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Optimizing Pistachio Irrigation Management Using the Relationship between Echo-physiological Characteristics and Water Stress

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ABSTRACT

In this research, some of the echo-physiological characteristics of pistachio trees were studied to understand crop response to drought stress and determine the best irrigation interval. This experiment was carried out in an orchard with a sandy loam textured soil and a commercial cultivar of pistachio named Ouhadi grafted on *Pistacia vera L.* rootstock for three years. The irrigation system selected was surface flooding with intervals of 30, 50, 80, and 110 days. These intervals were chosen so as to resemble common irrigation intervals of pistachio orchards in the region. This enabled a comparison between the best and worst conditions of trees in respect to drought stress. Total irrigation water received was a constant depth of water to all treatments. Quantitative and qualitative yield such as weight of fresh and dry nuts, percent of blank and split nuts, and number of nuts per ounce, vegetative and echo-physiological characteristics were considered and measured. In terms of yield quantity and quality, the results showed vegetative and echo-physiological attributes to be significantly different between the treatments of 30, 80 and 110 days irrigation intervals. This means that with an increase in irrigation intervals and considering soil water holding capacity, soils were not able to provide enough moisture for the plant to carry out its normal metabolic activities. However, in the prolonged irrigation intervals, there were not much differences between treatments i.e. the pistachio tree could adapt itself to the naturally occurring environmental stress conditions.

Keywords: Drought stress, Relative water content, Water use efficiency.

INTRODUCTION

The Pistachio tree is a drought resistant fruit specie. As with other trees, irrigation increases the yield, but particularly in pistachio, it also improves the nut quality and dampens the normal alternate bearing pattern (Kanber *et al.* 1993; Goldhamer, 1995). Pistachio plantation areas in the Kerman province (Iran) are faced with the problems of water stress and shortage of water resources as the limiting factor. In these areas, water is the most important factor limiting economic development. The population is constantly increasing and demand for water goes up while the amount of water supply is limited. Therefore, conducting research for improving the utilization of water resources in the areas of pistachio production is needful. Sepaskhah *et al.* (1982) studied one-year-old pistachio seedlings under different irrigation regimes with different salinity and found that with increasing water stress, salinity effects increased. Gholipour and Zamani. (1999) studied the effects of water stress on some basic pistachio rootstocks and concluded the importance of proline as a stress index. Walker *et al.* (1988) studied the effects of water stress and salinity on the Kerman

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pistachio cultivar and results showed that the pistachio response to water stress had the same characteristics as the other xerophytes plants. They found that although the rate of photosynthesis decreased with the decreasing level of leaf water potential, photosynthesis continued until the leaves water potential reached -5 MPa. Studied in terms of turgor pressure (internal pressure of a cell due to water held there by osmotic pressure) and showed that turgor pressure was maintained at very low leaf water potential condition, which is a rare phenomenon in woody trees (Behboudian, *et al.* 1986). Palma and Novello (1998) studied the effects of drip irrigation on gas exchange of Larnaka pistachio cultivars and found that irrigation with 50 percent of reference crop evapotranspiration (Etc) had the highest water use efficiency and photosynthesis. Phene *et al.* (1987) found that in mature pistachio trees growing in shallow soils, a reduction in irrigation of 50 percent of the crop evapotranspiration (ETc) during pit hardening (stage II) had no effect on final yield. Within Pistacia genus, some investigations have been carried out to evaluate seasonal changes of net carbon assimilation and chlorophyll content and to assess the rates of net carbon assimilation, stomatal conductance, transpiration, and related parameters in *P. vera* L. (Vemmos, 1994; Novello and de Palma, 1995; de Palma and Novello, 1996).

Studies on leaf gas exchanges properties allow a direct evaluation of the physiological responses to the environmental conditions, which can have an influence on the potential productivity of crop plants (de Palma and Novello, 1996). Unlike other woody species, few studies have investigated photosynthetic responses in nut crops under water stress condition, especially in *P. vera* L. Some researches have been carried out to assess the photosynthesis characteristics in seedlings or in one cultivar (Lin *et al.* 1984; Vemmos, 1994; Novello and Palma, 1995). De Herralde *et al.* (2003) reported that leaf photosynthetic activity can be used as a helpful means to classify tolerable plants under drought stress. Gomes-Laranjo *et al.* (2006) showed that there was an important correlation between irrigation and gas exchange activities, which can be suitable to find drought resistant crops. Wang *et al.* (2007) demonstrated that gas exchange activities strongly change under different environmental temperatures. Flexas *et al.* (2001) reported the positive correlation between photosynthesis and stomatal conductance in pistachio trees. David (2002) found a positive correlation between photosynthesis and evapotranspiration in olive trees. Moreover, it was shown that low relative water content strongly reduced photosynthesis, stomatal conductance, and evapotranspiration activities in olive trees (David, 2002).

The aim of this article is to provide the results of a research carried out using some echo- physiological characteristics such as chlorophyll fluorescence and gas exchange and photosynthesis parameters of pistachio trees to understand crop response to drought stress as well as to determine the best irrigation intervals.

MATERIALS AND METHODS

The experiment was conducted during 2004-2008 in a 16 year-old pistachio (*Pistacia vera* L. cv Ouhadi on *Pistacia vera* cv. Badami L. rootstock) orchard at the Station No. 2 of Iran's Pistachio Research Institute (30º 32' N, 56º 1' E; altitude 1,240 m). Prior to the project implementation, irrigation water and soil samples were prepared. The results are presented in Tables 1 and 2.

Volumetric soil moisture contents at field capacity (FC) and permanent wilting point condition (PWP) were 15.38% and 7.14 %, respectively. Based on the bulk density of soil (1.45 g cm^{-3}), soil moisture content based on dry weight for both *FC* and *PWP* were 10.6% and 4.92 %, respectively. The experiment started when vegetative bud growth started in the first week of March of

Table 1. Some chemical characteristics of water used in the experiment.

SAR[a]	Amount of element (Meq L^{-1})				pH	EC
	Na^{+1}	Mg^{+2}	Ca^{+2}	Cl^{-1}		dS m^{-1}
5	12.4	5.6	6.8	20	7.6	2.5

[a] sodium adsorption ratio.

Table 2. Some chemical and physical properties of the experimental soil.

Soil depth (cm)	pH	ECe dS m^{-1}	SAR[b]	Clay (%)	Silt (%)	Sand (%)	Soil texture class
0-40	8.1	3.8	6.4	4.4	7.4	82.2	SL[a]
40-80	8.2	3.1	4.6	6.4	13.4	80.2	SL
80-120	8.2	4.5	3.7	4.4	13.4	82.2	SL
Average	8.2	3.8	4.9	5.1	11.4	83.5	SL

[a] Sandy Loam, [b] sodium adsorption ratio.

each year. A randomized complete block design (RCBD) was used with four treatments (irrigation interval) including T_{30}: 30 days, T_{50}: 50 days, T_{80}: 80 days, and T_{110}: 110 days. Irrigation intervals were selected based on the common irrigation intervals of pistachio plantations practiced in the Rafsanjan area. The amount of water used for treatments was applied based on estimates of water requirements for pistachio in Rafsanjan by Farshi *et al*. (1997) (Table 3).

For each block, twenty branches were selected and, before each irrigation treatment, the amount of vegetative growth (length and diameters), leaf area, abscised bud percent, *Fv/Fm*, net photosynthesis rate, transpiration rate, stomatal conductance, leaves temperature, and stomata density in lower part of leaves were measured. The amount of soil moisture up to a depth of 120 cm and in the range of 0-40, 40-80 and 80-120 cm below the tree canopy and before each irrigation treatment were measured by soil sampling. At the end of the growing season and harvesting time, in the selected branches, leaf area, fresh and dry weight of leaves, leaf relative water content (RWC), chlorophyll a, b, and total, yield, percentage of nut splitting, blank nut, total dried and fresh weight were measured in each treatment and block. Based on planting density (925 trees per hectare), amount of water consumed, and the amount of dry product, water use efficiency (WUE) was determined for each treatment and for every year of the experiment. In late July and early August, for each treatment and block, leaf samples were obtained in order to measure the effects of water stress on leaf nutrient concentration.

Chlorophyll fluorescence of fully-expanded leaves, near those for gas exchange measurement, was measured using a portable plant efficiency analyzer (PEA, Hansatech, King's Lynn, UK). *Fo* (minimal fluorescence), *Fm* (maximal fluorescence), *Fv* (variable fluorescence), and *Fv/Fm* (maximal photochemical efficiency of PS2) were measured immediately after keeping the leaves for 10 minutes in the dark.

The chlorophyll content of the leaf was estimated spectro-photometrically in a known aliquot 80 percent acetone extract.

Table 3. The amount of water requirement in the Rafsanjan Pistachio plantation area and in different months based on flood irrigation (Farshi *et al*., 1997).

Month	April	May	June	July	August	September	October	November	Total
Water requirement (mm)	44.8	66	109.4	131.7	132.1	112.2	75.4	19.4	691

The absorbance was measured at 645 and 663 nm for the estimation of chlorophyll a, chlorophyll b and total chlorophyll. The following formulae suggested by Mackinney (1941) were used for the estimation of different fractions of chlorophyll:

Chlorophyll a= 12.7 (Abs. at 663 nm)-2.69 (Abs. at 645 nm)×V/1000 ×W

Chlorophyll b= 22.9 (Abs. at 645 nm)-4.68 (Abs. at 663 nm)×V/1000 ×W

Total chlorophyll= 20.2 (Abs. at 645 nm)+8.02 (Abs. at 663 nm)×V/1000×W

Where, *Abs*= Absorbance; *V*= Final volume of chlorophyll extract (mg), *W*= Fresh weight of the leaf extract (g).

The relative water contents (RWC) of leaves were determined by weighing ten leaf discs immediately after sampling. One centimeter-diameter discs were punched with a sharp borer from each treatment. The discs were then floated for four hours in covered petri dishes in a room at 20°C under lights near to the compensation point. The discs were then surface dried with filter paper and reweighed to obtain the turgid weight. Finally, the leaf discs were oven-dried at 85°C for three hours and weighed for the dry weight. The relative water content was calculated using the following equation (Yamasaki and Dillenburg, 1999):

RWC(%)= (FW-DW)/(TW-DW)×100

Where, *FW* is leaf fresh weight at the time of sampling, *DW* is leaf dry weight, and *TW* is the turgid weight.

Gas exchange and photosynthesis parameters (Net photosynthesis rate, transpiration rate, stomatal conductance, and leaves temperature) were measured using an LCA-4 Portable Photosynthetic System (ADC, Hoddesdon, England). The measurements started from 10:00 when photosynthetic photon flux density (PPFD) was above saturating irradiance and stopped at 12:00 (to avoid high irradiation stress). Conditions for measurements were ambient CO_2 concentration (Ca) of 350 μmol mol^{-1}, vapour pressure deficit (VPD) of 2.0±0.4 KPa, leaf temperature of 35±0.26°C, and PPFD of 1,800±42 μmol m^{-2} s^{-1}.

To count the number of stomata on the leaf surface, nail polish (electric nail) was used by completely covering the upper surface of the leaves and, after having been left to dry for a few minutes, the varnish layer was covered with adhesive tape and location been removed and was placed on a slide. Counting the number of stomata on the underside of leaves was done using Olympus light microscope with a magnification of 1,000.

Soil samples were air-dried in the laboratory, then ground and sieved through a 2 mm sieve. The soil pH was determined in a saturated paste by a glass electrode. The electrical conductivity (EC) was measured in the saturated extract. The exchangeable cations (Ca^{2+} and Mg^{2+}) in the soil sample were determined by atomic absorption spectrophotometer (AAS, Perkin-Elmer, 047-1705), whereas K^+ and Na^+ were measured by flame spectrophotometer. The soil solution data (Na^+, Ca^{2+}, Mg^{2+} given in cmolc kg^{-1}) was used to calculate the sodium adsorption ratio (SAR), where $SAR= Na^+ \ [(Ca^{2+}+Mg^{2+})/2]^{-0.5}$. Available P was determined colorimetrically. Dried plant tissue was digested in a concentrated nitric/perchloric acid (2/1, v/v) mixture, and Na, K, Ca, Mg, Fe, Mn, Cu, and Zn contents were measured by atomic absorption spectrophotometry. Phosphorus was measured by the molybdenum blue method.

All statistical analyses were done using MSTATC software (Michigan State University, USA) and the means were compared using Duncan's Multiple Range Test.

RESULTS

According to the results indicated in Table 4, changing irrigation interval from 30 to 50 days showed no significant differences in growth rates; however, changing irrigation interval from 30 to 80 or 110 days significantly reduced shoot growth rate to a considerably low rate. Thirty -day irrigation had the highest growth rate (13.83 cm) and

Table 4. Mean values of growth characteristics and qualitative and quantitative traits of pistachio in different treatments.

Measured traits	Irrigation treatments[a]			
	30 days (T30)	50 days (T50)	80 days (T80)	110 days (T110)
Branch current year growth (cm)	13.83 a	11.64 ab	11.08 b	10.78 b
Branch diameter of the middle part of the current year (mm)	6.29 a	6.35 a	6.39 a	6.4 a
Percentage of inflorescence buds abscission	40.09 b	46.1 ab	54.59 a	54.25 a
Percentage of vegetative buds	27.18 a	25.49 a	29.22 a	28.27 a
Product fresh weight (kg tree^{-1})	2.79 a	2.25 b	1.86 b	1.82 b
Product dry weight (kg tree^{-1})	0.96 a	0.77 b	0.63 c	0.63 c
Percentage of blank nut	10.69 c	13.74 b	16.14 a	17.26 a
Percentage of dehiscence nut	71.36 a	58.68 b	57.53 b	58.01 b
Number of nut in ounces (No. nut per 28.35 g)	32.28 b	33.82 ab	34.53 a	34.78 a
Water use efficiency (Kg product m^{-3} consumed water)	0.131 a	0.105 b	0.086 c	0.086 c

[a] Values are means of 6 replicates. Within each row, the same letter indicates no significant difference between treatments at 5% levels of Duncan's Multiple Range Test.

110-day irrigation had the lowest average growth rate (10.78 cm) of the branches. The results on the diameter of the branches showed that there was no significant difference between different treatments. It was also found that with an increased irrigation interval from 30 to 80 and 110 days, the average percentage of inflorescence bud significantly increased. However, irrigation at 80 and 110 days had the highest percentage of inflorescence buds abscission and 30-days irrigation had the lowest percentage of inflorescence buds abscission. In the case of vegetative buds results revealed there was no significant difference between all treatments. Results also showed that increasing the irrigation interval to more than 30 days had a negative effect on fresh and dry yield, especially in the case of dry product. Irrigation treatments of 30-day had the highest yield (0.96 kg of dry product per tree) and treatments of 80 and 110 days with a mean of 0.63 kg of dry product per tree had the lowest yield. Our results indicate that water stress affects the percentage of blank nuts. The highest percentage of blank nuts belonged to 110 days irrigation interval (17.26%) and the lowest value was for the 30 day treatment (10.69%). Results showed that irrigation intervals of more than 30 days could affect the percentage of dehiscence nut remarkably, as the highest percentage of dehiscence nut belonged to the irrigation interval of 30 days (71.36%) and the lowest one belonged to the 80-day irrigation interval (57.53%). Results regarding the number of nuts in ounce revealed that increases in irrigation interval from 30 to 50 days did not affect the number of nuts per ounce; however, the irrigation intervals of 80- and 110-day affected the mentioned trait remarkably. The lowest number of nuts per ounce belonged to the 30-day treatment (32.28 nuts) and the highest one was for the 110- day irrigation interval (34.78 nuts).

Also, water use efficiency (WUE) was strongly affected by water stress. As is shown in Table 4, even in 50-day irrigation interval, it was observed that there were significant decreases in the amount of *WUE*. Among all treatments, T_{30} with 0.131 kg product m^{-3} consumed water had the highest value of *WUE* and T_{80} and T_{110} with 0.086 kg product m^{-3} consumed water had the lowest *WUE*.

Soil Moisture Status in the Root Zone

Results indicated that with the increase in the irrigation interval, soil moisture was

Table 5. Mean values for soil moisture status in root zone in different irrigation intervals and depth.

Measured traits		Irrigation treatments[a] 30 days (T30)	50 days (T50)	80 days (T80)	110 days (T110)
	0-40 cm	5.81 a	5.41 b	5.28 b	4.26 c
Soil moisture by weight (%)	40-80 cm	7.04 a	6.02 b	5.24 c	4.28 c
	80-120 cm	8.59 a	7.03 b	6.93 c	5.56 d

[a] Values are means of 6 replicates. Within each row, same letter indicates no significant difference between treatments at 5% levels of Duncan's Multiple Range Test.

significantly decreased in all depths (Table 5). Considering the permanent wilting point and field capacity soil moisture content by weight (4.92% and 10.6%, respectively), only in 0-40 and 40-80 cm layers in the T_{110} and before the next irrigation, soil moistures were lower than "permanent wilting point". However, treatments T_{30} and T_{110} were found to be the best and the worst treatments in terms of soil moisture status.

Echo-physiological and Physiological Parameters

As can be seen in the results of this factor (Table 6), between the *RWC* in T_{30} and the other treatments there was significant difference: the leaf relative water content decreased with increasing irrigation intervals. Irrigation in the 30-days interval had the best condition (70.97%) among other treatments. Results of the number of stomata in the upper part of the leaves showed there was no significant difference among treatments. It appears that drought stress may not have an effect on number of stomata in leaves (Table 6). As is indicated in Table 6, effects of water stress significantly reduced leaves chlorophyll content, however, this effect was less severe in the case of chlorophyll b: as irrigation interval increased from 30 days to 50 days, it had no significant effect on the leaves chlorophyll b content. In contrast, total chlorophyll content was significantly of

Table 6. Mean values for traits related to physiological and echo-physiological parameters in different treatments.

Measured traits	Irrigation treatments[a] 30 days (T30)	50 days (T50)	80 days (T80)	110 days (T110)
Leaf relative water content (RWC) (%)	70.97 a	64.64 b	63.41b	63.14 b
Stomata density in upper part of leaves (No. mm^{-2})	198.5 a	196.1 a	197.2 a	197.4 a
Chlorophyll a content (mg g^{-1} fw)	0.924 a	0.765 b	0.684 bc	0.625 c
Chlorophyll b content (mg g^{-1} fw)	0.487 a	0.442 ab	0.407 ab	0.391b
The total chlorophyll content (mg g^{-1} fw)	1.411 a	1.207 b	1.091c	1.016 c
Minimum fluorescence (Fo)	164.7 a	164.4 a	163.8 a	163.5 a
Maximum fluorescence (Fm)	774.8 a	746 c	759.7 b	733.7 d
Variable fluorescence (Fv)	612.2 a	588.3 b	588.3 b	571.1 c
Ratio of variable fluorescence to maximum fluorescence (Fv/Fm)	0.79 a	0.77 b	0.774 b	0.777 b
Transpiration rate (E) (mmol m^{-2} s^{-1})	4.27 a	3.6 b	3.53 b	3.04 c
Leaf temperature (t) (^{o}C)	39.29 d	40.43 c	41. 88 b	42.58 a
Stomatal conductance (gs) (mol m^{-2} s^{-1})	0.054 a	0.05 b	0.042 c	0.043 c
Photosynthesis rate (Pn) (µmol m^{-2} s^{-1})	4.8 a	4.39 b	3.87 c	3.57 c

[a] Values are means of 6 replicates. Within each row, same letter indicates no significant difference between treatments at 5% levels of Duncan's Multiple Range Test.

higher intensity and irrigation of more than 30 days had a negative effect on this parameter. The results of chlorophyll fluorescence components (except Fo) were strongly affected by drought stress, however, *Fm, Fv*, and *Fv/Fm* decreased remarkably with increasing the irrigation interval (Table 6). Transpiration rates also decreased with an increase in irrigation intervals. The highest and lowest transpiration rates were for 30 and 110-day irrigation interval, which were 4.27 and 3.07 mmol m^{-2} s^{-1}, respectively (Table 6). Our results also showed that with increasing irrigation intervals leaf temperature was significantly increased. T_{30} and T_{110} with leaf temperature of 39.29 and 42.58°C showed the minimum and maximum leaf temperatures, respectively (Table 6). Increasing irrigation intervals also caused significant decreases in stomatal conductance (gs). The maximum and minimum stomatal conductance belonged to T_{30} and T_{80} (0.054 and 0.042 mol m^{-2} s^{-1}), respectively, however, there was no significant difference between T_{80} and T_{110} (Table 6). The photosynthesis rate (Pn) also showed the same trend as stomatal conductance and decreased in drought stress conditions. T_{30} and T_{110} with an average photosynthesis rate of 4.8 and 3.57 μmol m^{-2} s^{-1} had the highest and lowest rates of photosynthesis, respectively (Table 6).

Soil Chemical and Mineral Nutrient

Effect of different treatments on soil chemical and mineral nutrient concentration is shown in Table 6. Available phosphorus, calcium, and magnesium in the soil in different treatments were not significantly different. Lowest *EC*, pH, and *SAR* were 2 dS m^{-1}, 7.78, and 2.37, respectively, which related to T_{30} treatment. The highest amounts of these three parameters were 2.57 dS m^{-1}, 8, and 3.74, respectively, and belonged to T_{110} treatment. Meanwhile, in most cases, T_{30} treatment had significant differences with other treatments (Table 7). Results of drought stress on soil available potassium showed that, with increasing irrigation intervals, available potassium increased in soil. Also, sodium increased in the soil as irrigation interval was increased more than 30 days (Table 7).

Leaves Mineral Nutrient Concentration

Results revealed that leaves concentration of phosphorus, potassium, zinc, and copper

Table 7. Results of soil chemical and mineral nutrient concentration (40 to 80 cm depth) of different treatments.[a]

Treatments	EC (dS m^{-1})[b]	pH	SAR[c]	K (mg kg^{-1})	P (mg kg^{-1})	Ca^{2+} (meq L^{-1})	Mg^{2+} (meq L^{-1})	Na^{+} (meq L^{-1})
T30	2.00 b	7.78 c	3.37 b	464.0 c	5.67 a	7.63 a	5.33 a	6.00 b
T50	2.32 a 2	7.95 ab	3.92 a	567.8 b	5.50 a	7.00 a	5.33 a	9.72 a
T80	2.57 a	7.85 bc	3.48 a	597.5 ab	6.17 a	8.33 a	6.58 a	9.48 a
T110	2.57 a	8.00 a	3.74 a	620.3 a	6.17 a	8.17 a	6.42 a	10.08 a

[a] Values are means of 6 replicates. Within each row, same letter indicates no significant difference between treatments at 5% levels of Duncan's Multiple Range Test; [b] Electrical Conductivity, [c] Sodium Absorption Ratio.

Table 8. Results of leaf nutrient concentration in different treatments[a].

Treatments	P (%)	K (%)	Ca (%)	Mg (%)	Fe (ppm)	Zn (ppm)	Mn (ppm)	Cu (ppm)
T_{30}	0.31 a *	1.53 a	3.10 b	0.88 ab	163.2 b	11.57 a	63.67 a	19.83 a
T_{50}	0.31 a	1.52 a	4.00 a	0.73 b	164.8 b	11.3 a	49.67 bc	19.10 a
T_{80}	0.34 a	1.35 a	4.12 a	1.10 a	181.2 a	11.63 a	52.00 b	19.07 a
T_{110}	0.32 a	1.3 a	4.22 a	0.83 b	181.8 a	11.58 a	44.00 c	18.32 a

[a] Values are means of 6 replicates. Within each row, same letter indicates no significant difference between treatments at 5% levels of Duncan's Multiple Range Test.

did not change with an increase in irrigation intervals (Table 8). Calcium and iron increased with increasing the irrigation intervals: T_{30} treatment with 3.1% of calcium and 163.2 ppm Fe had the lowest values, while T_{110} treatment with 4.22 percent of calcium and 181.8 ppm of iron showed the highest value (Table 8). Other measured nutrients did not show a clear trend.

DISCUSSION

Between growth characteristics, only the percentage of inflorescence bud abscission and vegetative growth length were affected by drought due to increased irrigation intervals. With irrigation intervals of 80 and 110 days, reductions of 2.75 and 3.05 cm were observed, respectively, in vegetative growth length. Also, for the same treatments, respectively, 14.5 and 14.16 percent increase in percentage of inflorescence buds abscission were observed. Increasing irrigation intervals from 30 days to 50 days did not significantly affect growth characteristics. Another point in the results was the higher sensitivity of inflorescence bud compared to vegetative bud under drought. Such evidence can be seen in some pistachio orchards in Kerman pistachio plantation areas that have long suffered from draught stress, but just the economic product can be affected while the growth continues. Arji and Arzani (2008) studied the effect of drought stress on physiological, morphological, and biochemical characteristics of some varieties of olive (*Olea europaea L.*) and found that most growth characteristics were affected under water stress. This showed different reactions of plants against environmental stresses such as drought. Therefore, irrigation intervals of 30- and 50-day had the best conditions from the growth traits point of view.

According to the results, all factors of the product quality and quantity were significantly affected by stress due to increased irrigation intervals. Among these parameters, only the number of nuts per ounce of pistachios was not significantly different in T_{50} days compared with T_{30}. On the other hand, dry weight of the product and percent of blank pistachio were affected more than the other traits by increased irrigation intervals. Sedaghati and Alipour, (2005) studied the effect of different irrigation regimes on the percentage of early splitting pistachio and found that increase in irrigation interval from 25 to 45 days increased the percentage of blank pistachios significantly to 4.37%. With respect to soil texture (sandy loam), irrigation intervals of 30 days was the best treatment, because all quantitative and qualitative traits showed significant differences with other treatments. Based on the results obtained about *WUE*, and as the amount of water used in all treatments were similar, higher *WUE* in the 30-day treatment indicated that most water could be used by products.

As mentioned in the results, considering the permanent wilting point and field capacity soil moisture contents by weight in the test site (4.92% and 10.6% wt, respectively), only in 0-40 and 40-80 cm layers in the T_{110}, and before the next irrigation, the soil moisture contents were lower than permanent wilting point. Considering the generally accepted assumption that 75% depletion of the soil available water (i.e. FC minus PWP) is allowable, in our case, this level corresponds to 6.34% moisture content and, accordingly, any moisture below this would cause water stress. In this respect, only the 30-day irrigation interval, soil moisture at depths of 40-80 and 80-120 cm (depth of root development in pistachio trees) is above this level. Therefore, in this treatment, moisture stress in the soil did not affect the trees; thus, irrigation should be reduced to 30 days. Shariati (1995) recommended proper irrigation intervals for pistachio orchards using a surface irrigation system, 30-40 days in spring-autumn and 25 days in summer. In another article Samadi (2007) found that the best irrigation interval for pistachio orchards under Kerman climate condition was 40 days in early spring and autumn and 25 days in summer. We conclude that in sandy and sandy loam soil texture, irrigation intervals of more than 30 days, especially in July and August, cause drought stress for pistachio trees. Results show that, except for the number of stomata and minimum chlorophyll fluorescence, all echo-physiological traits are significantly affected by water stress. Water stress also decreased chlorophyll content sharply. Dubey (1997) reported different environmental stresses that cause chloroplasts to broken and decrease in leaf chlorophyll content will be observed and photosynthesis efficiency as well. Chlorophyll fluorescence components, except the minimum fluorescence (Fo), were significantly affected by drought stress. Chlorophyll fluorescence parameters (such as Fo, Fv, Fm and Fv/Fm) are often measured to explain the integrity or health of the photosynthetic apparatus during environmental stress (Krause and Weiss, 1991; Clark *et al*., 2000). Under drought conditions, in general, the mean values of *Fv, Fm,* and *Fv/Fm* decreased, which suggested that the efficiency of the photosystems decreased. This might be attributed to a reduced efficiency of the light-harvesting and antenna complexes to deliver quanta to the reaction centers and a reduced efficiency of those reaction centers to process that energy when delivered, with greater emphasis being on the latter. The general decrease in *Fm* and *Fv* have also been observed in a number of other plants subjected to soil drought e.g. barley, paddy rice, and so on (Li *et al*., 2006; Alejandro *et al*., 2005; Angelopoulos *et al*., 1996). Many researchers agree that the fluorescence emission observed at *Fo* emanates from Chl a molecules located in the antenna, but the source of *Fv* fluorescence is more controversial (Krause and Weis, 1991). The most convincing theory suggests that *Fv* is related to the decay of the primary radical pair P680 $^+$Pchl$^-$ in PSII (Schreiber, 2004). Several potential factors could lead to the reduction of *Fv* and thereby decrease the rate of photosynthesis. Many studies have shown that plants under water stress can degrade the D1 and D2 proteins of the photosystem II (PSII) reaction center, thereby inhibiting the electron transport chain (Giardi *et al*., 1996; He *et al*., 1995). Despite morphological differences between *PRD* (partial root zone drying) and *DI* (Deficit Irrigation) plants receiving the same irrigation volumes, there was no difference in adaptation of the photosynthetic apparatus to the two treatments. Regarding the study of Behboudian *et al.* (1986) as the rate of photosynthesis did not decrease under high water stress, a significant decrease in *Fv/Fm* is expected. The results of the current research were similar to the results of Jian-min *et al.* (2008) and Pirdashti *et al.* (2003). Results also showed that T_{30} treatment had the highest rate of transpiration, which can be attributed to high photosynthesis, and stomatal conductance rate. Reduction in transpiration rate is mainly due to increased leaves temperatures and leaves senescence that occurred under water stress conditions (David, 2002; Flexas, *el al.,* 2001). As can be seen, with increase in irrigation interval from 30 to 50 days, rates of transpiration decreased significantly. This means that, by using specific mechanism such as stomatal closure and reduction in stomatal conductance, plants controlled water exit through the leaves. These mechanisms also reduce the rate of photosynthesis, which can be seen in the results.

Based on the results, drought stress significantly increased leaf temperature. Treatments T_{30} and T_{110} showed the lowest and highest temperatures, respectively. Usually, water and salt stress in plants due to stomatal closure reduces transpiration rate of leaves. Decrease in transpiration rate caused increased in leaf temperature (Flexas *at al*., 2001). Increase in canopy temperature in plant under drought stress may be related to reduced transpiration and relative water content (David, 2002, Flexas *at al*., 2001). Increase in leaf relative water content in T_{30} treatment confirmed the matter. Results showed that there was no significant differences between T_{50}, T_{80} and T_{110} treatments from *RWC* point of view, therefore, it could be concluded that pistachio trees under moderate to severe stress use some special mechanisms, such as closure or reduction in stomatal conductance, to prevent increase in leaf *RWC*.

The results indicated that increases in irrigation interval caused significant decreases in stomatal conductance. The maximum and minimum stomatal conductance were observed in T_{30} and T_{110} treatments, respectively. Research results confirmed direct correlation between photosynthesis and stomatal conductance (Flaxes *et al*., 2001; Proctor, 1981*).* Results indicated that T_{30} and T_{110} treatments had the highest and lowest photosynthesis rate, respectively. Larcher (1969) concluded that although pistachio is a C3 plant, it has a high photosynthetic efficiency, so that the maximum photosynthetic efficiency of pistachio is higher than temperate fruits such as apples, peaches, plums, cherries, apricot, and walnut that are almost equal to almond. Thus, different stresses that cause leaves senescence and broken chloroplasts decreased the chlorophyll content and reduced efficiency of the photosynthetic rate. As mentioned, the available phosphorus, calcium, and magnesium in the soil in different treatments did not significantly increase with irrigation interval, but potassium in the soil increased with irrigation interval. Lowest *EC*, pH, and *SAR* were observed in 30-day irrigation interval showing best salt leaching. Based on analysis of the concentration of leaves phosphorus, potassium, zinc, and copper in different treatments, there was no significant differences, however, water stress increased leaf iron and calcium concentrations, due to increase in leaf area index and decrease in plant dry matter. On the other hand, it seems that higher yield in the T_{30} treatment depleted soil nutrient element supply and, finally, reduced their concentration in leaves. Other nutrients did not show clear trend in leaves.

From the obtained results it can be deduced that in pistachio orchards with sandy to sandy loam- soils and irrigation interval of 30 days, all the growth parameters, product quality and echo-physiological characteristics of trees are in desirable condition. By increasing irrigation interval to 50 days, although the growth characteristics of trees were not affected by water stress, but qualitative and quantitative traits of the products and echo-physiological characteristics significantly decreased by shortage of water. However, the changing of irrigation interval from 50 days to 110 days did not affect growth characteristics. This is evident in the pistachio orchards that have long suffered from water shortage, although the trees cannot produce economic yield, they still continue the growth. However, there were significant differences in leaf relative water content of T_{30} with other irrigation intervals, while no significant difference of these parameters were observed in irrigation intervals of 50 to 110 days, indicating that pistachio trees in moderate to severe stress use special mechanisms such as stomatal closure or reduction in stomatal conductance to prevent from lowering the excessive swelling of leaf cells and leaf relative water content, but, stomatal closure eventually cause negative effects on transpiration, photosynthesis, as well as on qualitative and quantitative parameters. Decrease in quantity and quality of pistachio caused reduction in water use efficiency, which is one of the most important parameters affected by irrigation.

As a conclusion, results showed that yield quantity and quality as well as vegetative and echo-physiological attributes were significantly different among the 30-, 80- and 110-days irrigation intervals. This means that with an increase in irrigation intervals, considering soil water holding capacity, soils were not able to provide enough moisture for the plant to complete metabolic activities. However, in the prolonged irrigation intervals, there were not much differences between treatments i.e. the pistachio tree could adapt itself to the naturally occurring environmental stress conditions.

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مطالعه ارتباط خصوصیات اکوفیزیولوژیکی درختان پسته با تنش آبی برای اعمال مدیریت بهینه آبیاری

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چکیده

در این پژوهش از برخی خصوصیات اکوفیزیولوژیک برای شناخت عکس العمل درختان پسته به تنش آبی و تعیین بهترین دور آبیاری استفاده شد. این آزمایش در یک باغ با بافت خاک شنی لومی و رقم تجاری اوحدی بر روی پایه اهلی و به مدت ۳ سال اجرا شد. آبیاری غرقابی در بلوکهای مختلف با دورهای آبیاری ۳۰، ۵۰، ۸۰ و ۱۱۰ روز انجام گردید. دورهای آبیاری بر اساس دورهای موجود در منطقه انتخاب شد تا به این وسیله مقایسه ای بین بهترین و بدترین وضعیت درختان از نظر تنشهای خشکی داشته باشیم. میزان آب آبیاری برای همه تیمارها یکسان بود. صفات کمی و کیفی محصول نظیر وزن تر و خشک محصول، درصد پوکی، خندانی و تعداد دانه در انس، صفات رویشی و خصوصیات اکوفیزیولوژیکی نیز اندازه گیری شد. بر اساس نتایج طرح در اغلب صفات کمی و کیفی محصول، رویشی و اکو فیزیولوژیک اختلاف بین تیمار دور ۳۰ روزه با تیمارهای دور ۸۰ و ۱۱۰ روزه معنی دار بود. این بدان معنی است که با افزایش دور آبیاری عملا خاک با توجه به گنجایش رطوبتی خود قادر به تامین رطوبت کافی جهت انجام فعالیتهای متابولیکی گیاه نمی باشد. ولی در دورهای بالا اختلاف چندانی بین تیمارها مشاهده نشد که نشان دهنده این مطلب است که گیاه تحت تنش تا حدی خود را با شرایط محیطی سازگار می سازد.