Response of a clingstone peach cultivar to regulated deficit irrigation

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ABSTRACT: Regulated deficit irrigation (RDI) involves inducing water stress during specific fruit growth phases by irrigating at less than full evapotranspiration. The objectives of this research were to study the effects of RDI perfomed at stage II of fruit growth and postharvest, on productivity of clingstone peaches, fruit quality as well as photosynthetic rate and midday leaf water potential. The research was conducted in a commercial clingstone peach (*Prunus persica* L. Batch cv. A-37) orchard in Greece. Trees were irrigated by means of microsprinklers and their frequency was determined using local meteorological station data and the FAO 56 Pennman-Monteith method. Photosynthetic rate was measured by a portable infrared gas analyzer. Midday leaf water potential was measured by the pressure chamber technique. During the years 2005 and 2006, the treatment RDII with irrigation applied at growth stage II of the peach tree did not affect productivity, fresh and dry mass of fruits. RDII reduced preharvest fruit drop in comparison to the control. RDII as well as the combined treatment RDII plus RDIP with irrigation applied at postharvest, at both years reduced shoot length of the vigorous shoots inside the canopy. RDII in comparison to the control increased the soluble solids content of the fruits and the ratio soluble solids/acidity. However it did not affect fruit acidity and fruit firmness. RDII as well as RDII plus RDIP in 2006 increased 'double' fruits and fruits with open cavity in comparison to the control and RDIP. Water savings were considerable and associated with the climatic conditions of each year.

Key words: fruit drop, leaf water potential, photosynthetic rate, water savings

Resposta de um cultivar de pêssego com caroço aderente à irrigação por défice regulado

RESUMO: A irrigação por défice regulado (RDI) envolve a indução de défice de água durante fases específicas do crescimento das frutas, irrigando a taxas menores que a evapotranspiração. Os objetivos desse estudo foram verificar os efeitos da RDI no estágio II do crescimento das frutas e no periodo pós-colheita, avaliando a produtividade de pêssegos, a qualidade dos frutos, bem como a taxa fotossintética e o potencial da água na folha. A pesquisa foi desenvolvida em um pomar comercial de pêssegos com caroço aderente (*Prunus persica* L. Batch cv. A-37) da Grécia. As árvores foram irrigadas por meio de microaspersores e sua frequência foi determinada por meio de dados meteorológicos obtidos em estação automática e o método FAO 56 Pennman-Monteith para determinação de evepotranspiração. A taxa de fotossíntese foi medida por analisador de gás na faixa do infravermelho. O potencial da água na folha foi medido ao meio-dia usando a técnica da câmara de pressão. Durante 2005 e 2006 o tratamento RDII com irrigação aplicada no estágio II não apresentou efeito sobre a produção, pesos seco e fresco dos frutos. RDII reduziu a queda de frutos antes da colheita, em relação ao controle. RDII, como também o tratamento combinado de RDII mais RDIP com irrigação aplicada em pós-colheita, reduziu o comprimento de ramos vigorosos dentro do dossel nos dois anos de estudo. Em comparação com o controle, RDII aumentou o conteúdo de sólidos solúveis dos frutos e a relação sólidos solúveis/acidez, mas não afetou a acidez dos frutos e a firmeza da polpa. Em 2006 RDII e RDII mais RDIP aumentaram os 'frutos dobrados' e frutos com cavidade aberta, em comparação com o controle. A economia de água foi considerável e associada às condições climáticas de cada ano.

Palavras Chave: queda de fruto, potencial da água, taxa fotossintética, economia de água

Introduction

Irrigation affects soil water availability and consequently, plant water status, shoot growth, productivity and fruit size (Li et al., 1989; Boland et al., 1993; Naor et al., 1999). Regulated deficit irrigation (RDI) involves inducing tree water stress during specific fruit growth phases by irrigating at less than full evapotranspiration (Etc). The stress tolerant phases of peach, which have a double sigmoid fruit development pattern, have been identified as the 'lag phase' of fruit growth (stage II) and the postharvest phase (Goldhamer et al., 2002). Regulated deficit irrigation was originally applied to control excessive vegetative growth by reducing irrigation during stage II of fruit growth (Chalmers et al., 1981). Subsequently, RDI experiments have focused on saving water during pre and postharvest periods (Johnson et al., 1992; Girona et al., 1993). Additionally, a general tendency to improve fruit taste and quality and an improvement of postharvest shelf life was reported (Fereres and Goldhamer, 1990; Crisosto et al., 1994).

Deficit irrigation at stages I and II of fruit growth did not affect yield (Li et al., 1989), whereas deficit irrigation at stage III decreased fruit size (Naor et al., 1999). Although previous authors analyzed the effect of water deficit on fruit growth (Chalmers et al., 1981; Li et al., 1989; Boland et al., 1993; Naor et al., 1999; Goldhamer, 1999; Lopez et al., 2008), the results were not always conclusive, probably, because of different experimental conditions (soil and climatic conditions, genotype etc). Soil depth and soil water holding capacity have been reported as interacting factors in the success of RDI (Behboudian and Mills, 1997). Water stress is one of the most important environmental factors inhibiting photosynthesis. Photosystem II (PSII) has been shown to be very sensitive to water stress. *In vivo* studies demonstrated that water stress resulted in damage to the oxygen-evolving complex of PSII and to the PSII reaction centres (Lu and Zhang, 1999). Plants have developed various mechanisms to withstand drought, such as higher root-shoot ratios, fewer and smaller leaves, concentrated solutes osmotic adjustment and increased activity of oxidative stress enzymes in leaf cells (Lei et al., 2006).

The objectives of this experiment were to study the effects of different RDI strategies on productivity of clingstone peaches, fruit quality as well as photosynthetic rate and midday leaf water potential.

Material and Methods

The research was conducted in a commercial clingstone peach (*Prunus persica* L. Batch cv. A-37) orchard in northern Greece (22° 12' E; 40° 29' N; elevation 225 m). The mean maximum temperature of the experimental area is 38°C in July, and 9.5°C in January, whereas the mean minimum temperature in January is -7°C. 'A-37' peach cv. was selected from open pollinated 'Andross' trees. Fruit is ripen about two weeks earlier than 'Andross', has similar productivity and is suitable for a better distribution of clingstone peaches throughout the period for the canning industry. The trees were 14 years old and grafted on GF 677 rootstock. The experimental trees were trained as a palmette at distances 5 × 4 m apart. Irrigation was performed by means of microsprinklers and its frequency was determined by the data of the local meteorological station and by using the FAO 56 Pennman-Monteith method (Allen et al., 1998).

Soil samples from the experimental orchard were collected from a layer of 0-60 cm and analyzed according to Page et al.(1982). The soil (0-60 cm) is classified as typic Xerofluvent (Soil Survey Staff, 1998) and is characterized by loamy texture with pH 6.22 (soil:water 1:1), electrical conductivity 0.23 mS cm^{-1}, organic matter 16.9 g kg^{-1} and $CaCO_3$ 5.2 g kg^{-1}.

Four irrigation treatments were used: control and three RDI regimes, one at growth stage II (supplying 35% of water in comparison to the control), called RDII, a second at postharvest (supplying 35% of water in comparison to the control) started at September 15 and finished at October 31 of the years 2004-2006), called RDIP, and a third of the combination RDII plus RDIP. The control treatment was fully irrigated using crop Etc calculated from FAO 56 Pennman-Monteith reference crop water use (ETo). Water amount provided in the control treatment through irrigation in 2005 was 426 mm (plus 137 mm of effective precipitation) and in 2006 was 497 mm (plus 71 mm of effective precipitation). The irrigation treatments were initiated in the postharvest stage in 2004 (71 mm of water were supplied through irrigation and 79 mm through effective precipitation, in the control treatment). The irrigation schedule procedure in the control treatment in 2005 was the following: May 23, June 23, July 3, July 22, August 18 and September 12. In 2006 was: May 25, June 10, June 22, July 7, July 20, August 2 and August 21. The estimated crop coefficients (Kc) adapted from Goldhamer and Snyder (1989) were modified *in situ* based on plant water status (Etc = ETo × Kc). Initial K_{c1} (rapid growth) =0.25, Kc_2 (midseason) = 1 and Kc_3 (late season) = 0.6.

At harvest time of the years 2005 and 2006, the productivity of the trees was recorded (kg 0.1 ha^{-1}) by harvesting and measuring periodically all the mature fruits, as well as the percentage of preharvest fruit drop and the percentage of 'double' fruits. Furthermore, fruit samples (30 per replication) were collected and the following measurements were taken: mean fruit weight, flesh firmness (measured by an Effegi penetrometer), soluble solids (measured with the Atago PR-1 electronic refractometer), acidity (after titration with 0.1 M NaOH solution), and fruit color (parameters H, L, a, b) measured by Minolta chroma meter CR-200. At mid summer, the length of the vigorous shoots (10 shoots per replication) inside the canopy was measured. Furthermore, photosynthetic rate (Pn) was measured in 2005 in ten leaves per replication (leaves from the middle of moderately vigorous shoots around the periphery) at full sunshine (1590–1840 μmol m^{-2} s^{-1}) from 12h00 to 13h00 by using a portable infrared gas analyzer (IRGA) apparatus (LI-6200, LI-COR). 15 measurements were performed over the growth season (five at stage II, seven at stage III and three at the postharvest stage). Midday leaf water potential was measured in 2005 by using the pressure chamber technique (Skye instruments) in ten leaves per replication (leaves from the middle of moderately vigorous shoots around the periphery). Fifteen measurements were performed as described above.

The experimental design was a randomized block with five replications of four treatments (five trees per replication). Differences between means were evaluated using Duncan's multiple range test at $p < 0.05$.

Results and Discussion

Productivity and fruit quality

During the years 2005 and 2006, RDII did not affect productivity, fresh and dry mass of fruits (Table 1). However, Chalmers et al. (1981) and Mitchell and Chalmers (1982) reported increases in productivity and fruit weight of fruits when trees were subjected to RDII. Other researchers showed that RDII did not have any effect on productivity (Larson et al., 1988; Berman and DeJong, 1996; Boland et al., 2000b; Girona et al., 1989). These contradictory results may be due to differences in soil texture, soil depth and water capacity of the soil. Girona et al. (2003) reported that irrigation water should not be restricted at stage III of tree growth as it has an adverse effect on productivity.

RDII reduced preharvest fruit drop in comparison to the control (Table 1). At stage II of fruit growing, pit hardening occurs and fruit increase ceases. At the end of stage II, fruits have accomplished about 20% of their final size, whereas shoots about 80% (Vasilakakis and Therios, 1990). RDII as well as RDII plus RDIP in both years reduced shoot length of the vigorous shoots inside the canopy (Table 1). This was also apparent for RDIP in 2005 but not 2006 since in this year due to rainfall it was not possible to induce RDIP (Table 3). Therefore, RDII plus RDIP have a positive effect as more light penetrates the tree canopy which results in better fruit coloration and increase of soluble solids of the fruits (Crisosto et al., 1994; Boland et al., 2000a), and because less plant mass is removed on pruning. Li et al. (1989) and Girona (2002) reported various degrees of shoot length decrease on peach trees under RDI, whereas reduced vegetative growth was also measured in olive (*Olea europea* L.) plants (Aganchich et al., 2007). On the other hand, there were some disadvantages of RDI. RDII as well as RDII plus RDIP in 2006 significantly increased 'double' fruits and fruits with open cavity at the upper part of the fruit in comparison to the control and RDIP (Table 1). This may be due to an effect of RDI on bud differentiation that occurred in the summer of the previous year.

RDII in comparison to the control increased soluble solids content of the fruits and of the ratio soluble solids/acidity, however did not affect fruit acidity and fruit firmness (Table 2). This may attributed to the increased light interception inside the tree canopy which results in an increase of the photosynthetic rate and production of more carbohydrates (Crisosto et al., 1994; Boland et al., 2000a). Cui et al. (2008) reported that fruit firmness, soluble solid content, sugar/acid ratio and vitamin C content of pear-jujube (*Ziziphus jujuba* L.) trees were enhanced as a result of deficit irrigation. Fruits from deficit irrigated apricot (*Prunus armeniaca* L.) trees had higher values of soluble solid content, total acidity and

Table 1 - Effect of irrigation on productivity, fresh and dry weight of fruits, preharvest fruit drop, shoot length, double fruits and fruits with open cavity for the years (2005-2006).

Treatments	Productivity		Fruit fresh mass		Fruit dry mass		Preharvest fruit drop		Shoot length		'Double' fruits		Fruits with open cavity	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
	---- kg/0.1 ha ----		------------------------ g ------------------------				---------- % ----------		------ cm ------		------------------- % -------------------			
Control	6,129 a*	6,169 a	191 a	199 a	32.3 a	33.9 a	16.0 a	14.8 a	48 a	42 a	5.5 a	4.9 b	4.5 a	3.7 b
RDII	6,130 a	6,154 a	195 a	203 a	32.8 a	34.8 a	10.3 b	9.3 b	32 c	26 c	5.8 a	9.0 a	4.2 a	6.6 a
RDIP	6,119 a	6,157 a	184 a	196 a	31.7 a	32.9 a	15.7 a	15.0 a	42 b	40 a	5.9 a	5.0 b	4.9 a	3.9 b
RDII + RDIP	6,116 a	6,142 a	188 a	200 a	32.2 a	33.8 a	14.5 a	12.7 a	39 b	33 b	5.3 a	8.5 a	4.7 a	6.1 a

*Means followed by the same letter in the same column are not significantly different (Duncan's multiple range test at $p < 0.05$).

Table 2 - Effect of irrigation on soluble solids, titratable acidity, soluble solids/titratable acidity, fruit firmness and fruit color for the years 2005 and 2006.

Treatment	Soluble solids		Titratable acidity		Soluble solids/ titratable acidity		Fruit firmness		Hue angle		a		b		L	
	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006	2005	2006
	-------- °Brix --------		g malic acid /liter of juice				-- kg cm^{-2} --									
Control	10.8 b*	10.2 b	2.2 a	2.8 a	4.91	3.64	3.2 a	3.8 a	70 a	78 a	12 b	16 b	37 a	33 a	61 a	69 a
RDII	11.7 a	11.1 a	1.9 a	2.3 a	6.16	4.83	3.3 a	4.1 a	62 b	68 b	16 a	22 a	40 a	36 a	62 a	70 a
RDIP	11.3 ab	10.5 b	2.0 a	2.4 a	5.65	4.38	3.4 a	4.2 a	68 a	76 a	13 b	17 b	41 a	37 a	64 a	70 a
RDII + RDIP	11.5 a	10.7 ab	2.1 a	2.7 a	5.48	3.96	3.1 a	4.1 a	63 b	69 b	14 ab	22 a	41 a	35 a	63 a	69 a

*Means followed by the same letter in the same column are not significantly different (Duncan's multiple range test at $p < 0.05$).

Table 3 - Water balance components for the two years and the growth periods (evapotranspiration, rainfall, water savings).

	Stage I	Stage II	Stage III	Postharvest
ETc (mm/period)				
2005	81.5 b	89.8 b	248.3 a	75.4 c
2006	83.0 c	99.7 b	313.8 a	44.7 d
Rainfall (mm/period)				
2005	38.2 c	45.5 b	67.1 a	28.8 d
2006	77.7 b	26.6 d	47.2 c	91.5 a
Water savings (mm) at RDII				
2005	-	28.8	-	-
2006	-	47.5	-	-
Water savings (mm) at RDIP				
2005	-	-	-	30.3
2006	-	-	-	0
Water savings (mm) at RDII + RDIP				
2005	-	28.8	-	30.3
2006	-	47.5	-	0

*Means followed by the same letter in the same row are not significantly different (Duncan's multiple range test at $p < 0.05$).

Hue angle than those of the control treatment, whereas fruit firmness was not affected (Perez-Pastor et al., 2009).

As regards fruit color parameters, the Hue angle was lower (more intense red color) at RDII as well as RDII and RDIP in comparison to the rest treatments (Table 2). This was a result of higher values of the 'a' parameter. This may attributed to the increased light interception inside the tree canopy which results in an increase of photosynthetic rate and an increase of anthocyanin synthesis which provide the red fruit color (Boland et al., 2000a).

Leaf water potential - Photosynthetic rate

During the vegetative period, a gradual decline of plant midday leaf water potential (Ψ_{md}) was recorded at stage II of fruit growth and during postharvest for RDII and RDIP treatments in comparison to the control (Figure 1). Lower Ψ_{md} values were recorded at the end of the season in comparison to the initial stages. At stage III of fruit growth a gradual decline of Ψ_{md} was measured for all treatments. Marsal and Girona (1997) reported that Ψ_{md} measurements may be used for the characterization of water status of fruit trees under soil water deficit because they are correlated with the midday stomata closure. Results of the relationship between leaf water potential and maximum stomatal conductance in olive (*Olea europea* L.) trees, showed that the stomatal apparatus of the Frantoio cultivar was more sensitive to water deficit than that of the Leccino cultivar (D'Andria et al., 2009).

The seasonal pattern of Pn followed that of Ψ_{md} (Figure 2). Lower Pn values were measured during postharvest period in comparison to the other fruit growth stages. During growth stage II, RDII resulted in lower Pn values than the remaining treatments as was also reported by Marsal and Girona (1997). The same trend was found in the postharvest growth stage for RDIP as well as RDII and RDIP. The reduced shoot length that was reported previously is probably associated with the reduction of Pn. Drought stress in *Citrus* reduced stomatal conductance, leaf transpiration rate, and net CO_2 assimilation rate (Perez-Perez et al., 2009). Furthermore, Dichio et al. (2006) reported that stomatal conductance and net photosynthetic rate declined with increasing drought stress. Water stress induced a decrease in the quantum yield of PSII electron transport of wheat plants (*Triticum aestivum* L.), suggesting that water stress resulted in modifications in PSII photochemistry (Lu and Zhang, 1999).

Plants have developed various mechanisms to withstand drought (Lei et al., 2006). Increases in cell wall elasticity might contribute to the maintenance of cell turgor or symplast volume and have been reported in several species as response to water stress (Patakas and Noitsakis, 1997). Osmotic adjustment has been reported to contribute to maintain turgor pressure. These compounds benefit cells in two ways: by acting as cytoplasmic osmolytes, thereby facilitating water uptake and retention, and by protecting and stabilizing macromolecules and structure (Martinez et al., 2004). The accumulation of proline in many plants represents a general response to drought stress as was reported also for *Citrus* trees (Syvertsen and Smith, 1983). A tolerant genotype of the common bean (*Phaseolus vulgaris* L.) showed a great deal of plasticity at the biochemical and cellular levels when exposed to drought stress, in terms of stomatal conductance, photosynthetic rate, abscisic acid synthesis, and resistance to photoinhibition (Lizana et al., 2006).

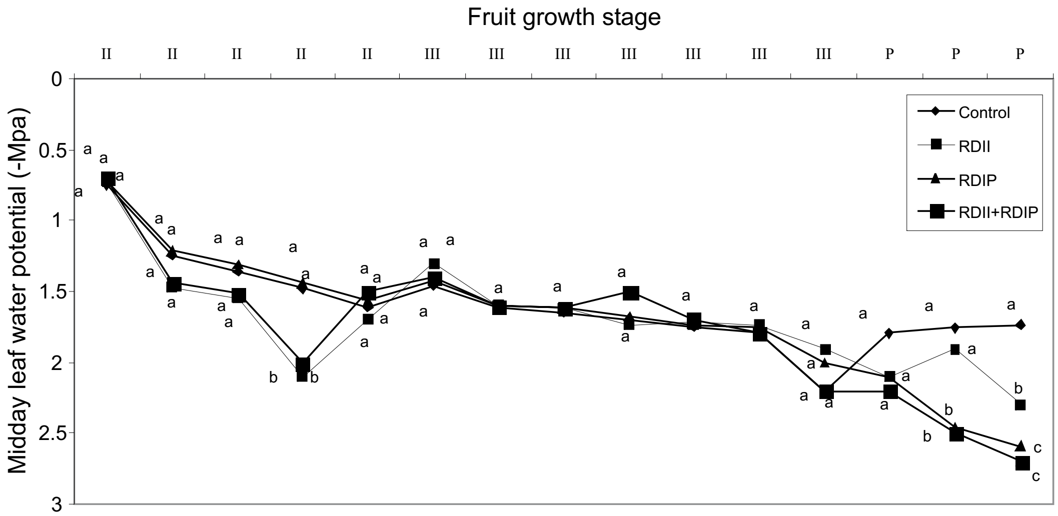

Figure 1 - Seasonal pattern of midday leaf water potential for the year 2005. Means followed by the same letter for every measurement date are not significantly different (Duncan's multiple range test at $p < 0.05$).

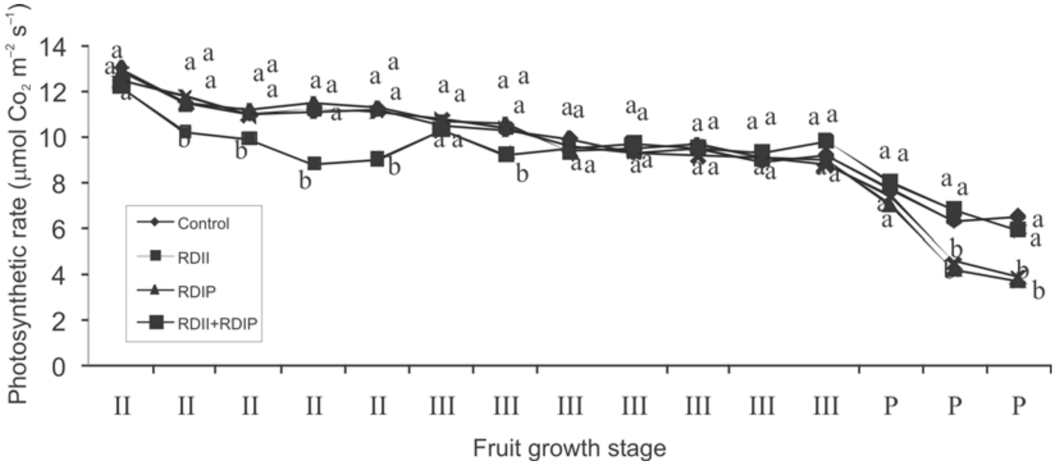

Figure 2 - Seasonal pattern of photosynthetic rate for the year 2005. Means followed by the same letter for every measurement date are not significantly different (Duncan's multiple range test at $p < 0.05$).

Water savings

Water balance components (Table 3) were associated with the climatic conditions of each year. In particular, in 2005, for RDII water savings were 28.8 mm, for RDIP, 30.3 mm and for RDII plus RDIP, 59.1mm. In 2006, for RDII water savings were 47.5 mm, for RDIP, 0 mm and for RDII plus RDIP, 47.5 mm. Water savings of 7 to 23% for RDII and RDIP were reported by other researchers (Li et al., 1989; Girona, 1989; Girona, 2002; Girona et al., 2003). Water savings are of significant importance since the availability of irrigation water in many agricultural areas is diminished due to climatic changes and the high demand.

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