Effects of Regulated Deficit Irrigation on Vegetative Growth, Fruit Yield and Quality of Japanese Plum (*Prunus salicina* Lindell 'Methly')

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Summary

Regulated deficit irrigation (RDI) can be used as an effective strategy for increasing water use efficiency (WUE) under arid and semiarid climate. Therefore, in this study the effect of RDI (50 and 75% evapotranspiration of a crop under irrigation (ETc)) as compared to control during pit hardening and after fruit harvest on vegetative growth, fruit yield and quality of Japanese plum 'Methly' was investigated during two consecutive years. The results showed that water available limitation in RDI 50% both during pit hardening and after fruit harvest significantly reduced shoot growth. RDI treatment during postharvest decreased both node number and internode length. The highest flowering rate and fruit set percentage was found when plum tree was irrigated 75% ETC during pit hardening in both years. In the first year, RDI decreased fruit yield, whereas, in the second year, RDI 75% during pit hardening even increased slightly fruit yields for 6 and 11% as compared to control and postharvest stage, respectively. Fruit weight was significantly reduced under RDI 50%. Fruit produced under 50% RDI showed higher firmness and lower soluble solids concentration (SSC) and titratable acidity (TA) than control and other treatment. Furthermore, RDI treated fruits had lower N, P, Mg content and N/Ca and Mg/Ca ratio and higher Ca content than control. Overall, moderate water stress (75% RDI) improved fruit yield and saved water without undesirable effect on plum fruit quality.

Key words

firmness, nutrient elements, pit hardening, vegetative growth and fruit quality

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Introduction

Water deficiency is the main limiting factor for producing horticulture crops in arid and semiarid area in the world. In recent years, it became clear that maintenance of a moderate water deficit at a particular phenological stage can change partitioning carbohydrate into fruits and control excessive vegetative growth (Chalmers, et al., 1981), giving rise to what has been termed by Chalmers et al. (1981) as 'Regulated Deficit Irrigation' (RDI). RDI is an irrigation technique successfully adapted for vineyards irrigation (Santesteban et al., 2011) and is extensively used to implement irrigation in other fruits. Under water stress condition, RDI is a useful technique to improve water use efficiency (WUE) through reducing water use or eliminating the irrigations with low efficiency (Chalmers et al., 1981). However, this strategy decreases crop production per area; but, it can appropriately improve cultivation in low-water land regions; therefore, resulting in an increase of crop production (McCarthy et al., 2002). Under RDI, plants reduce vegetative growth and improve WUE which results in increased fruit yield (Santesteban et al., 2011).

The RDI technique has been identified as one of the key water-saving strategy in agriculture (Chai et al. 2014) since it helps to improve WUE and reduce irrigation rates during a specific period of growth and development, maintaining or improving fruit yield and quality (Chai et al., 2016). This technique has been successfully applied to many fruit trees such as apricot (Pérez-Sarmiento et al., 2016), pears (Stino et al., 2016), Asian pears (Behboudian et al., 1994), apple (Chenafi et al., 2016), plum (Maatallah et al., 2015) and loquat (Cuevas et al., 2007). Thus, the effective use of irrigation can be a key component in the reliable production of high quality fruit crops.

Chenafi et al. (2016) found that RDI impact during summer allowed a water-use reduction of 47% without undesirable effect on fruit yield and fruit quality. Furthermore, soluble solids content (SSC), fruit taste and the colour improved under RDI treatments (Perez-Sarmiento et al., 2010). In apricot, SSC, soluble solids concentration, titratable acidy ratio (SSC/TA) and fruit colour were improved while vegetative growth was decreased by RDI. However, fruit yield was unaffected (Perez-Sarmiento et al., 2016). In contrast, application of excess water at inappropriate time is waste of water resources and leads to poor fruit quality (Behboudian and Mills, 1997). Berman (1996) found that the relationship between fruit growth and water stress is dynamic and depends on the phenological stage. Mahhou et al. (2012) found that that vegetative growth and fruit growth are differentially sensitive to water deficit. Therefore, choosing the appropriate growth stage for applying RDI treatment play an important role.

Stino et al. (2017) found that pear leaf potassium, phosphorus, magnesium, iron and copper content were attributed to the lowest irrigation regime when applied during stage II (pit hardening) but zinc and manganese content increased by applying excessive irrigation during stage II.

Water affects different aspect of plant growth anatomical, morphological, and physiological and biochemical changes. Cheng et al. (2012) found that water stress reduced shoot growth by 9.6% - 18.8% in pear. Bolat et al. (2014) showed that increased water stress decreased the relative shoot length, diameter, and plant total fresh and dry weight. Therefore, the aim of this study was to evaluate the effects of RDI in two different phenological stages of Japanese plum.

Materials and Methods

The experiment was performed during 2016 and 2017 at a commercial plum orchard which is located in Alborz Province, Iran (36°N, 50.31°W and 1200 m.a.s.l.). The plant material consisted of 8-years-old plum trees (*Prunus salicinia* Lindell 'Methly' grafted on wild plum rootstock) and spaced 4.5 × 3.5 m.

The irrigation system was a double drip lateral with four drippers at each tree. The plum trees were irrigated from mid-April to mid-October, based on the plant's water requirement. The average of the thirty years of meteorological data, and some other climatic factors are summarized in Table 1.

Two RDI strategies, 75% evapotranspiration of a crop under irrigation (ETc) and 50% ETc during stage II of fruit growth (pit hardening) and immediately after fruit harvest were compared with full irrigation over fruit growth and development (ETc 100%). The metrological data were obtained from local synoptic weather station near the orchard (Table 2). Thereafter, water requirement for each plum tree was calculated according to CROPWAT 8.0 software. Irrigation scheduling was set based on holding capacity of soil for unavailable moisture and defined treatments using following relations (Equation 1 and 2). Therefore, control received full irrigation over fruit growth and development season (32 L/tree per hour) and 75%, and 50% of full irrigation water for treatments.

$$In = \frac{Fc - PWP}{100} \rho_b . Dr . F$$

$$I_i = \frac{In}{K\,(ETc)}$$

In: Net irrigation water content (mm), Fc: Field capacity (%), PWP: Permanent wilting point (%), *pb*: Soil bulk density (gr/cm^3), *Dr* effective depth of root (120 cm) *I*: Irrigation interval (day), *K*: Coefficient of plant, ETc: evapotranspiration of a crop under irrigation.

However, vegetation evaporation and transpiration were corrected with respect to the shadow level of the tree, so that the water requirement for drip irrigation was calculated more accurately.

Fruit quality and storage condition

Plum fruits were harvested at commercial maturity stage (SSC = 15 - 18˚Brix) approximately in the early September. In each tree, fruits were harvested from four different sites of canopy. For each replication 20 uniform fruits free from defect were harvested and transferred to the laboratory. Fruits were divided into two groups, 10 fruits were evaluated immediately after harvest, and the remaining 10 fruits were put in plastic basket and transferred to cold storage with 0 ± 1° C and 90 - 80% of humidity for 60 days. At the end of storage some fruits characteristics were evaluated again.

Table 1. The monthly average of climatic factors during thirty years on experimental site

Months	Wind Speed (m/s)	Relative humidity (%)	Relative humidity (%)	Average of monthly temperature (°C)
April	2.5	55	39.1	14.2
May	3.3	49	19.5	19.2
June	3.0	35	2.7	24.6
July	3.5	22	3	27.1
August	3.9	19	1.2	26.8
September	3.4	24	1.6	22.9
October	3.2	30	15.1	17.1
November	3.1	42	27.7	9.9
December	3.8	54	33.5	4.6
January	3.6	68	30.8	1.8
February	2.7	61	32.1	4.1
March	2.6	58	45.4	8.7

Table 2. The average of evapotranspiration (ETc) of the main plant, the crop coefficient (Kc) in specified period, the total effective rainfall and the required irrigation during the growing season of Japanese plum 'Methly' fruit

Growth period	Crop evapotranspiration (mm/dec)	Crop coefficient (Coeff)	Total of effective rainfall (mm/dec)	Requirement of irrigation (mm/dec)
Primary	28.15	0.8	25.2	29.8
Development	60.59	1	34.5	389.6
Middle	66.67	1.2	10.7	522.7
Terminal	22.65	1.04	55.2	42.8

Twig growth

Twig length, node number and internode length was recorded immediately after leaves fall. In the following spring, the flowers number was recorded at popcorn stage and was expressed as flower number per unit length of branch. In addition, the fruitlets number was recorded as number of fruits per one meter of twig (Girona et al., 2003).

Fruit yield and Weight

Total fruit weight of each tree was record and expressed as a kg/tree. Twenty fruits from each replication were weighed and mean fruit weight was calculated.

Fruit firmness, SSC and TA

Immediately, after harvest and at the end of two months of cold storage fruit firmness, titratable acidity (TA) and soluble solids content (SSC) were evaluated for five fruits. Flesh firmness was measured from two opposite side of fruits using a penetrometer with an 8 mm diameter probe and expressed as kg/cm^2. SSC was determined with a digital refractometer and TA was measured by titration of juice against 0.1 M NaOH and phenolphthalein as an indicator. The effect of RDI treatments in post-harvest stage on fruits quality was investigated in the second year of study.

Fruit mineral nutrient composition

The effect of RDI after fruit harvest on fruits mineral elements content was investigated in the second year of study. Mineral nutrient element content such as nitrogen, phosphorus, potassium, calcium, magnesium and the ratios were evaluated in fruits. The Kjeldahl method is used to determine the nitrogen content (Jones, 2001). The phosphorus content of samples was determined by the vanadate-molybdate colorimetric method (Chapman and Pratt, 1982). The absorbance of samples was measured at 470 nm in a UV/Visible spectrophotometer (model PG Instrument T80+, Leicester, UK). Potassium (K) was determined by the flame photometric method as described by (Jones, 2001). Calcium (Ca) and magnesium (Mg) were measured using atomic absorption spectroscopy. Briefly, digested extracts were diluted with distilled water (1:9 v/v), then 4.75 mL lanthanum nitrate [La (NO_3)3] was added to 250 mL of the diluted extract. Finally, the absorbance was measured at 422.7 nm for Ca and 285.2 nm for Mg by atomic absorption (Jones, 2001). All nutrient content values were expressed as gram per 100 gram dry mass basis.

Statistical analysis

Analysis of variance was performed on all fruit data as a factorial design. In the first year analysis of variance of characteristics, except for vegetative attributes, was performed as randomized block design. All statistical analyses were undertaken using the general linear model (GLM) procedure of the SAS version 9.0. The Duncan's multiple range test ($P \leq 0.05$) was used to evaluate differences between treatments.

Results and Discussion

Vegetative growth characteristics

According to the variance analysis (Table 3) twigs growth was significantly affected both by RDI treatment and growth stage during two consecutive years. As the results showed, water available limitation during both pit hardening and postharvest reduced significantly twigs growth. Plum trees which were irrigated with 50% full water requirement (RDI 50%) after fruit harvest stage showed the lowest twig growth in two consecutive seasons (Table 4). In agreement with obtained results, previous study also showed that in response to deficit irrigation, the twig length and the trunk diameter decreased which results in a reduction in the size of the tree and the crown (Perez-Pastor et al., 2009). Furthermore, Sortiropoulos et al. (2010) also found that deficit irrigation during pit hardening and after harvest reduced branch growth in peach trees. Li (1993) reported that deficit irrigation during fruit development and postharvest in peach trees significantly reduced vegetative growth, but fruit production was not significantly affected until the fourth consecutive year. Pérez-Pastor et al. (2014) reported that vegetative growth decreased according to the intensity and duration of the water deficit applied, and depending on the phenological period when the water deficit occurred.

The effect of RDI on node number and internode length was dependent to phenological stage (Table 3). The lowest node number and internode length was found in plum trees which received RDI 50% after fruit harvest (Table 4). Thereafter, plum tree which received RDI 70% showed lower values than control. It seems that the lowest twig length in RDI treatments is result of decreasing both node number and internode length. Previous study showed that fruit growth at stage II in stone fruits coincides with vigorous growth rates shoot; therefore, moderate water stress during this stage will reduce tree crown development (Lopez et al., 2008). Thus, this stage provides an opportunity to reduce the tree's growth potential by deficit irrigation without harming the fruit growth. This reduction in vegetative growth is a useful technique in high-density orchards, especially in peach orchards, where it is necessary to control vegetative vigor in order to optimize tree-light interception and to improve the economic success of the orchards (Chalmers et al., 1981). Podesta et al. (2011) reported that water deficit can be used to control vigor and promote early production of cherries, while saving significant amounts of water. Withholding irrigation applied after harvest also reduced vegetative growth of early maturing peach trees and improved fruit quality (Gelly et al., 2004).

Flower number and fruit set

The analysis of variance showed that flower number and fruit set percentage of plum tree was significantly affected by both RDI treatment and phenological stage (Table 3). The highest flower number was found in plum trees when received 75% of their water requirement during pit hardening stage. However, RDI 50% significantly reduced flower numbers. As the results showed, moderate water stress during pit hardening stage increased flower number (Table 5).

In the first year of experiment, the plum trees irrigated with RDI 75% during pit hardening had the highest rate of fruit set while the lowest fruit set was found with RDI 50% (Table 5). As the results showed, deficit irrigation during pit hardening increased fruit set in the following year of treatment.

Stone fruit tree productivity can be greatly influenced by the tree water status and crop level (Naor, 2004). Thakur and Singh (2013) reported that RDI technique during the postharvest stage has to be performed avoiding high levels of drought stress, which could negatively influence the accumulation of reserve carbohydrates, flower development and thus, indirectly, crop yield. They also found that deficit irrigation with 58% and 33% increased flower density in 'Summer Bright'. It seems that nitrogen content decreased and C:N ratio increased in shoots with deficit irrigation (Thakur and Singh, 2013). Girona et al. (2003) found that water stress during pit hardening did not affect return bloom, whereas water stress during postharvest apparently reduced both parameters. However, Samperio et al. (2015) showed that RDI increased fruit number per tree.

Fruit Yield

The results of variance analysis showed that RDI treatment significantly affected fruit yield in two consecutive seasons (Table 6). The results showed that severe water stress in RDI 50% significantly reduced fruit yield of plum (Fig 1 and 2). No significant difference was found between control and RDI 75% in the first year, but in second year RDI 75% slightly increased fruit yield as compared to control (Fig 2).

In each RDI treatments including RDI 75% and RDI 50%, fruits yield increased 11 and 6%, respectively, in pit hardening stage as compared to post-harvest stage. The decrease in fruit yield in second years by application 50% ETc during post-harvest (RDI 50%) can be attributed to reduced vegtative growth, fruit set and fruit weight that was also confirmed by (Naor et al., 2006). It can be related to lower pollen viability and lower winter starch reserves in the shoot (Lopez et al., 2007). In contrast, a moderate level of post-harvest water stress (RDI 75%) had less effect on fruit weight, fruit set percentage as it was found by Girona et al. (2005) for peach trees. Munitz et al. (2017) found that RDI treatment from flowering time to bunch closure and lower irrigation from bunch

Table 3. Analysis of variance of effect of regulated deficit irrigation (RDI) during two different phenological stages on vegetative growth, flower number and fruit set of Japanese plum 'Methly' tree during two years

Treatments	DF	MS				
		Twig growth	Node number	Internode length	Flower number	Fruit set
First Year						
Block	2	4.66^{ns}	0.88^{ns}	0.00001^{ns}	3.50^{ns}	1.50^{ns}
RDI	2	3338.16**	403.72**	0.098**	138.50**	10.50**
Growth Stage	1	338.00**	40.50**	0.0117**	193.38**	12.50**
RDI × Growth Stage	2	87.16**	13.50**	0.003**	48.38**	3.16**
CV (%)		1.91	1.77	0.43	0.85	4.17
Second Year						
Block	2	1.38^{ns}	0.50^{ns}	0.0003**	48.16^{ns}	4.38^{ns}
RDI	2	6329.05**	1160.16**	0.074**	645.50**	16.88*
Growth Stage	1	180.50**	24.50**	0.0046**	329.38**	14.22*
RDI × Growth Stage	2	45.50**	6.16**	0.0018**	145.72**	6.22ns
CV (%)		1.24	1.001	0.34	2.08	7.65

** - Significant differences at 1% level, * - Significant differences at 5% level, ^{ns} - Not significant

Table 4. Mean comparison effect of regulated deficit irrigation (RDI) and growth stage on vegetative growth characteristics of Japanese plum 'Methly' during two years

Growth stage	RDI treatments	Twig growth (cm)		Node number		Internode length (cm)	
		First Year	Second Year	First Year	Second Year	First Year	Second Year
Pit hardening	100%	155.33 a	165.00 a	74.66 a	94.66 a	1.82 a	1.85 a
	75%	138.33 b	158.33 b	63.66 b	94.00 a	1.79 b	1.79 b
	50%	115.33 d	109.00 d	48.33 c	72.33 c	1.61 d	1.67 d
Postharvest	100%	155.33 a	165.00 a	74.66 a	94.66 a	1.82 a	1.85 a
	75%	126.66 c	149.33 c	50.66 c	87.66 b	1.71 c	1.77 c
	50%	101.00 e	99.00 e	41.33 d	53.66 d	1.54 e	1.60 e

Values with the different letters are significantly different according to Duncan's Multiple Range Test at $P<0.01$ and $P<0.05$

Table 5. Mean comparison effect of regulated deficit irrigation (RDI) and growth stage on flower number and fruit set of Japanese plum 'Methly' in the second year

Growth stage	RDI treatments	Flower Number		Fruit set (%)	
		First Year	Second Year	First Year	Second Year
Pit-hardening	100%	165.66 b	175.00 bc	15.00 b	20.00 a
	75%	176.66 a	185.66 a	16.66 a	25.33 a
	50%	167.00 b	171.66 c	14.33 b	22.00 a
Post-harvest	100%	165.66 b	175.00 bc	15.00 b	20.00 a
	75%	166.66 b	179.33 ab	14.33 b	21.33 a
	50%	157.33 c	152.33 d	11.66 c	20.66 a

Values with the different letters are significantly different according to Duncan's Multiple Range Test at $P<0.01$ and $P<0.05$

Table 6. Analysis of variance of RDI and growth stage on fruit yield and quality of Japanese plum 'Methly' fruit at harvest and at the end of two month storage

Treatments	DF	Fruit Yield (kg·tree⁻¹)	Mean Square							
			Fruit weight (g)		Firmness (kg/cm²)		SSC (%)		TA (%)	
			at harvest	after storage	at harvest	after storage	at harvest	after storage	at harvest	after storage
First Year										
Block	2	8.11^{ns}	2.1^{ns}	0.11^{ns}	0.004^{ns}	0.02^{ns}	0.11^{ns}	0.007^{ns}	0.08^{ns}	0.02^{ns}
RDI	2	138.7*	183.4*	136.7*	0.27*	1.84**	1.47*	2.1*	0.16^{ns}	0.74 *
CV		5.83	2.05	1.09	2.09	4.73	2.22	1.42	2.89	2.62
Second year										
Block	2	4.22^{ns}	0.66^{ns}	1.05^{ns}	0.003^{ns}	0.008^{ns}	0.18^{ns}	0.1^{ns}	0.01^{ns}	0.003^{ns}
RDI	2	260.7**	458.1**	333.7**	0.25**	1.41**	4.08**	5.53**	0.97 **	0.76*
Growth stage	1	37.5*	53.3*	37.5*	4.4**	3.82**	0.045^{ns}	0.53*	0.2*	0.34*
RDI×Growth stage	2	12.05*	13.7*	10.5*	1.11**	0.96**	0.06^{ns}	0.18*	0.05 *	0.15*
CV		2.66	1.47	1.5	3.61	3.89	1.43	0.7	1.35	2.25

** - Significant differences at 1% level, * - Significant differences at 5% level, ^{ns} - Not significant

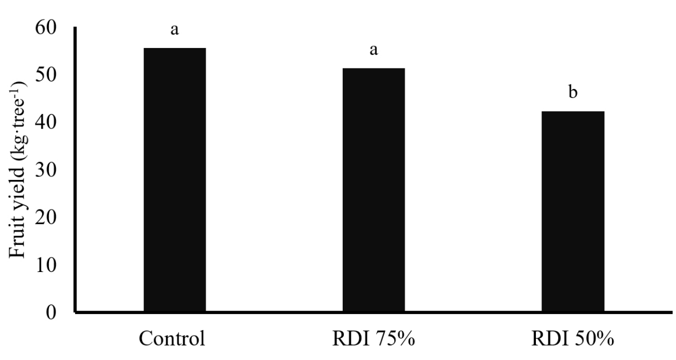

Figure 1. Effect of RDI on fruits yield of Japanese plum 'Methly' in the first year.

*Values with the different letters are significantly different according to Duncan's Multiple Range Test at *P<0.05*

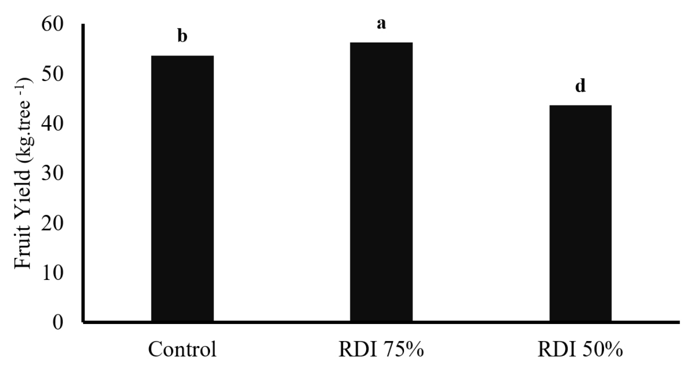

Figure 2. Figure 2. Effect of RDI on fruits yield of Japanese plum 'Methly' in the second year.

*Values with the different letters are significantly different according to Duncan's Multiple Range Test at *P<0.05*

closure to harvest has the potential to generate the best balance between vegetative growth, high yield and wine with enhanced color and aroma compounds. However, Razouk et al. (2013) in plum and almond and Cheng et al. (2012) in pear found that RDI treatments didn't have significant effect on fruit yield on plum and almond, while, higher fruit yield and quality was obtained in peach with RDI 75% (Razouk et al., 2013).

Fruit Weight

The variance analysis showed that fruits weight was significantly affected just by RDI treatments in the first year, but in the second year the fruit weight was affected by the interaction of RDI and phenological growth stages (Table 6). The mean comparison showed that RDI 50% significantly decreased plum fruit weight (Table 7). But, no significant difference was found between control and RDI 75% in the second year (Table 8).

In agreement with this finding, previous study showed that severe RDI treatment (RDI 50%) decreased fruit weight (Mahhou et al., 2012). Marsal et al. (2000) also demonstrated that RDI pear fruits were significantly smaller than control. However, Cheng et al. (2012) showed that no significant difference was found in fresh fruits weight at harvest between water stress treatments and control. The effect of water stress on fruit growth could be explained by insufficient water for cell elongation (Mitchell and Chalmers., 1982) and the smallest fruits were produced when trees were under an imposed water deficit during rapid growth stage (Li et al., 1989).

Fruit firmness

Fruits firmness was significantly affected by RDI treatment in first year (Table 6). The highest and lowest fruit firmness was found in RDI 50% and the control, respectively (Table 7).

Table 7. The effect of regulated deficit irrigation (RDI) on fruit weight and quality of Japanese plum 'Methly' fruits at harvest and after two month storage in the first year

RDI treatments	Fruit weight (g)	Firmness (kg/cm²)		SSC (%)		TA (%)	
	At harvest	At harvest	After storage	At harvest	After storage	At harvest	After storage
100%	105 a	2.23 c	1.16 b	19.6 ab	19.56 a	8.03 a	7.5 a
75%	101 a	2.46 b	2.43 a	20.3 a	20.6 a	7.86 a	7.66 a
50%	90 b	2.83 a	2.53 a	18.93 b	18.43 b	7.56 a	6.73 b

Values with the different letters are significantly different according to Duncan's Multiple Range Test at $P<0.01$ and $P<0.05$

Table 8. The effect of regulated deficit irrigation (RDI) and phenological growth stage on fruit weight and quality of Japanese Plum fruits at harvest and after two month storage in the second year

Growth stage	RDI treatments	Fruit weight (gr)	Firmness (kg/cm²)		SSC (°Brix)		TA (% Malic acid)	
		At harvest	At harvest	After storage	At harvest	After storage	At harvest	After storage
Pit-hardening	100%	103.6 a	2.46 c	1.23 c	18.93 b	19.06 b	8.16 a	7.9 ab
	75%	103.6 a	2.76 b	2.73 a	20.46 a	19.26 a	8.06 a	7.93 a
	50%	90.3 c	1.36 d	1.4 b	18.8 b	17.26 d	7.56 c	7.56 b
Post-harvest	100%	103.6 a	2.46 c	1.23 c	18.93 b	19.06 b	8.16 a	7.9 ab
	75%	99.1 b	2.96 a	2.8 a	20.13 a	19.6 a	7.8 b	7.73 ab
	50%	84.6 d	1.4 d	1.36 b	18.83 b	17.96 c	7.2 d	6.9 c

Values with the different letters are significantly different according to Duncan's Multiple Range Test at $P<0.01$ and $P<0.05$

However, in the second year, RDI 50% treatment decreased fruit firmness compared to control in the both pit hardening and postharvest stages (Table 8). In general, the results showed that RDI 50% in the first year and RDI 75% in the second year increased fruit firmness compared to control. Increasing fruit firmness has already been reported previously by Maatallah et al. (2015), which was attributed to an increased cellular density due to a reduction in fruit size. Mpelasoka and Behboudian (2002) also found that apple fruit firmness increased with deficit irrigation strategy. They also found that both early deficit irrigation and late deficit irrigation increased flesh firmness in apple fruits.

Soluble solid content (SSC)

In the first year of experiment, RDI treatments significantly affected fruit SSC both at harvest and after two months of storage (Table 7). Fruits SSC reduced significantly by RDI 50%. However, no significant difference was found between RDI 75% and control (Table 7). In the second year, no significant difference was found between control and RDI 50% (Table 8). However, fruit SSC content in RDI 75% treatment both at harvest and of after two months storage was significantly higher than control and RDI 50% (Table 8). In fact, moderate water stress of RDI 75% could increase SSC of plum fruits.

In agreement with finding of this study, Perez-Sarmiento et al. (2010) showed that SSC content of apricot fruit increased significantly by RDI treatment. In another study, SSC, fruit taste and colour enhanced by RDI treatments (Perez-Sarmiento et al., 2016). However, Razouk et al. (2013) reported that the acidity and sugar content remained unchanged with the variation of irrigation treatment in plum, but was significantly affected in peach.

Titratable Acidity (TA)

As the results showed, in the first year, no significant difference was found between RDI treated fruits and control for TA content at harvest time, but it significantly affected on it after two month of storage (Table 6). TA content of RDI 50 % was significantly lower than RDI 75% and control (Table 7). In the second year, RDI treatment both in pit hardening and after fruit harvest significantly affected TA content both at harvest and at the end of storage (Table 8). However, no difference was found between RDI 75% and control. In agreement with finding of this study, Treeby et al. (2007) showed that water stress decreased TA content of navel orange fruit. In contrast, Gasque et al. (2010) reported that TA level in the control was lower than in RDI treatments. However, in apricot (Pérez-Sarmiento et al., 2016) and in plum (Intrigliolo and Castel, 2010) TA content was unaffected by RDI irrigation.

Fruit mineral nutrient composition

Nitrogen content

The results showed that RDI treatment significantly affected fruits nitrogen (Table 9) in two consecutive seasons. Nitrogen content of RDI treated fruits was significantly lower than in control. On the other hand, water stress applied during growth season significantly reduced fruits nitrogen (Table 10). With increasing water stress, the nitrogen content declined (Table 10). The results showed 20.9% decrease in nitrogen content for RDI 75% and 39.5% for RDI 50% in the first year (Table 10). In the second year, fruit nitrogen content was reduced by 9.5% and 29.5% for RDI 75% and RDI 50%, respectively, compared to control (Table 10).

Table 9. Analysis of variance of effect of regulated deficit irrigation (RDI) and phenological stage on mineral nutrient content and ratio of Japanese plum 'Methly' fruit

Source	DF	Mean Square					
		N	P	Ca	Mg	N/Ca	Mg/Ca
First Year							
Block	2	0.1^{ns}	0.01^{ns}	0.0001^{ns}	0.00007^{ns}	0.34^{ns}	0.0007^{ns}
RDI	2	2.03 *	0.003 ns	0.014**	0.0028**	13.3 *	0.084**
CV	-	7.1	4.9	1.12	0.87	7.1	2.01
Second year							
Block	2	0.06^{ns}	0.005^{ns}	0.0002^{ns}	0.00008^{ns}	0.61^{ns}	0.0036^{ns}
RDI	2	2.43 **	0.06 *	0.0043**	0.0056**	16.1 **	0.0856**
Growth stage	1	0.008^{ns}	0.005^{ns}	0.0000^{ns}	0.0001^{ns}	0.34^{ns}	0.0005^{ns}
RDI×Growth stage	2	0.003^{ns}	0.03^{ns}	0.00006^{ns}	0.00007^{ns}	0.04^{ns}	0.0002^{ns}
CV	-	5.15	6.9	1.44	1.28	6.1	2.45

** - Significant differences at 1% level, * - Significant differences at 5% level, ^{ns} - Not significant

Table 10. The effect of regulated deficit irrigation (RDI) on mineral nutrient elements content (g·100 g^{-1} dry mass) and ratio of Japanese plum 'Methly' fruits at harvest time and after two experimental years

RDI treatments	First year					
	N	P	Ca	Mg	N/Ca	Mg/Ca
100%	4.3 a	1.16 a	0.51 b	0.63 a	8.32 a	1.21 a
75%	3.4 b	1.2 a	0.64 a	0.61 b	5.36 b	0.95 b
50 %	2.6 c	1.13 a	0.63 a	0.57 c	4.24 c	0.9 c
Second year						
100%	4.4 a	1.26 a	0.47 b	0.64 a	9.37 a	1.36 a
75%	3.98 b	1.18 a	0.51 a	0.62 b	7.71 b	1.2 b
50 %	3.1 c	1.06 b	0.51 a	0.58 c	6.09 c	1.12 c

Values with the different letters are significantly different according to Duncan's Multiple Range Test at *P<0.01* and *P<0.05*

Nitrogen is one of the main macronutrient that plants require it large amount. Drought stress may decrease nitrogen mobility in the soil (Bloem et al., 1992). Furthermore, the absorption of nitrogen by roots requires the presence of water in the soil, since it is the agent factor that transports solutes to the soil–root interface (Jaroszewska, 2011). Drought stress reduced crop transpiration rate and decreased N transport from roots to shoots, thereby limiting nitrogen uptake (Tanguilig et al., 1987). In agreement with finding of this study, Jaroszewska, (2011) also observed a decreased nitrogen content in plum, cherry and apricot under deficit irrigation.

Phosphorus content

No significant difference was found for phosphorus content between RDI treated fruits and control in the first season. But in the second year, RDI significantly affected fruit phosphorus concentration (Table 9). The results showed that phosphorus content significantly decreased under RDI treatment. Therefore, the highest phosphorus concentration was found in control fruit and the lowest one in 50% RDI (Table 10). However, no significant difference was found between treatments 100 ETc and 75% RDI for phosphorus. The phosphorus content in fruit under RDI 50% was 15.8 % lower than in control (Table 10).

In agreement with our finding, Turner (1985) showed that phosphorus deficiency appears to be one of the earliest effects of mild to moderate drought stress in soil-grown plants. Sanchez-Rodriguez et al. (2010) found lower concentration and uptake of phosphorus in watermelon and cherry tomato under water deficit conditions. In contrast, Jaroszewska, (2011) reported that water stress treatments had no significant effect on fruit phosphorus contents of plum, cherry and apricot trees.

Calcium and Magnesium

The variance analysis showed that calcium and magnesium content of plum fruits was affected by RDI treatments in both years of experiment (Table 9). The results showed that RDI increased fruits calcium content. The highest calcium content was found in RDI 75% treatment and the lowest content found in control fruits. In contrast, RDI reduced fruits magnesium content compared to control and the lowest fruits magnesium content was found in RDI 50 % (Table 10).

Calcium is a nutrient which greatly impact fruit quality. Its deficiency causes cracking of cherries and plums. Previous study showed that mineral uptake decreased when water stress intensity was increased (Singh and Singh, 2004). In agreement with these findings, Jaroszewska (2011) reported that irrigation increased calcium concentration of cherry fruits. Podsiadlo et al (2009) indicated that irrigation did not cause any change in calcium content in cherries.

N/Ca and Mg/Ca ratio

The analysis of variance showed that RDI significantly decreased N/Ca and Mg/Ca of plum fruits in two consecutive seasons (Table 9). With increasing RDI intensity, nitrogen content decreased, while Ca content increased (Table 10). The highest Mg/Ca ratio was found in control fruits and the lowest of it was found in RDI 50% (Table 1).

In order to find the balanced state of mineral elements and the impact on internal quality of fruits, N/Ca ratios need to be considered (Pacheco et al., 2008). Reducing the ratio of nitrogen or potassium to calcium increases the quality of fruits (Bramlage and Weis, 2004).

Conclusion

RDI is a useful technique to improve WUE in crop production. In this study, RDI 50% significantly reduced fruit weight and fruit yield of Japanese plum cultivar 'Methly'. However, a moderate water stress with RDI 75% slightly increased fruit yield. Plum fruits quality attributes such as firmness, SSC and TA significantly affected by RDI treatment. The highest fruit firmness was found when RDI 50% was used while such fruits have showed the lowest SSC and TA. However, no significant reduction in fruit quality was found with RDI 75% as compared to control. The results also showed that nitrogen, phosphorus and magnesium content of RDI treated fruits significantly decreased under RDI treatment. The results showed that RDI increased fruit set, while calcium content fruit was slightly increased. The highest calcium content was found in RDI 75% treatment. It is recommended a moderate water stress by RDI 70% during fruit pith hardening stage save water without undesirable effects on fruit yield and quality.

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References

Behboudian M. H., Mills T. M. (1997). Deficit irrigation in deciduous orchards. Hortic Rev 21(4):105-132.

Behboudian M. H., Lawes G. S., Griffiths K. M. (1994). The influence of water deficit on water relations, photosynthesis and fruit growth in Asian pear (*Pyrus serotina* Rehd.). Sci Hortic 60: 89-99

Berman M. E., Dejong T. M. (1996). Water stress and crop load effects on fruit fresh and dry weights in peach (*Prunus persica*). Tree Physiology 16: 859-864.

Bloem, J., Deruiter P. C., Koopman G. J., Lebbink G., Brussaard L. (1992). Microbial numbers and activity in dried and rewetted arable soil under integrated and conventional management. Soil Biol Biochem 24: 655–665.

Bolat I., Dikilitas M., Ercisli S., Ikinci A., Tonkaz T. (2014). The Effect of water stress on some morphological, physiological, and biochemical characteristics and bud success on apple and quince rootstocks. Sci World J 20:1-8.

Bramlage W. J., Weis S. A. (2004). Postharvest fruit quality and storage life in relation to mineral nutrients. J Am Soc Hortic Sci 12: 11-12.

Chai Q., Gan Y., Turner N. C., Zhang R. Z., Yang C., Niu Y., Siddique K. H. M. (2014). Water-saving innovations in Chinese agriculture. Adv Agron 126:147–197.

Chai Q., Gan Y., Zhao1 C., Xu H., Waskom M. R., Niu Y., Siddique K. H. M. (2016). Regulated deficit irrigation for crop production under drought stress. A review Agron Sustain Dev 36(3):1-21.

Chalmers D. J., Mitchell P. D., Van Heek L. (1981). Control of peach tree growth and productivity by regulated water supply, tree density and summer pruning. J Am Soc Hort Sci 106: 307-312.

Chapman H. D., Pratt F. P. (1982). Determination of minerals by titration method. Methods of analysis for soils, plants and water, 2nd edn. Oakland, CA: Agriculture Division, California University, 169-170

Chenafi A., Monney P.H., Arrigoni E., Boudoukha A., Carlen, C.H. (2016). Influence of irrigation strategies on productivity, fruit quality and soil-plant water status of subsurface drip-irrigated apple trees. Fruits 71(2): 69-78.

Cheng F., Sun H., Shi H., Zhao Z.H, Wang Q., Zhang J. (2012). Effects of regulated deficit irrigation on the vegetative and generative properties of the pear cultivar 'Yali'. J Agr Sci Tech 14: 183-194.

Gasque M., Granero B., Turegano J. V., Gonzalez-Altozano P. (2010). Regulated deficit irrigation effects on yield, fruit quality and vegetative growth of 'Navelina' citrus trees. Spain J Agri Res 8(2): 40-51.

Gelly M., Recasens, I., Girona, J., Mata, M., Arbones, A., Rufat, J., Marsal, J., 2004. Effects of stage II and postharvest deficit irrigation on peach quality during maturation and after cold storage. J Sci Food Agric 84: 561–568.

Girona, J., Gelly, M., Mata, M., Arbones, A., Rufat, J., Marsal. J. 2005. Peach tree response to single and combined deficit irrigation regimes in deep soils. Agr Water Manag. 72:97-108.

Girona, J., Mata M., Arbones A., Alegre S., Rufar J., Marsal J. (2003). Peach tree responses to single and combined regulated deficit irrigation regimes under shallow soils. J Am Soc Hortic Sci 128(3): 432-440.

Intrigliolo D., Castel J. R. (2010). Response of plum trees to deficit irrigation under two crop levels: Tree growth, yield and fruit quality. Irrigation Sci 28(6): 525-534.

Jaroszewska A. (2011). Quality of fruit Cherry, Peach and Plum cultivated under different water and fertilization regimes. J Elementol 16(1): 51–58.

Jones J. B. (2001). Laboratory guide for conducting soil tests and plant analysis. CRC Press. 384 Pages.

Li S. H. (1993). The Response of sensitive periods of fruit tree growth, yield and quality to water stress and water saving irrigation. Plant Physiol Commun 29 (1): 10–16.

Li S. H., Huguet J. G., Schoch P. G., Orlando P. (1989). Response of peach tree growth and cropping to soil water deficit at various phenological stages of fruit development. J Hortic Sci 64:541L 552.

Lopez G., Arbones A., Del Campo J., Mata M., Vallverdú X., Girona J., Marsal J. (2008). Response of peach trees to regulated deficit irrigation during stage II of fruit development and summer pruning. Spain J Agric Res. 6:479-491.

Lopez, G., Girona J., Marsal, J. (2007). Response of winter root starch concentration to severe water stress and fruit load and its subsequent effects on early peach fruit development. Tree Physiol. 27:1619-1626.

Maatallah S., Guizani M., Hjlaoui H., El Houda Boughattas N., Lopez-Lauri F., Ennajeh M. (2015). Improvement of fruit quality by moderate water deficit in three plum cultivars (*Prunus salicina* L.) cultivated in a semi-arid region. Fruits. 70(6): 325-332.

McCarthy M.G., Loveys B.R., Dry P.R., Stoll M. (2002). Regulated deficit irrigation and partial root zone drying as irrigation management techniques for grapevines. Deficit irrigation practices, FAO Water Reports. 22: 79-87.

Mahhou A., Dejong T. M., Cob T. K., Shackel S. (2012). Water stress and crop load effects on vegetative and fruit growth of 'Elegant Lady' peach (*Prunus persica* L. Batch) trees. Fruits. 60: 55–68.

Marsal J., Rapoport H. F., Manrique T., Girona J. (2000). Pear fruit growth under regulated deficit irrigation in container-grown trees. Sci Hortic 85: 243-259.

Mitchell P. D., Chalmers D. J. (1982). The effect of reduced water supply on peach tree growth and yields. J Am Soc Hortic Sci 107: 853-856.

Mpelasoka B. S., Behboudian M. H. (2002). Production of aroma volatiles in response to deficit irrigation and to crop load in relation to fruit maturity for 'Braeburn' apple. Postharvest Biol Tech. 24: 1–11.

Munitz S., Netzer Y., Schwartz A. (2017). Sustained and regulated deficit irrigation of field-grown Merlot grapevines. Aust J Grape Wine Res 23(1): 87-94.

Naor A., Peres M., Greenblat Y., Gal Y., Ben-Arie R. (2004). Effects of pre-harvest irrigation regime and crop level on yield, fruit size distribution and fruit quality of field-grown 'Black Amber' Japanese plum. J Hortic Sci Biotechnol 79: 281-288.

Pacheco C., Calouro F., Vieira S. (2008). Influence of nitrogen and potassium on yield, fruit quality and mineral composition of kiwifruit. Energy Environ 2:517-521.

Perez-Pastor A., Domingo R., Torrecillas A., Ruiz-Sanchez M. C. (2009). Response of apricot trees to deficit irrigation strategies. Irrigation Sci 27: 231-242.

Pérez-Pastor A., Ruiz-Sánchez M.C., Domingo R. (2014). Effects of timing and intensity of deficit irrigation on vegetative and fruit growth of apricot trees. Agric. Water Manage. 134: 110-118.

Perez-Pastor A., Ruiz-Sanchez M. C., Martinez J. A., Nortes P., Artes F., Domigo R. (2007). Effect of deficit irrigation on apricot fruit quality at harvest and during storage. J Sci Food Agric 87: 2409-2415.

Perez-Sarmiento F., Alcobendas R., Mounzer O., Alarcon J., Nicolas E. (2010). Effects of regulated deficit irrigation on physiology and fruit quality in apricot trees. Span. J. Agric 8(S2): 86-94.

Perez-Sarmiento F., Miras-Avalos J. M., Alcobendas R., Alarcon J. J., Mounzer O., Nicolas E. (2016). Effects of regulated deficit irrigation on physiology, yield and fruit quality in apricot trees under Mediterranean conditions. Spain J Agric Res. 14(4): 1-12.

Podesta L. N., Vallone R. C., Morabito J. A., Sanchez, E. E. (2011). Long-term effect of water deficit irrigation on cherry vigor and precocity. Acta Hortic. 889:439-444.

Razouk, R., Ibijbijen, J., Kajji, A and Karrou, M. (2013). Response of Peach, Plum and Almond to water restrictions applied during slowdown periods of fruit growth. Amer J Plant Sci 4(3): 561-570.

Samperio, A., Henar Prieto, M., Blanco-Cipollone, F., Vivas, A and Monino, M. J. (2015). Effects of post-harvest deficit irrigation in 'Red Beaut' Japanese plum: Tree water status, vegetative growth, fruit yield, quality and economic return. Agric Water Manag 150: 92–102.

Sanchez-Rodriguez E., Rubio-Wilhelmi M. D, Cervilla L. M., Blasco B., Rios J. J., Leyva R., Romero L., Ruiz J. M. (2010). Study of the ionome and uptake fluxes in cherry tomato plants under moderate water stress conditions. Plant Soil 335:339–347.

Santesteban L.G., Mirandam Royo J.B. (2011). Regulated deficit irrigation effects on growth, yield, grape quality and individual anthocyanin composition in *Vitis vinifera* L. cv.'Tempranillo'. Agric Water Manag 98(7): 1171-1179.

Sortiropoulos T., Kalfountzos D., Aleksious I., Kotsopoulos S., Koutinas N. (2010). Response of a clingstone peach cultivar to regulated deficit irrigation. Sci Agric 67(2):164-169.

Stino R. G., Abd El-Mohsen M. A., Shawky M. E., Yhai M. M. (2016). Impact of applied irrigation regime during specified phenological stages on cropping and its' attributes of "Le-conte" pear. Annals of Agric Sci 54(4): 877-789.

Tanguilig V. C., Yambao E.B., O'Toole J. C., Dedatta S. K. (1987). Water-stress effects on leaf elongation, leaf water potential, transpiration, and nutrient-uptake of rice, maize, and soybean. Plant Soil. 103:155–168.

Thakur A., Singh Z. (2013). Deficit Irrigation in Nectarine: fruit quality, return bloom and incidence of double fruits. Eur J Hortic Sci 78(2): 67-75.

Treeby M., Henriod R., Bevington K. B., Milne D. J. (2007). Irrigation management and rootstock effects on navel orange [*Citrus sinensis* (L.) Osbeck] fruit quality. Agric Water Manag 91(1-3): 24-32.

Turner L. B. (1985). Changes in the phosphorus content of *Capsicum annum* leaves during water stress. J Plant Physiol 121:429–439.

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