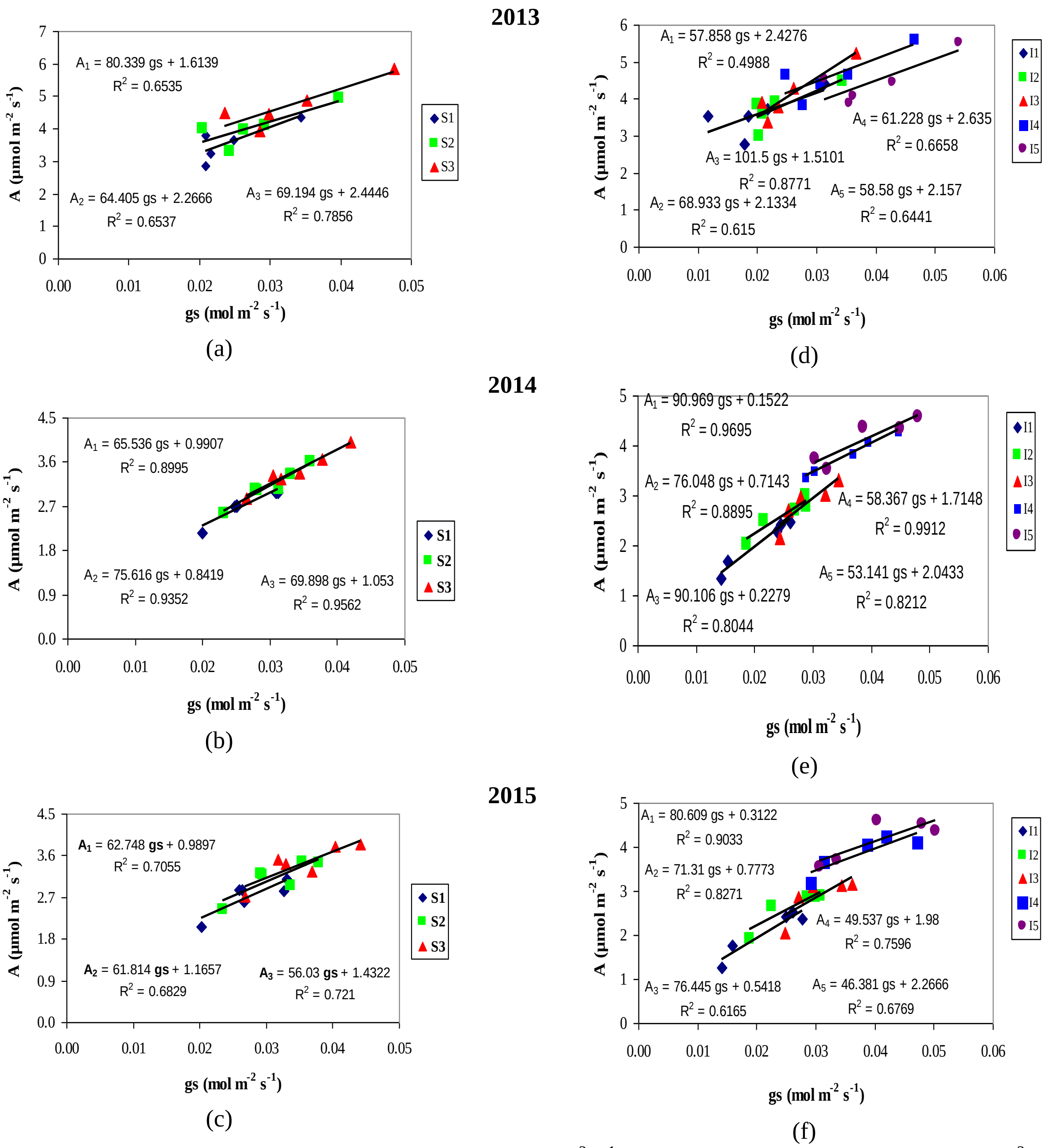

Figure 2. Relationship between photosynthesis (A, µmol m^{-2} s^{-1}) and stomatal conductance (gs, mmol m^{-2} s^{-1}) (Slope of each line= Intrinsic Water Use Efficiency, *IWUE*) at various Salinity (S1, S2, and S3) and Irrigation (I1, I2, I3, I4, and I5) levels, based on measurements in five different times (June to November) in 2013, 2014, and 2015 (n= 5, P ≤0.05)

$$IWUE = \frac{A}{gs} \quad (1)$$

$$TE = \frac{A}{Tr} \quad (2)$$

In addition, the linear regression analysis was performed for all treatments.

RESULTS AND DISCUSSION

Intrinsic Water Use Efficiency (IWUE)

To study the effect of different salinity and irrigation levels on the intrinsic water use

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efficiency in olive, the changes of photosynthesis (A) versus the stomatal conductance (gs) were drawn (Figure 2) separately for the study years (2013, 2014 and 2015). The two parameters of photosynthesis (A) and stomatal conductance (gs) are under the direct influence of sunlight, air temperature, and relative humidity and these changes were more tangible in the October; therefore, *A* and *gs* data were used in drawing the diagram from June to November in 2013 and from April to October for the years of 2014 and 2015. For the purpose of statistical analysis of the salinity and irrigation levels effect, linear regression ($P\leq 0.05$) with five points ($n= 5$) were fitted and the slope of the fitted lines were used in this analysis. The charts on the left side of Figure 2 show the effect of different salinity levels on *IWUE* (excluding irrigation levels). In 2013, the greatest *IWUE* was observed in S_1 (80.34) and the least in S_2 (64.40). In 2014, S_2 had the greatest *IWUE* (75.61) and the least was in S_1 (65.53), and in 2015, the greatest effect was for S_1 (62.74) and the least effect for S_3 (56.03). Slope difference in the salinity level of S_3 (69.9) was almost identical with S_1 and S_2 in 2014, and salinity levels of S_1 and S_2 (61.81) in 2015.

With respect to the effect of different irrigation levels on *IWUE* (regardless of salinity levels) (charts on the right side of Figure 2), the greatest and the least *IWUE* in 2013 were in I_3 (101.5) and I_1 (57.85), respectively. In this year, the highest *IWUE* was obtained at low salinity levels and average levels of irrigation. In 2014, the highest and the least *IWUE* were those of I_1 (90.97) and I_5 (53.14), respectively. The slope of the fitted lines was almost equal in irrigation levels of I_1 and I_3 (90.10), which were almost identical in terms of the effect on the *IWUE*. The slope difference of the fitted lines in irrigation levels of I_4 (58.36) and I_5 was not high. However, the slope difference of the fitted lines in irrigation level of I_2 (76.05) was high compared with other irrigation levels and acted independently in terms of the effect on *IWUE***.** In 2014, the highest *IWUE* was obtained in S_2 salinity level and low to moderate irrigation levels. In 2015, the greatest and the least effect was that of irrigation levels of I_1 (80.60) and I_5 (46.38), respectively. The slope difference of the fitted lines in irrigation levels of I_4 (49.53) and I_5 was insignificant. The slope difference of the fitted lines in irrigation levels of I_4 and I_5 was high in comparison with other irrigation levels, which acted independently in terms of effect on *IWUE*. Generally, in 2015, the highest *IWUE* value was obtained in irrigation levels of S_1 and the low to moderate irrigation levels (like the year 2014).

Analyzing the effects of the different levels of salinity on *IWUE* (Figure 3) in 2013, and at irrigation level of I_1, the least *IWUE* was that of the S_1 (the slope of the regression line of 56.7) and the greatest *IWUE* was that of the S_3 (slope of 59.3). But, the slope difference of the fitted lines was significant ($P< 0.05$) between salinity levels of S_1 (56.7) and S_3 (59.3). In other words, the effect of different salinity levels on the *IWUE* was not equal in S_1 and S_3. However, there was no significant difference between salinity level of S_1 with S_2 (58) and S_2 with S_3. In the I_2 irrigation level, the most *IWUE* was observed in salinity level of S_3 (85.92) and the least in S_1 (68.02). The differences between the slopes of the fitted lines were significant in all three levels of salinity. In I_3, the highest *IWUE* was observed in salinity level of S_1 (131.94) and the least in S_3 (86.64). The difference between the slope of the fitted lines in salinity levels of S_2 (89.9) with S_3 (86.6) was not high. In other words, the effect of these salinity levels on *IWUE* was equal in this irrigation level. In I_4, the highest *IWUE* was observed in salinity level of S_1 (63.13) and the least one in S_3 (51). The differences between the slopes of the fitted lines in all salinity levels in this irrigation level were similar. In other words, the difference of levels' effect on *IWUE* was not significant in this irrigation treatment. In the irrigation level of I_5, the maximum *IWUE* was observed in the salinity

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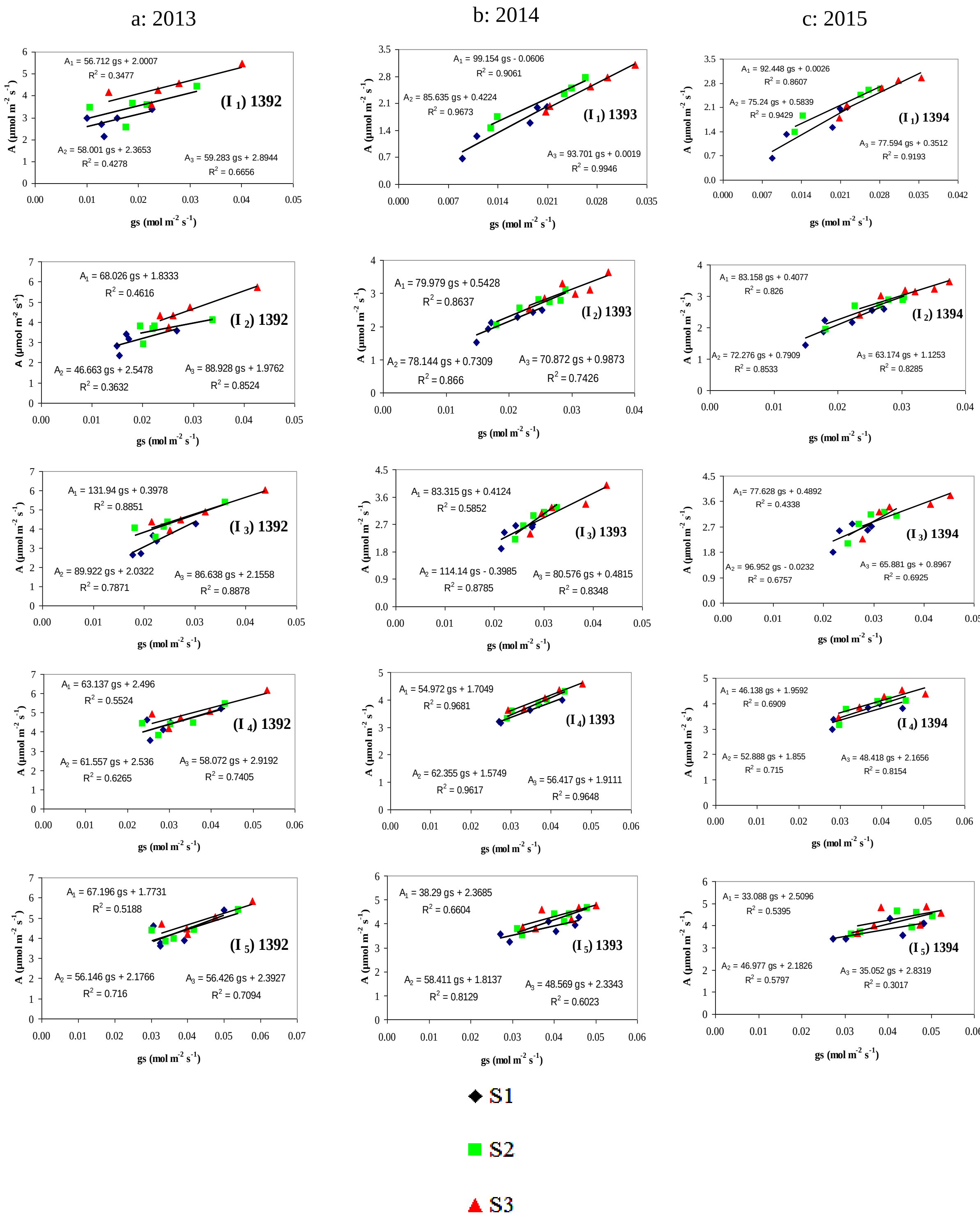

Figure 3. Relationship between photosynthesis (A, µmol m^{-2} s^{-1}) and stomatal conductance (gs, mol m^{-2} s^{-1}) (Slope of each line= Intrinsic Water Use Efficiency, IWUE) in various Salinity and Irrigation levels (S_1, S_2, S_3 and I_1, I_2, I_3, I_4, I_5), based on measurements in five different times in: a: 2013, b: 2014, and c: 2015 (n= 5, P≤ 0.05)

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level of S_1 (67.2) and the least at the salinity level of S_3 (56.42). The difference between the slope of the fitted lines was almost equal in salinity level of S_2 (56.14) and S_3. In other words, the effect of S_2 and S_3 levels on *IWUE* was not significant in this irrigation level. Generally, in 2013, the highest and the least *IWUE* were obtained in I_3S_1 (131.94) and I_2S_2 (46.66), respectively.

In 2014, in irrigation level of I_1, the greatest *IWUE* was that of S_1 (the slope of the regression line being 99.15) and the least was that of S_3 (with a slope of 85.63). But due to the difference of the fitted lines slope, the difference at 5% level was different between the S_2 salinity level (85.6) and other levels. In other words, the difference between S_1 and S_3 salinity levels with S_2 salinity level in this irrigation level was significant on IWUE. In the I_2 irrigation level, the most *IWUE* was observed in S_1 (79.97) and the least IWUE in S_3 (70.87). The difference between the slope of the fitted lines in S_3 (78.14) and S_1 (79.97) was not significant and were almost equal in terms of the effect on the *IWUE*. In the I_3 irrigation level, the most *IWUE* was observed in the salinity level of S_2 (114.14) and the least at the salinity level of S_3 (80.57). The difference between the slope of the fitted lines was not high at S_1 (83.31) compared with S_3. In other words, the effect of these salinity levels on *IWUE* was equal in this irrigation level. In the I_4, the most *IWUE* was observed in S_2 (62.35) and the least in the S_1 (54.97). The difference between the slopes of the fitted lines was not significant in S_3 (56.4) and S_1 in comparison with S_2. In the I_5 irrigation level, the most *IWUE* was observed in S_2 (58.41) and the least *IWUE* in S_1 (38.3). The difference between the slopes of the fitted lines in the S_3 (48.56) was almost equal with S_3 and S_1. In other words, the effect of salinity levels in this irrigation level was significant on *IWUE*. In general, the most and the least *IWUE* in 2014, were obtained in I_3S_1 (114.14) and I_5S_1 (38.29) treatments, respectively.

In 2015, Figure 3 (right), in I_1 the most effect was that of S_1 (the slope of the regression line being 92.44) and the least was that of S_2 (slope of 75.24). The difference in the slope of the fitted lines in S_2 and S_3 (77.59) was low and not significant in terms of the effect of the different salinity levels on *IWUE*. In the I_2, the most and the least *IWUE* were observed in salinity levels of S_1 (83.16) and S_3 (63.17), respectively. The difference between the slopes of the fitted lines was significant in different levels of salinity and in terms of the impact on *IWUE*. In I_3, the highest *IWUE* was obtained in S_2 salinity level (96.95) and the least *IWUE* in S_3 salinity level (65.83). Like the I_2 irrigation level, the difference between the slopes of the fitted lines at different salinity levels was also significant in this irrigation level. In I_4, the highest and the least *IWUE* were observed in S_2 (52.88) and S_1 (46.14). The difference between the slopes of the fitted lines in different levels of salinity was not significant. In I_5, the most and the least *IWUE* were observed in S_2 (46.97) and S_1 (33.10), respectively. The difference between the slope of the fitted lines was low in salinity levels of S_3 (35.05) and S_1. In other words, the effect of the S_3 (35.05) and S_1 salinity levels on *IWUE* was not significant. In general, the highest and the least *IWUE* in 2015 were obtained in I_3S_1 (96.95) and I_5S_1 (33.10) treatments, respectively. The effect of different levels of salinity in different irrigation levels in two consecutive years of 2014 and 2015 were similar. Note that in each of the three study years, the I_3S_1 treatment had the highest effect on *IWUE*.

Relationship between Water Potential of Olive Stem or Leaf with Stomatal Conductance

As the soil around the plants roots dries out, the plant restricts water transfer from inside the stomata to outside i.e. plant reduces the stomatal conductance (Kang and Zhang, 2004; Liu *et al*., 2006). Therefore, in this research, the relationship between ψ_{stem} and *gs* (R^2= 0.57, P≤ 0.05) (Figure 4) showed that the plant reaction to salinity tension and irrigation (reducing water potential of leaves on branches) was to close stomata and thus reduce stomatal

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conductance (gs). This conclusion is consistent with the results of Sperlinga *et al*. (2014).

Relationship between Saturation Vapor Pressure Deficit Near Leaf Surface ($VPD_{l.a}$) with Stomatal Conductance (gs)

Climatic conditions including relative humidity surrounding the olive trees can cause signals from plant to the leaves, which result in stomata closure in leaf surface. Therefore, in areas with dry climate (study area) Vapor Pressure Deficit (VPD) can affect stomatal conductance. Thus, in this study, we tried to examine the relationship between stomatal conductance and *VPD* (Figure 5). Thus, to establish a relationship between vapor pressure deficit near leaf surface ($VPD_{l.a}$, kPa) and stomatal conductance (gs, mol m^{-2} s^{-1}), the three-year measurements data were used. This means that, in 2013, the measurements of late September, December, and March were used. In 2014, the data of June, August, and early October, and in 2015, the measurements of the early October, November, and December were used. The results of this research showed that there was a relationship between $VPD_{l.a}$ and *gs*. In Figure 5, by increasing the $VPD_{l.a}$, the amount of *gs* is reduced at first with a negative and steep slope, then, in the range of $VPD_{l.a}$= 2.7 to 2.8 *kPa*, the slope is moderated and reaches zero. Finally, slope increases from $VPD_{l.a}$= 2.8 *kPa* (R^2= 0.39, $P \leq 0.05$). It should be noted that this finding was consistent with the results of Olyaee *et al*. (2015) and Moriana *et al*. (2002).

In Figures 6 (a-b), the relationship between stomatal conductance (gs) and saturation vapor pressure deficit near leaf surface is shown for different irrigation levels (regardless of salinity levels) and at different salinity levels (regardless of irrigation levels), respectively. As shown, *gs* varied between 0.01 to 0.045 mol m^{-2} s^{-1} and $VPD_{l.a}$ varied between 1.2 to 3.6 kPa. For the statistical analysis of the process of the changes and impact of the different irrigation levels on *gs*, their linear regression was drawn. Despite low R^2, the impact of different irrigation levels on *gs* and its relationship with $VPD_{l.a}$ can be seen clearly. According to Figure 6, in all irrigation levels, *gs* decreases by an increase in the $VPD_{l.a}$. By increasing irrigation levels from I_1 to I_5, the slope of curves decreased. This process continued to the $VPD_{l.a}$ = 2.5-2.7 kPa range and then increased. Increasing or decreasing of slope in the irrigation level was different such that the maximum slope was related to I_1 and the minimum slope was related to I_3 and I_4 (this result was consistent

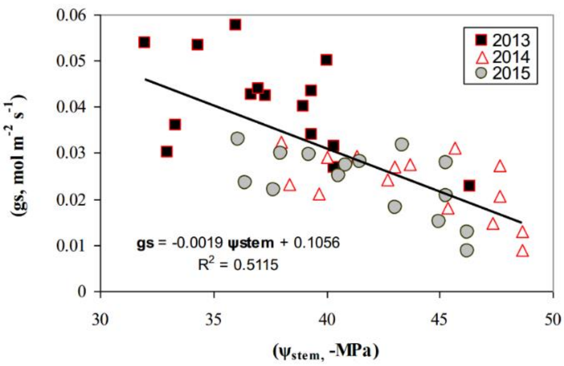


Figure 4. Relationship between stomatal conductance (gs, mol m^{-2} s^{-1}) and stem water potential (ψ_{stem}, -Mpa), based on measurements in two different seasons of autumn (2013) and summer (2014 and 2015).

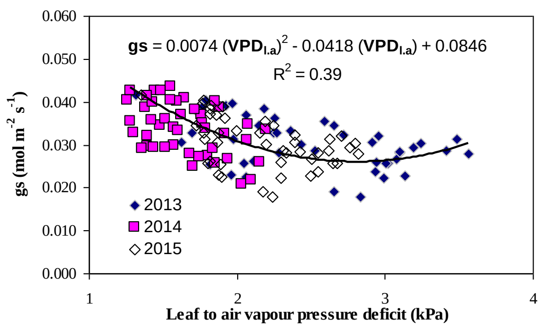
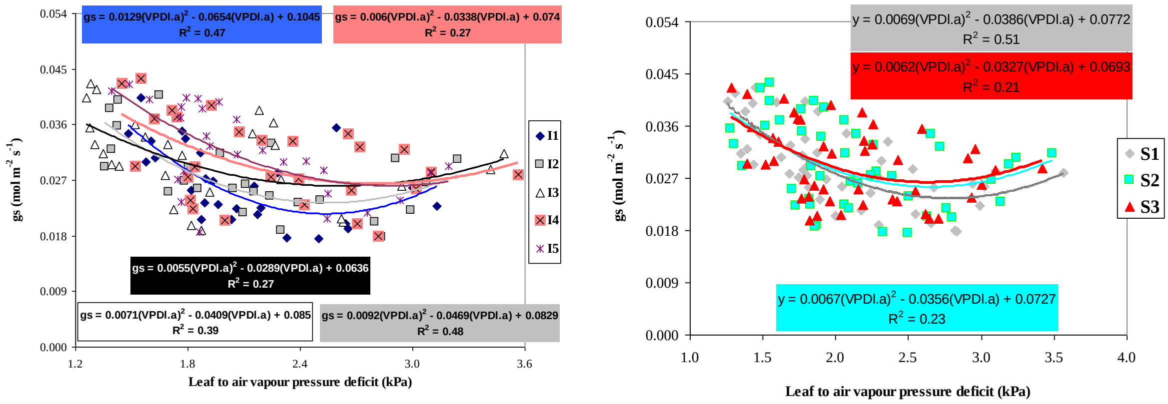


Figure 5. Relationship between stomatal conductance (*gs*) and saturation vapor pressure deficit in various treatments, based on measurements in three different times in **2013** (January, March and September), 2014 (June, August and October), and 2015 (July, September and November).



(a) (b)

Figure 6. Relationship between stomatal conductance (gs) and saturation Vapor Pressure Deficit ($VPD_{l.a}$,) (a) in average of various irrigation levels (without salinity levels), (b) in average of various salinity levels (without irrigation levels), based on measurements in three different times in **2013** (January, March and September), 2014 (June, August and October) and 2015 (July, September and November).

with the results of Moriana *et al*., 2002).

In Figure 6-b, the effect of salinity level on *gs* and $VPD_{l.a}$ is shown. In all S_1 and S_2 salinity levels, by increasing $VPD_{l.a}$, the gs decreased at first such that, in both levels, the lowest *gs* was observed in $VPD_{l.a}= 2.1$ *kPas*. Therefore, by increasing $VPD_{l.a}$ the gs increased almost with an equal slope in both of the salinity levels. In S_1, by increasing $VPD_{l.a}$, the *gs* decreased. In high salinity, due to the stress applied to the olive tree, leaf water potential decreased and, consequently, the water in the leaves could not meet the existing $VPD_{l.a}$, thus causing stomatal closure and reduction in *gs*.

Transpiration Efficiency

Transpiration Efficiency (TE) is an index that shows the photosynthesis rate per unit of transpiration. This index is positively correlated with photosynthesis (Shadan *et al*., 2013). The two parameters of photosynthesis (A) and Transpiration (Tr) are under direct influence of sunlight, air temperature, relative humidity, and carbon dioxide levels. In the study area, the changes were more tangible until October. Therefore, the data pertaining to the mentioned month was used for statistical analysis of the *TE*. In this study, effect of the salinity and irrigation levels were linearly fitted ($P\leq 0.05$) with five points and the statistical analysis was performed by the slope of the fitted lines. According to Figure 7 (a), in 2013, the most effect was related to S_3 salinity level (1.08) and the least was that of S_2 (0.56). Due to the slope of the linear regression, the difference between S_1 (0.59) and S_2 was not significant. In other words, the effect of S_1 and S_2 levels on *TE* was similar. However, the differences between S_1 and S_2 levels were significant in comparison to S_3 salinity level. In 2014, concerning the effect of different salinity levels on *TE* (Figure 8 (b)), the most effect was that of S_3 (0.86) and the least belonged to S_1 (0.54). The slope of the linear regression in S_2 (0.82) and S_3 levels had little difference with that of S_1 salinity level. In other words, the effect of S_2 and S_3 levels on *TE* was almost identical. In 2015, (Figure 7 (c)), S_3 (0.68) and S_1 (0.42) salinity levels were observed to have the most and the least effect on *TE*, respectively. The difference between S_1, S_2 (0.62) and S_3 salinity levels was significant. In other words, each of the salinity levels independently affected *TE*. As from S_1 to S_3 the impact was greater. In the case of the effect of different irrigation levels (regardless of salinity) (Figure 7 (d)) on *TE* in 2013, the most and the least were for I_4 (1.04) and I_5 (0.54), respectively. The

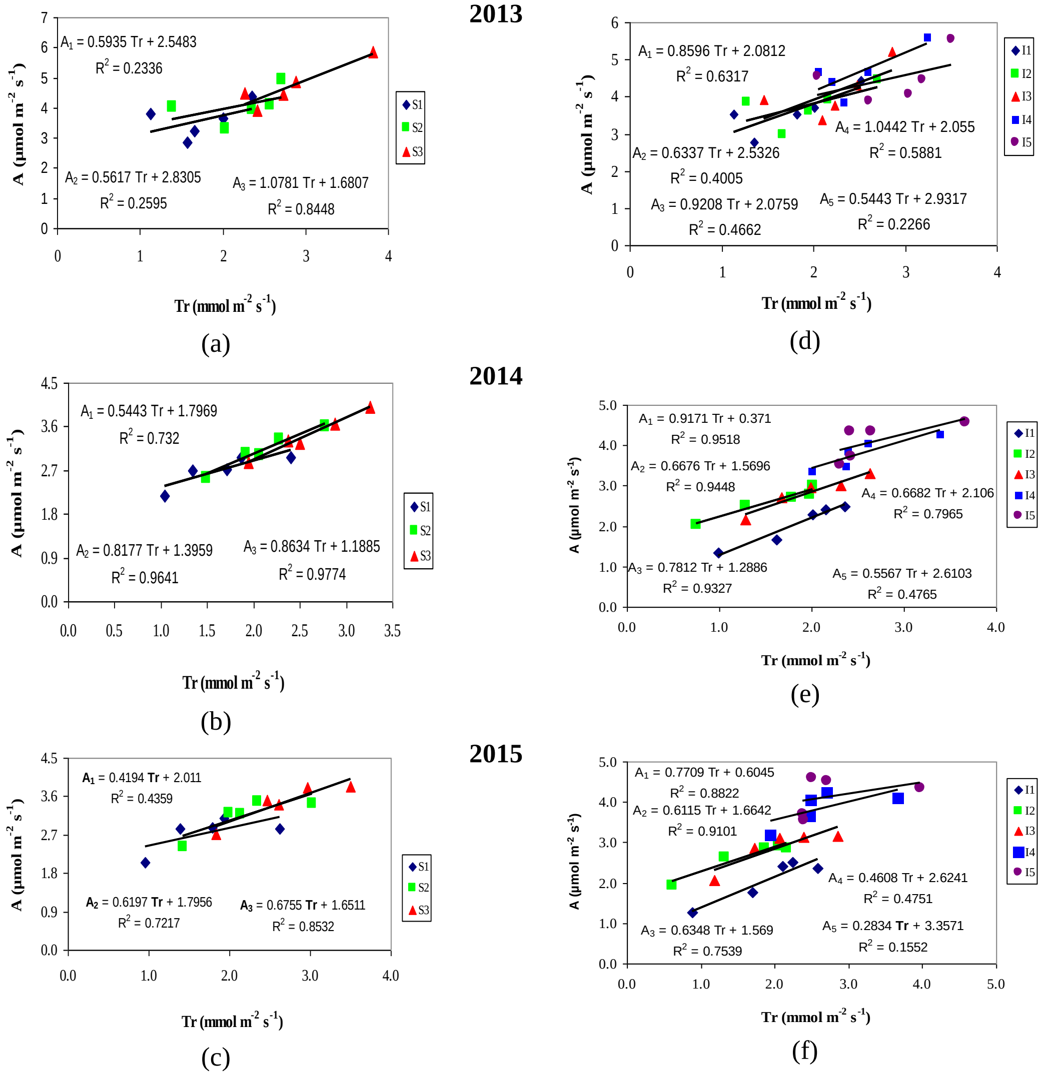


Figure 7. Relationship between average photosynthesis (A) and Transpiration (Tr) (n= 5, P≤ 0.05) in various salinity (S1, S2, and S3) and irrigation levels (I1, I2, I3, I4, and I5), based on measurements in five different times (June to November) in 2013, 2014, and 2015.

difference between the slope of the linear regression in I_1 (0.86), I_2 (0.63), I_3 (0.92), I_4 and I_5 showed that their effects was not equal on *TE* or in other words, The difference between the slope of the linear regression in I_1 (0.86), I_2 (0.63), I_3 (0.92), I_4 and I_5 showed that their effects were not equal on TE or in other words, the effect of different irrigation levels on TE is different but the effect of normal irrigation (I_4) was the highest (1.044). but among the different levels of salinity, the effect of S_3 salinity level on *TE* was high. In 2014, (Figure 7 (e)), the most and the least effect of the irrigation level on *TE* was related to I_1 (0.92) and I_5 (0.55), respectively. The difference of the slope of the linear regression showed that the effect of the I_2 and I_4 irrigation levels on *TE* was equal or in other words, their difference was not significant. However, in other levels of irrigation, the differences were significant. In 2015, Figure 8 (f), like the year 2014, the irrigation levels of I_1 (0.77) and I_5 (0.28) had the highest and lowest effect on *TE*, respectively. The difference between slopes of the linear regression was significant for all levels of irrigation. The effect of I_2 (0.61) and I_3 (0.63) irrigation levels on *TE* was

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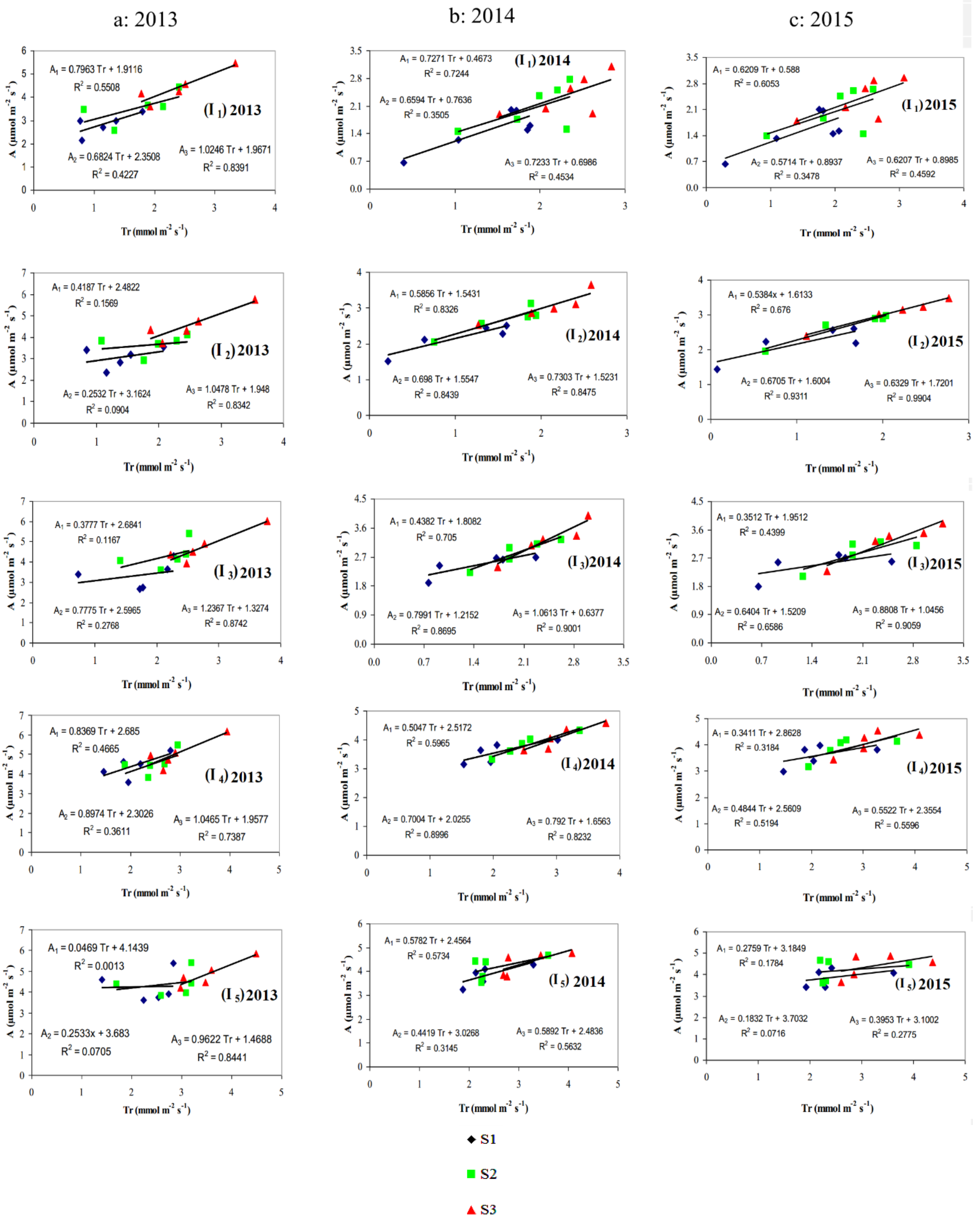

Figure 8. Relationship between photosynthesis (A) and Transpiration (Tr) (n=5, P≤ 0.05) in various salinity and irrigation levels (S_1, S_2, S_3 and I_1, I_2, I_3, I_4, I_5), based on measurements in five different times in: a: 2013, b: 2014 and c: 2015.

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similar, but the effect of other irrigation levels was not similar. Analyzing the effect of different salinity levels on *TE* in the irrigation level of I_1, in 2013 (Figure 8), the least effect was that of S_2 salinity level (with the slope of the regression line equal to 0.68) and the most belonged to S_3 (with a slope of 1.02). However, due to the difference in the fitted lines slopes, the difference in the effect on *TE* was significant ($P< 0.05$) between S_1 (0.79), S_2 and S_3 salinity levels. In other words, the effect of different salinity levels on *TE* was not equal in these two salinity levels. In the I_2 irrigation level, the most and the least *TE* were observed in S_3 (1.04) and S_2 (0.25) irrigation levels, respectively. The differences between the slopes of the fitted lines in all three salinity levels were significant and meaningful. In I_3 irrigation level, the most and the least *TE* were observed in S_3 (1.24) and S_1 (0.37), respectively. The difference between the slope of the fitted lines in S_2 (0.77), S_1 and S_3 salinity levels was high and the effect of different levels on *TE* in this irrigation level was not equal. The most and the least *TE* in I_4 were observed in S_3 (1.04) and S_1 (0.84) salinity levels, respectively. The difference between the slope of the fitted lines in the salinity level of S_2 (0.9) was almost equal with the S_1 and the difference in the effect of the salinity levels on *TE* was not significant. In I_5 irrigation level, the most and the least *TE* were observed in S_2 (0.96) and S_1 (0.05), respectively. The difference between the slopes of the fitted lines was almost high and significant in all salinity levels. As was observed, the most effect on *TE* happened in S_3 salinity level at all irrigation levels. The most and the least *TE* in 2013 were obtained in I_3S_3 (1.24) and I_5S_1 (0.05) treatments, respectively.

According to Figure 8, the irrigation level of I_1 had the least effect with S_2 salinity level (with 0.65 slope of the regression line), but due to the slopes of the fitted regression lines in S_1 and S_3 levels of salinity (both having 0.72), they were the most effective on *TE*. Nonetheless, their differences with S_1 were insignificant. In I_2 irrigation level, the most *TE* was observed in S_3 salinity level (0.73) and the least in S_1 (0.58), and the difference between the slope of the fitted lines was significant and meaningful. In I_3, the highest *TE* was observed in S_3 salinity level (1.06) and the least in S_1 (0.43). The difference between the slope of the fitted lines in S_2 (0.79), S_1 and S_3 was high, and the effect of the different levels on *TE* was not equal in this irrigation level. In I_4 irrigation level, the highest *TE* was observed in S_3 salinity level (0.79) and the least in S_1 (0.50). The difference between the slopes of the fitted lines in S_2 salinity level (0.70) compared with the other two levels was high and the impact difference of the salinity level on *TE* was significant. In I_5, the most *TE* was observed in S_3 salinity level (0.58) and the least in S_2 (0.44). The slopes of the fitted lines in S_1 (0.57) and S_3 salinity levels was almost equal, and the impact of these salinity levels on *TE* was not significant in I_5. As was observed, from I_1 to I_4 irrigation levels, the highest effect on *TE* happened in S_3 salinity level. In 2014, the most and the least *TE* were obtained in I_3S_3 (1.06) and I_3S_1 (0.43) treatments, respectively.

In 2015, like the year 2014, in I_1 irrigation level, the effect of S_1 and S_3 (0.62) on *TE* was equal, with insignificant difference. The most and the least *TE* were observed in S_2 (0.67) and S_1 (0.54) salinity levels, and the difference between the slope of the fitted lines was significant. Like the year 2014, in I_3, the highest *TE* was observed in salinity level of S_3 (0.88) and the least in S_1 (0.35). The difference between the slope of the fitted lines in S_2 (0.64), S_1 and S_3 salinity levels was high, and the impact of the different levels on *TE* was not equal *in* I_3*. In* I_4 *and* I_5 *irrigation* levels, like the I_3, the difference between the slope of the fitted lines in different salinity levels was high and their impact on *TE* was not equal.

As was observed, from I_1 to I_4 irrigation level, the most effect happened on *TE* in S_3 salinity level. The highest and the least *TE* in 2015 were obtained in I_3S_3 (0.88) and I_5S_2 (0.18) treatments, respectively.

CONCLUSIONS

Photosynthesis is one of the first plant processes affected by water stress and salinity. In this process, the sunlight energy is converted by plants and some of the bacteria into the chemical energy stored in nutrients. Under moderate to high salinity conditions, the accumulation of sodium in the olive leaf cause decrease photosynthesis. Low concentration of CO_2 in the chlorophyll of olive leaves in salinity condition is due to the low concentration of CO_2 in stomata and mesophyll and will be one of the factors limiting photosynthesis. In the present research, we investigated the interaction between salinity of the irrigation water and water deficit on physiological growth of the olive plant during three years (2013-2015) in a 7-years-old olive grove (Roghani-Fishomi cultivar). The relationship between water potential of olive stem (ψ_{stem}) and stomatal conductance (gs) showed that the plant reaction to salinity stress and deficit irrigation was due to stomatal closure and, thus, *gs* reduction. Our findings showed that in all three years of study, I_3S_1 had the most effect of salinity and deficit irrigation interaction on Intrinsic Water Use Efficiency (IWUE), while the low water salinity level and the average irrigation level had the highest *IWUE*. Furthermore, in all three years of study, the strongest interaction of salinity and deficit irrigation on transpiration efficiency was observed in I_3S_3 treatment. The I_3 irrigation level had the best *IWUE* and *TE* performance. Generally, for I_1 to I_4 irrigation levels, the highest salinity effect on Transpiration Efficiency (TE) happened in S_3 salinity level.

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برهم‌کنش شوری آب و سطوح مختلف آبیاری بر رشد فیزیولوژیکی زیتون

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چکیده

کشور ایران طی چند سال اخیر بدلیل کمبود بارندگی و یا عدم پراکندگی مناسب بارش با مشکل کم‌آبی روبرو شده است. این امر مناطق حاصلخیزی از جمله استان فارس، بدلیل قطب بودن در تولید گندم و عدم استفاده کافی و مناسب از روش‌های نوین آبیاری و الگوی متناسب با شرایط خشکسالی، بویژه شهرستان مرودشت را با مشکلات زیادی روبرو نموده است که از آن جمله می‌توان به شور شدن و کم شدن منابع آب زیرزمینی بخش مرکزی این شهرستان اشاره نمود. از طرفی، منابع آب زیرزمینی در این شهرستان به شدت مورد

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هجوم مصرف کنندگان قرار گرفته و افت شدید کیفیت و کمبود این منابع را باعث شده است. کشاورزان در راستای مقابله با این امر، اقدام به تغییر الگوی کشت نموده و با کشت گیاهان مقاوم به شوری از جمله کشت زیتون و پسته، سعی در مرتفع نمودن وضعیت پیش آمده نموده‌اند. بنابراین، در این تحقیق، سعی شده است برهمکنش شوری آب آبیاری و کم‌آبیاری بر روی رشد فیزیولوژیکی گیاه زیتون مورد بررسی قرار گیرد. بدین منظور، آزمایش به مدت سه سال (۲۰۱۵–۲۰۱۳)، در باغ زیتون ۷ ساله (رقم روغنی) کشت شده در خاک شنی، با تراکم کشت ۵/۵×۵/۵ متر، در ۵ سطح آبیاری (۲۵، ۵۰، ۷۵، ۱۰۰ و ۱۲۵ درصد نیاز آبی زیتون) و ۳ سطح شوری (S_1، S_2 و S_3) آب آبیاری و با ۳ تکرار در قالب آزمایش فاکتوریل، به صورت بلوک‌های کاملا تصادفی انجام شد. آبیاری درختان با روش قطره‌ای و به صورت روزانه اجرا گردید. نتایج نشان داد که بیشترین و کمترین IWUE در سال ۲۰۱۳، به ترتیب در تیمارهای I_3S_1 (۱۳۱/۹۴) و I_2S_2 (۴۶/۶۶)، در سال ۲۰۱۴ به ترتیب در تیمارهای I_3S_1 (۱۱۴/۱۴) و I_5S_1 (۳۸/۲۹) و در سال ۲۰۱۵ به ترتیب در تیمارهای I_3S_1 (۹۶/۹۵) و I_5S_1 (۳۳/۱۰) حاصل شد. لذا در هر سه سال متوالی، تیمار I_3S_1 بیشترین تاثیر را بر روی IWUE داشته است. بعبارتی سطح پایین شوری و سطح متوسط آبیاری بهترین IWUE را به خود اختصاص داد. یافته‌های این تحقیق در مورد TE نشان داد که در هر سه سال متوالی، بهترین تاثیر برهمکنش شوری و کم‌آبیاری در تیمار I_3S_3 بوده است. در شوری بالا به‌دلیل استرس وارد شده به گیاه، پتانسیل آب برگ کاهش یافته و در نتیجه فشار آب موجود در برگ‌ها کمتر از $VPD_{l.a}$ (کمبود فشار بخار اشباع در سطح برگ) شده و باعث کاهش هدایت روزنه‌ای (gs) و بسته شدن روزنه می‌شود. به‌طور کلی از تیمار I_1 تا I_4 آبیاری، بیشترین اثر بر راندمان تعرق در سطح شوری S_3 اتفاق افتاد.

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