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Peach response to water deficit in a semi-arid region

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Abstract. During three years a deficit irrigation experiment was performed on peach response under the semi-arid conditions of south-eastern Romania. Three sprinkler-irrigated treatments were investigated: fully irrigated, deficit irrigation treatment, and non-irrigated control treatment. Soil water content ranged between 60 and 76% of the plant available soil water capacity in fully irrigated, between 40 and 62% in deficit irrigation treatment, and between 30 and 45% in control. There were significant differences in fruit yield between the treatments. Irrigation water use efficiency was maximum in deficit irrigation treatment. Fruit yield correlated significantly with irrigation application. Total dry matter content, total solids content and titrable acidity of fruit were significantly different in the irrigated treatments *vs*. the control. Significant correlation coefficients were found between some fruit chemical components. For the possible future global warming conditions, when water use becomes increasingly restrictive, deficit irrigation will be a reasonable solution for water conservation in regions with similar soil and climate conditions.

Keywords: soil water content, irrigation water use efficiency, fruit yield, fruit quality

INTRODUCTION

Regulated deficit irrigation (RDI) and deficit irrigation (DI) have been used in various agriculture experiments. In horticultural crops, such studies were carried out during both pre-harvest and post-harvest stages. RDI assumes imposing moderate reduction in irrigation water amount during some non-critical stages of tree development and preserving fruit yield and quality (Behboudian and Mills, 1997; Chalmers *et al*., 1981). DI is an optimization strategy in which irrigation is applied during drought-sensitive growth stages of a crop, resulting in plant drought stress, production loss, but maximising irrigation water productivity (English, 1990); DI is actually applied to the whole crop season in both sensitive and non-sensitive periods, but emphasis is put on the first. Some authors have emphasised water relations and plant measurements in fruit growing RDI; for instance, Shackel (2011), working with various fruit trees, reported that the management of irrigation to achieve benefits of RDI is difficult without a reliable plant-based measure of stress, like midday stem water potential, stomatal conductance, vegetative growth, fruit growth and composition, such as soluble solids.

The idea of saving water and increasing irrigation efficiency with decreasing irrigation water application was confirmed by English and Raja (1996). Other authors have also reported that in arid regions, irrigation should increase water use efficiency and decrease the impact on the environment, preserving soil and water quality (Dichio *et al*., 2011). In the short term, DI leads to water saving without yield loss (Fereres and Soriado, 2007; Naor, 2006), while in the long-term fruit yield can be reduced due to the cumulative effects on trees (Intrigliolo *et al*., 2005). Domingo *et al*. (2011) studied RDI in various stages in peach and reported 13 to 16% irrigation water savings and an increase in soluble solids concentration, combined with some drawbacks like a decrease in trunk growth and fruit yield and size. Among the scientists dealing with irrigated peach and detailed aspects of water stress one can mention the contribution of Abrisqueta *et al*. (2008), Bryla *et al*. (2005), Caruso *et al*. (2001), Chalmers *et al*. (1981), Gibert *et al*. (2007). Other authors brought new ideas into the field of water stress (Girona *et al*., 2005; Glenn *et al*., 2006; Goldhamer *et al*., 2002; Mitchel and Chalmers, 1982; and Naor *et al*., 2001). The most recent paper cited here for this field is by Vallverdu *et al*. (2012).

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However, most of the studies were carried out in the Mediterranean regions or climate which differ substantially from the temperate zone climate. The trend of recent global changes in both reference and crop evapotranspiration has recently been emphasised in the region by Paltineanu *et al*. (2011; 2012). The authors have shown the increasing risk in aridization and recommended measures of water conservation.

The purpose of this study was to analyze the influence of continuous deficit sprinkler irrigation on fruit yield amount and quality parameters in peach grown in the semi-arid, temperate-climate.

MATERIAL AND METHOD

The study was performed in the 2009-2011 growing seasons. The studied orchard is located in Valu lui Traian commune, Dobrogea, Romania. This is a semi-arid region with a climatic water deficit (WD), calculated as a difference between annual precipitation (P) and Penman-Monteith reference evapotranspiration (PM-ETo) (Monteith, 1965) ranging from about -400 mm on the Black Sea costal area to -320 mm (Paltineanu *et al*., 2007b).

The climatic data: solar radiation, air temperature, relative humidity, wind velocity at the height of 2 m, precipitation (P) and PM-ETo were recorded by an automatic weather station (WatchDog Weather Station 2000) with 1 h step. The climate conditions at the experimental site are characterized by a mean annual temperature of 10.7°C and a mean annual precipitation of 409 mm, not uniformly distributed across the year (Paltineanu *et al*., 2007a); for the whole year the PM-ETo totals 778 mm. In springtime, late frosts mainly occur during late April, as it happened in 2010 and more severely in 2011, and those weather events caused fruit damage. The year 2011 was also characterised by a dryer than usual summer. The soil is a calcareous chernozem with a loamy texture and alkaline reaction. Land slope is 2.0-2.5% and soil bulk density ranges from 1.18 to 1.25 g cm^{-3}.

Experimental design and irrigation application refer to the peach tree (*Prunus persica* (L.) Batsch) which was selected for this study as one of the most cultivated fruit tree species worldwide and in the southern part of Romania. The Southland cultivar was grafted on franc rootstock, and 16-18 years old fruit trees were planted in a 4 x 3 m scheme with NS row orientation. The soil management system was represented by clean cultivation both between tree rows and in the row.

The experiment design was based on the split-plot method with three treatments: T1 – fully irrigated according to the irrigation needs calculated with the help of ETc (PM-ETo multiplied by Kc according to Allen *et al*. (1998) as previously described for the region by Paltineanu *et al*. (2007a), and irrigation application was carried out when soil water content (SWC) was about to reach the mid-interval between field capacity (FC) and wilting point (WP), *ie* the management allowed deficit (MAD) or critical depletion level, T2 – a deficit irrigation treatment irrigated with half the amount of water in T1 and almost simultaneously applied with that one, and T3 – control, a non-irrigated treatment. Sprinkler irrigation was applied using a 12 x 18 m grid scheme, pressure of about 0.3 MPa at the sprinkler nozzle which was 7 mm in diameter, giving 7.4 mm h^{-1} application rate as measured in catch cans placed in a 1 m grid, and infiltration occurred without ponding. The irrigation uniformity was acceptable and the coefficient of variation was around 20%.

These plots comprised three adjacent fruit tree rows, with the central row containing five trees for measurements. In addition to ETc, SWC dynamics and soil water matric potential, the weather forecast was also considered in irrigation scheduling in T1.

Soil water matric potential and SWC were measured weekly with Watermark resistance blocks (6450 Watermark Soil Moisture Sensor) installed on the rows in two replicates for each fruit tree at four depths: 20; 40; 60 and 80 cm at 1m distance from the tree trunk. Data were recorded by WatchDog dataloggers and downloaded periodically by a laptop. The relationship between soil water matric potential measured with Watermark sensors and SWC measured gravimetrically was previously determined from field data only when drying, to minimise hysteresis. This field calibration was then applied to soil matric potential readings done every 30 min during the experiment in order to estimate SWC values. In T3, SWC was only measured on some occasions gravimetrically, because its low values were usually out of the watermark soil moisture sensor range.

Fruit yield quantity and quality were determined at harvest, which usually occurred around the 10th of August, including the experiment years, with differences of maximum one week from year to year. In 2011, twenty fruits per tree were sampled for chemical tests made in the laboratory with the help of classic methods: total dry matter content and ash content by the gravimetric method, total soluble solids content by the refractometric analysis (degrees Brix), titrable acidity by the titrimetric method, total solids content by the Fehling method.

Analysis of variance and regression were used to process the results obtained in this experiment by using SPSS 14 and MS Excel.

RESULTS AND DISCUSSION

Climatic and Penman-Monteith reference evapotranspiration (PM-ETo) data for the irrigation period are described for 10-day intervals. Data for PM-ETo, optimum T1 crop evapotranspiration (ETc) obtained by multiplying PM-ETo with Kc values reported by Paltineanu *et al*. (2007a), precipitation (P), irrigation depth (I) and climatic water deficit

(DEF=P–PM-ETo) are presented in Fig. 1(a,b,c). It can be noted that 2011 was the driest during the summer months; however, negative DEF values existed in each month during the irrigation application time (late May through early August). The totals of PM-ETo, ETc, P, DEF and irrigation application (I) for T1 determined during the irrigation period are shown in Fig. 1 d. One can note that the biggest DEF value (240 mm) occurred during the above period in 2011.

However, the climatic conditions during the three years were varied, with extreme rainfall events during some days in July in first two years, and a dry growing season in last one.

Dynamics of SWC in all the treatments studied is seen in Fig. 2. SWC generally varied between about 30 and 80% of the plant available water capacity (AWC) in the irrigation period for this crop in the region. SWC decreased, as expected, from T1 to T3. There were higher differences between treatments for SWC values in the driest periods (2011). On average, SWC ranged between 60 and 76% of AWC in T1 and these values justified the fact that T1 was practically non-stressed, between 40 and 62% in T2, and between 30 and 45% in T3, in the three years of research. Standard deviation over the bars of the graph shows that the mean SWC variation was generally lower in T1 and higher in T3.

Fruit yield and irrigation water use efficiency in the treatments studied can be viewed in Fig. 3. Under the semi-arid conditions of Dobrogea during the three years of study, fruit yield was maximum in T1 followed by T2, and T3, (Fig. 3a). Following the results obtained by analysis of variance, it was found that there were significant differences between T1 *vs*. T3 in all the years, and also between T2 and T3 in 2009 and 2010, and close to significant in 2011. However, fruit yield was higher in T1 *vs*. T2 by about 110 to 116% during the 2009-2011 growing seasons, but these differences were not significant due to large standard deviation values within each treatment, respectively. In turn, fruit yield in T2 was much higher than in T3, by 125-183%, with two significant differences out of three years. Finally, T1 exceeded T3 by 144-210% being always significant.

There were also large differences between the same treatment values obtained in different years *eg* between 2009 and 2011 for both T1 and T2, respectively. These differences, which could be explained by climate factors of the previous year or current year, such as late freezing, have produced various bud differentiation levels and frost damage, respectively. Another explanation of the decreasing yield could be orchard ageing or other unknown factors.

Irrigation water use efficiency (IWUE), calculated as the ratio between yields obtained in the irrigated treatments (T1 and T2, respectively) minus yield from the control treatment (T3), all divided by the irrigation water amount, is depicted in Fig. 3b. The deficit irrigation treatment (T2) showed higher IWUE values, ranging from 50 to 212 kg mm^{-1} of irrigation water, *vs*. the non-stressed treatment T1 (with 43-144 kg mm^{-1} of irrigation water). These results are consistent with others used worldwide (Fereres and Soriano, 2007).

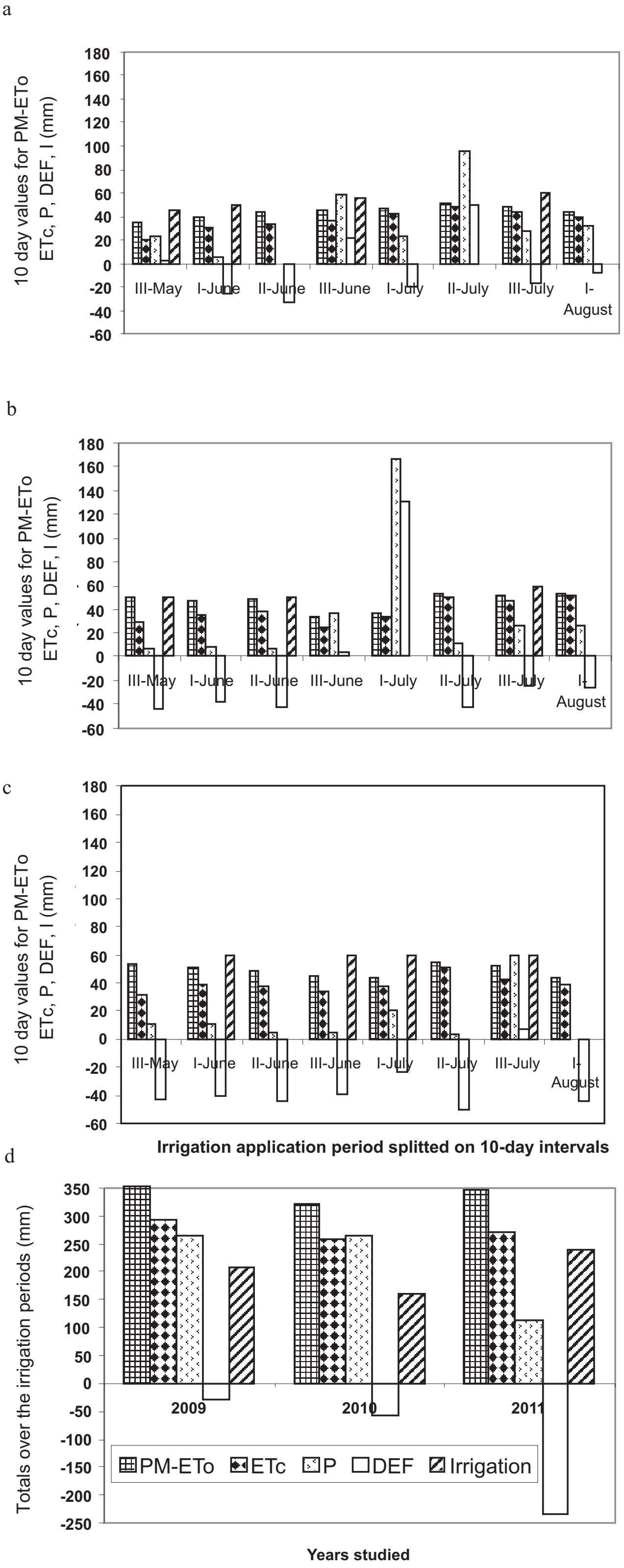

Fig. 1. 10-day values for PM-ETo, ETc, P, DEF and I – irrigation application for the non-stressed treatment determined during the irrigation period (T1) in: a – 2009, b – 2010, c – 2011, d – as well as their annual totals.

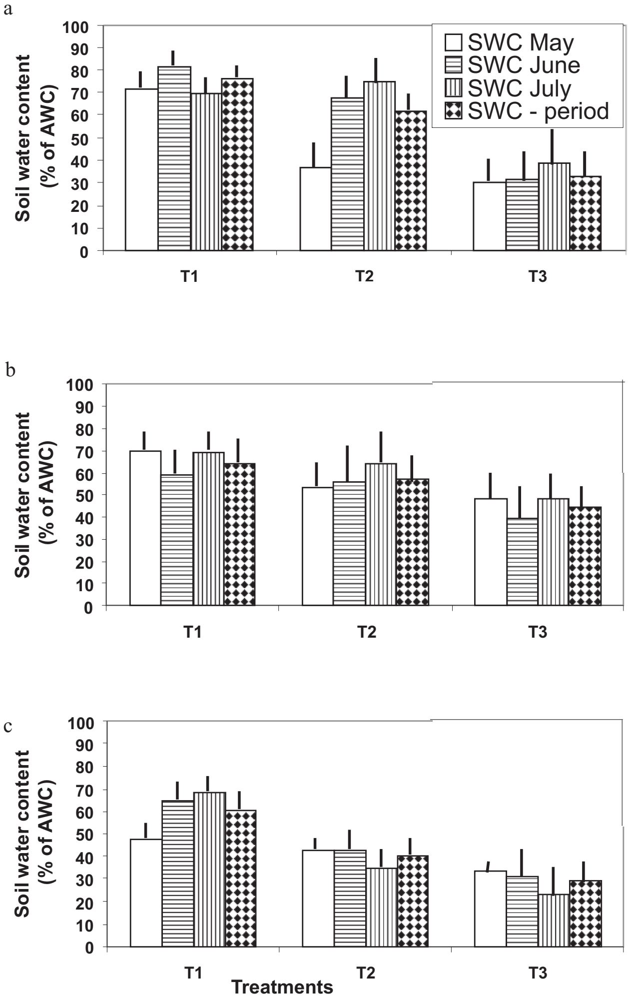

Fig. 2. Dynamics of soil water content (SWC) average values over the 0-80 cm soil depth in the studied treatments during the whole irrigation period: a – 2009, b – 2010, c – 2011; AWC – total plant available soil water capacity, in the graphs above 0% means wilting point (WP) and 100% means field capacity (FC); thin vertical bars mean standard deviation for SWC.

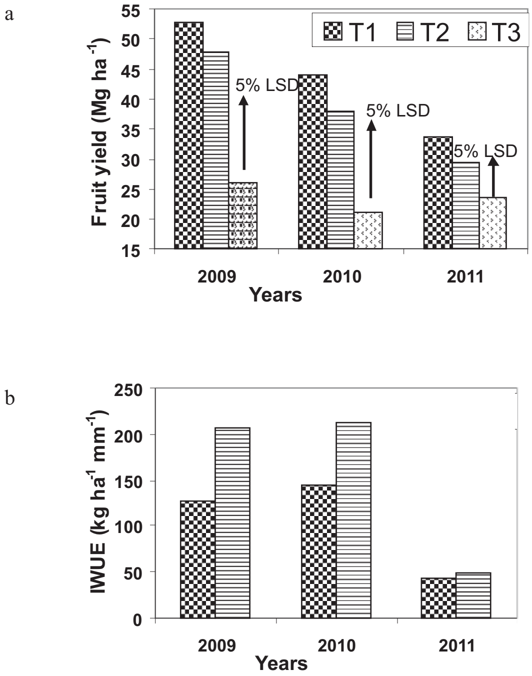

Fig. 3. Fruit yield (a) and IWUE – irrigation water use efficiency (b) in the treatments studied, 2009-2011. LSD – least significant differences for p<5%.

The lower yield of the third season, attributed to late frost damage, is the cause of that important drop in IWUE for that year. These results suggest that irrigation application increases fruit yield, but within the context of global warming, when use of water resources may become increasingly limited, application of irrigation water to maximize yield may not be a viable solution. Using irrigation water more rationally by applying deficit irrigation to peach can produce water savings with an acceptable decline in fruit yield.

Relationship between fruit yield and irrigation application is depicted in Fig. 4. One of the most common things in literature is the frequently published linear relationship between seasonal transpiration rate and seasonal biomass production or a linear relation between photosynthesis rate and transpiration rate. For instance, in this context Hanks and Hill (1980) discussed an approach of modelling crop responses to irrigation in relation to soils, whereas Novák and van Genuchten (2008) reported an empirical relationship between seasonal transpiration and yield for a corn crop (*Zea mays* L.) grown on loess soil in Slovakia. In the present study, there was a highly significant (R^2=0.4619***) curvilinear relationship between peach fruit yield and irrigation application. Under the specific conditions of the region, the convex curve obtained shows the peach response to irrigation water, namely that the fruit yield increases with irrigation application to about 180 mm where it reaches a maximum; further on there generally is no increase in yield. This should be considered in irrigation scheduling for this crop in the region. This shape of the graph is similar to others reported abroad for warmer climates (Fereres and Soriano, 2007). If rainfall and irrigation water combined are considered, the relationship with fruit yield is linear and highly significant (R^2=0.5388***). The fruit yield might still increase with water content (Fig. 4). Another approach of the study would be to take into account the relationship between crop water uptake or transpiration and fruit yield.

Unlike the relationship shown in Fig. 4a, where irrigation water infiltrated without ponding and was mainly used as crop water uptake, in Fig. 4b the rain water coming from storms in 2009 and 2010 did not all infiltrate into the soil, and was partly lost by runoff. This situation, combined with the differences in precipitation from the three years and other climatic factors *ie* late freezing, might have caused the shapes of the two graphs.

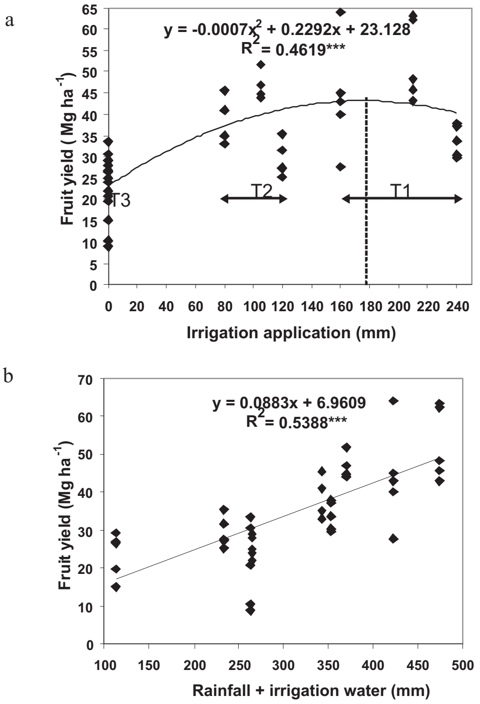

Fig. 4. Relationship between fruit yield and: a – irrigation application, b – rainfall plus irrigation application during 2009-2011; ***$p < 0.001$.

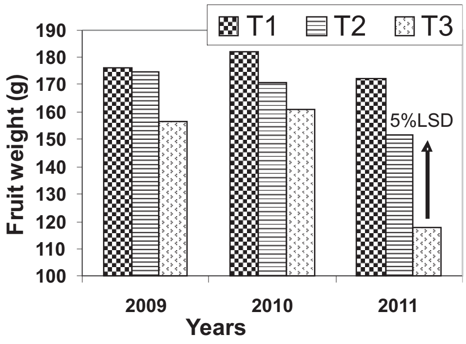

Fig. 5. Average fruit mass in the treatments studied, 2009-2011.

Experimenting in Turkey in near similar conditions, Gunduz *et al*. (2011) found that the effect of irrigation water (drip) on peach yield was highly significant and reported a maximum average yield in the fully irrigated treatment; at the same time they obtained the maximum water use efficiency in the same treatment.

Fruit mass ranged from: 172 to 182, 153 to 176, and 118 to 160 g/fruit, respectively in T1, T2 and T3 (Fig. 5). However, similar to fruit yield, fruit mass showed a certain decrease in the third year of research, more obviously in T3, and this fact could be mainly attributed to the highest DEF value from 2011 or other climatic factors. However, there were three consecutive years with similar fruit mass and decreasing yield. This situation is different than the one reported by Fereres and Goldhamer (1990), when yield decreased and fruit size increased, showing a compensation effect between yield and fruit size. In spite of the big differences in irrigation water, there were no significant differences in fruit mass between the treatments studied, except in 2011, when there was such a difference between the irrigated treatments and the control, respectively. So, it appears that other factors *eg* fruit thinning are also involved in determining fruit mass.

Table 1. Total peach fruit dry matter content, total soluble solids content, total solids content and ash content, as well as the titrable acidity from the treatments studied (2011)

Fruit component	Treatment	Value	5% least significant difference	Significance at 5% probability*
Total dry matter (%, g g^{-1})	T1	11.48	1.45	b
	T2	12.00		ab
	T3	13.15		a
Total soluble solids (° Brix)	T1	12.07	1.26	a
	T2	12.13		a
	T3	12.90		a
Total solids (%, g g^{-1})	T1	9.64	0.96	b
	T2	9.80		b
	T3	11.16		a
Ash content (%, g g^{-1})	T1	0.58	0.25	a
	T2	0.46		a
	T3	0.67		a
Titrable acidity (%, g g^{-1})	T1	0.79	0.09	a
	T2	0.68		b
	T3	0.69		b

*Values with different letters are statistically different at 5% probability.

Fruit quality was expressed by various chemical characteristics (Table 1). The analysis of variance revealed that the total dry matter content was significantly different in the irrigated treatments, with values of 11.5% in T1 and 11.8% in T2, *vs.* the control which showed higher values (13.2%). This difference was peach response to the irrigation regime applied. Values of 9.2-14.0% are specific for peach in the region (Dumitru *et al*., 2009). This finding is consistent with the total soluble solids content, but the value from T3 was not significantly higher than those of T1 and T2.

Table 2. Correlation coefficients (R) and determination coefficients (R^2) of the chemical peach fruit components from all the treatments studied

Chemical fruit component correlated	Total dry matter content (%)	Ash (%)	Total soluble solids content (°Brix)	Total solids content (%)
Total dry matter content (%)	1	0.216	0.691	0.790
Ash (%)	0.465	1	0.163	0.228
Total soluble solids content (°Brix)	0.831***	0.404	1	0.724
Total solids content (%)	0.889***	0.477	0.851***	1

R values are displayed to the left of diagonal 1, and R^2 values to the right, ***means highly significant.

Fruit mass and chemical composition depend not only on irrigation regime, but also on soil properties, fertilization amount, and other environmental characteristics, and of course, on the cultivar studied. For instance, in Turkey under various water deficit conditions, fruit mass for Redhaven cultivar varied from 203 to 253 g and soluble dry matter content ranged between 10.8 and 14.5% (Gunduz *et al*., 2011).

The fruit total solids content was also significantly higher in the non-irrigated *vs*. irrigated treatments, similar to Domingo *et al*. (2011), whereas titrable acidity was significantly higher in the non-stressed *vs*. the other treatments. Values of 0.31-0.94 % are common for peach in the region (Dumitru *et al*., 2009). No clear trend was noted for the ash.

There were correlations between the chemical peach fruit components from all the treatments studied and these were shown as both correlation coefficients (R) and determination coefficients (R^2) (Table 2). High, direct and significant correlation coefficients were found between total dry matter and total soluble solids content, between total dry matter and total solids content, and between total soluble solids content and total solids content. For these correlations, R^2 ranged between 69 and 79%.

Dichio *et al*. (2004), investigating various water stress levels in peach by varying irrigation water from 25 to 100% of the maximum crop evapotranspiration, reported no significant differences in fruit yield obtained in the 50% ETc treatment *vs*. 100% ETc treatment, as well as water savings of 100 to 240 mm; however, in the severe stressed treatment (25% ETc) fruit quality decreased significantly. The authors recommended the 50% ETc treatment. Later on, the same author (Dichio *et al*., 2011) emphasised the increased water use efficiency in arid regions. In the same way, Domingo *et al*. (2011) reported important irrigation water savings in deficit irrigation experiments, combined with some drawbacks like reduced fruit yield and size.

In light of the above results, our data on the efficiency of irrigation water, fruit size and fruit yield are consistent with the results of worldwide research, mainly in warmer climates, yet have specificities related to regional characteristics. So, to reduce irrigation water, application of deficit irrigation can be recommended in peach in this region.

CONCLUSIONS

1. Irrigation application substantially increased fruit yield under the conditions of the region. There were significant differences between irrigated and non-irrigated treatments. Fruit yield correlated highly significantly with irrigation application and increased to a maximum of 180 mm; after this irrigation amount there generally was no increase in yield. This finding should be considered in irrigation scheduling for this crop in the region.

2. Irrigation water was used efficiently within the deficit irrigation treatment *vs*. the fully irrigated one, showing important possible water saving.

3. In spite of the big differences in irrigation water used by trees, there were no significant differences in fruit mass between the treatments studied, except in a very dry and hot year when late frost also occurred.

4. Total dry matter content, fruit total solids content and titrable acidity were significantly different in the irrigated treatments *vs*. the control. Significant correlation coefficients were found between some fruit chemical components.

5. For the possible future global warming, when water use becomes increasingly restrictive, deficit irrigation is a reasonable solution for water conservation in this region and similar regions nearby which differ substantially from the Mediterranean climate where this fruit tree is mainly cultivated.

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