American Journal of Plant Sciences, **2013, 4, 109-113**
Published Online December 2013 (http://www.scirp.org/journal/ajps)
http://dx.doi.org/10.4236/ajps.2013.4.12A3013

Effect of Regulated Deficit Irrigation on Productivity, Quality and Water Use in Olive cv "Manzanilla"

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Received October 26th, 2013; revised November 29th, 2013; accepted December 18th, 2013

ABSTRACT

The objective of this experiment was to determine the effect of different regulated deficit irrigation (RDI) strategies on productivity, oil quality and water-use efficiency on olive grown in the Sonoran Desert. The experiments were carried out in 2009 and 2010, and in a ten years old traditional (10 × 5 m) "Manzanilla" olive orchard. The control treatment was irrigated at 100% ETc during the whole season while RDI treatments were applied at 75% ETc or 50% ETc. The two RDI were applied during two phenological stages: at postharvest to evaluate the effect on table olive or from pit hardening to harvest to evaluate the effect on oil olive. Our results indicated that RDI applying 50% ETc during postharvest period reduced significantly fruit set and table olive yield, while applied during pit hardening to harvest period, it decreased oil yield but increased oil content. The RDI applying an ETc of 75% during the postharvest period gave similar table olive yield to the control, and applied form of pit hardening to harvest also gave similar oil yield to the control. The RDI using an ETc of 75% resulted in the highest water-use efficiency for oil or table olive production.

Keywords: *Olea europaea* L.; Water Stress; Yield and Quality; Water Save

1. Introduction

Mexico has about 9000 ha cultivating olive tree, where almost 50% Mexican are located in the arid and semi-arid regions. Caborca and Sonora, the main areas of table olive producer in México, have about 2000 ha planted with this tree and produce approximately 10,000 ton annually, all of which are exported to United State [1].

The climate conditions are characterized by low precipitation (100 to 150 mm per year) occurring mainly during the summer months-high temperature and low atmospheric humidity. These conditions result in an annual ETo of 2200 mm which determines a high water demand by crops [2].

The contribution of precipitation to the water demand of olive trees is insignificant and basically the crop depends exclusively on irrigation. The sustainability of olive production in the area requires improving the crop's water productivity.

Regulated deficit irrigation (RDI) causes a temporary and controlled water deficit in a specific phenological stage. RDI is commonly used in several fruit trees in order to reduce the amount of water applied with minimal or no reduction in fruit production [3]. For olive trees, the second phase of fruit growth, corresponding to the pit hardening period, is the most resistant to water deficit [4]. In the first phase, fruit growth corresponds, when most cell division occurs, and in the third phase, when the olive oil is accumulated, it is sensitive to water stress [5,6].

Some studies indicate that RDI did not affect the yield fruit and fruit weight [7,8], acidity and peroxide value [9]; however it increases oil content, polyphenol concentration and oil stability [7,10]. On the other hand, RDI reduced flowering next year [11] and accelerated ripening [12]. The response to RDI depends on the olive variety [13]. Little information is available about RDI effects on table olive and oil olive quality of the Manzanilla cultivar which is grown in the arid warm climates.

The objective of this work was to determine the effect

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of different RDI strategies on productivity, oil quality and water-use efficiency in the cv Manzanilla.

2. Materials and Methods

2.1. Orchard Selection and Management

The experiments were carried out in 2009 and 2010 at the National Research Institute for Forestry, Agricultural and Livestock (INIFAP), located in Caborca, Sonora, Mexico (30˚42'55"N, 112˚21'28"W and 200 m. a. s. l.), in a ten years old traditional (10 × 5 m) "Manzanilla" olive orchard. The soil was sandy loam with pH 7.96 and electrical conductivity of 1.22 dSm^{-1}. Olive trees were maintained in accordance to commercial recommendations [1]. The trees were drip irrigated by using two emitters for tree (12.0 $L \cdot ha^{-1}$). Orchard olive was fertilized in both years with 15-15-15 at a rate of 1.5 kg $tree^{-1}$ (468 $kg \cdot ha^{-1}$) during February and March and with ammonium nitrate (300 $kg \cdot ha^{-1}$) during the postharvest period. The trees were slightly pruned in November in both years. Table olive was harvested during last week of August and the oil olive was harvested during second week of September. Both harvests were made manually.

2.2. RDI Treatments Applied

Different irrigation treatments, based on RDI strategies were applied in 2009 and 2010. The first experiment consisted in the following treatments: 1) Control (100% ETc), 2) RDI-75 and 3) RDI-50. RDI-2 consisted in applying an ETc of 75% from the second week of August to the third week of November 2009 (postharvest), and RD-3 in applying an ETc of 50% in the same period. The second experiment, conducted in 2010, had the same treatments but the period of water restriction was from third week of May to last week of September, the period from the pit hardening to harvest. In both experiments the cultivar was Manzanilla but in the first experiment was for table olive and in the second experiment for oil olive. ETo was calculated every week based on the meteorological data using an automatic station (Campbell Scientific Ltd., Shepshed, UK) during the whole season.

2.3. Measurement Variable

In the first Experiment the vegetative parameters plant height, shoot length and width canopy were evaluated taking 12 trees per treatment, in mid November of each season. Yield components as floral density floral (flower per cm^{-2}) and fruit set (%), choosing one floral shoot per each side of the tree was also evaluated. Yield (kg $tree^{-1}$) of table olive and quality fruit were evaluated. Fruit weight, fruit diameter, fruit length and pulp and pit ratio were evaluated taking a random sample of 100 fruits for each tree. Water use efficiency was obtained according the next equation: WUE = Yield $kg \cdot ha^{-1}$/water applied (mm). In the second experiment similar variables were evaluated but in addition, fruit oil percentage was measured according to [14,15] and some parameters of oil quality as acidity (% oleic acid), peroxide value (meq. of O_2 per kg) and total polyphenols (ppm of caffeic acid) as described by [15,16]. Also, we recorded weather pa- rameters during both experiments (**Table 1)**.

2.4. Statistical Analysis

Experimental design in both years was a randomized complete block and four replications with an experimental unit of 12 trees. Means were separated with the least significant difference test (LSD) at 0.05 probability level.

3. Results and Discussion

3.1. Experiment 1

3.1.1. Vegetative Parameters and Yield Components

RDI strategies during the period of postharvest did not affect significantly plant height, shoot length and canopy size (**Table 2**). Fruit set was statistically affected ($p < 0.05$) while the density flower was not (**Table 3**). The fruit set percent in Control and RDI-75 was similar (1.43% and 1.38% respectively), while in RDI-50 was statistically reduced to 1.25%. These results do not agree with Tognetti *et al*. [17] who found that RDI at 50% decreased canopy volume and trunk diameter in Koroneiki cultivar. Other study of water stress indicated that a Kc of 75% and 50% decreased 8.6% height plant and 14.2% trunk diameter with respect to control (Kc 100%) in Manzanillo cultivar of six years old [18]. The reduction of

Table 1. Weather parameters recorded during the study period.

Weather parameters	Experiment 1	Experiment 2
Medium temperature (˚C)	21.9	30.0
Rainfall (mm)	17.8	74.4
Relative humidity (%)	38.7	38.9
Solar radiation (Kilowatt. m^{-2})	0.153	0.206

Table 2. Vegetative growth parameters in different RDI applied during postharvest on table olive.

Treatments	Plant height (m)	Shoot length (cm)	Canopy width (m)
Control	5.1 ± 0.26	25 ± 1.87	4.2 ± 0.21
RDI-75	5.0 ± 0.19	25 ± 3.53	4.1 ± 0.26
RDI-50	4.7 ± 0.12	23 ± 2.55	3.8 ± 0.14
Significance	ns	ns	ns

Means followed by same letter in a column do not differ significantly (LSD 0.05); ns = non significant.

Table 3. Yield components in different RDI applied on table olive.

Treatments	Floral density (flowers cm^{-2})	Fruit set (%)
Control	3240 ± 530	1.43 ± 0.06 a
RDI-75	2950 ± 337	1.38 ± 0.02 a
RDI-50	3100 ± 420	1.25 ± 0.08 b
Significance	ns	*

Means followed by same letter in a column do not differ significantly (LSD 0.05); ns = non significant; *Significant at 0.05 probability level.

vegetative growth could reduce pruning cost [17]. Floral density was not statistically different among RDI treatments while fruit set percent decreased as the water was reduced. Fruit set for Control and RDI-75 were similar with values of 1.43% and 1.38%, while for RDI-50 was reduced to 1.25% ($p < 0.05$) with. Other researchers [19] indicated that water stress during whole season decreased drastically fruit set on Koroneiki cultivar when ETc were 50% and 25%. Grattan *et al*. [20] found the number of fruits per branch, the number of fruits per inflorescence, fruit density and fruit set increased with an increase of ETc up to 71% - 89%.

3.1.2. Table Olive Yield and Fruit Quality

According to **Table 4** there is significant difference among RDI tested on table olive yield ($p < 0.01$), fruit weigh ($p < 0.01$) and fruit diameter ($p < 0.05$). The higher yield was obtained in Control and RDI-75 with 11,040 and 10,280 kg·ha^{-1} without statistical difference between them, while RDI-50 had reduction on the table olive yield of 28.6% and 21.3% in comparison with Control and RDI-75, respectively. The low yield in RDI-50 was due to a lower fruit set in this treatment. Goldhamer [8] found that a reduction of 15% and 25% in water supply during midsummer, did not have a negative impact on canning olive yield, but a reduction by 44%, decreased yield by 10%. Others studies indicated different effects on yield when RDI was imposed and the responses were different among years [7]. Weight and fruit diameter were similar between the control and RDI-75. In both parameters RDI-50 was the better treatment and statistically different to control and RDI-75%. Fruit weight in RDI-50 was 12.2% and 8.1% greater in comparison to the control and RDI-75, respectively, and fruit diameter in RDI-50 was 11.1% greater than the other treatments. The differences in fruit weight and fruit diameters may be due to the different fruit load among treatments. Moriana *et al*. [5] found that fruit weight decreased drastically in response to the level of water stress and fruit load. During severe deficit irrigation, fruit diameter growth slowed; however, after reintroduction of full irrigation, growth accelerated [21]. RDI did not significantly affect pulp and pit ratio.

3.2. Experiment 2

3.2.1. Oil Yield and Oil Content

There were statistical difference ($p < 0.01$) among treatments in oil yield and oil content when RDI strategies were applied during pit hardening to harvest period in the same variety. Oil production per hectare in RDI-75 was 26.5% and 10.4% less in comparison with the Control and RDI-50, respectively. In contrast, the oil content was higher in RDI-50 with 8.7% and 9.6% more that Control and RDI-75, respectively (**Table 5**). The high oil content in RDI-50 is probably as a consequence of lower water content in the olive. Vita *et al.* [7] found that RDI at 50% ETc applied in the same period decreased 26% oil yield. However, other studies indicated not differences in oil yield when RDI was imposed [12,22]. Goldhamer *et al.* [23] found that oil content was significantly higher for all RDI strategies applied in comparison to the control, and the most severely stressed had an increase in oil content about 30%.

3.2.2. Oil Quality

No statistical differences among treatments on peroxide value, acidity and total polyphenols were found in the experiment (**Table 6**). Total polyphenols was increased as the amount of supplied water decreased, although without statistical difference. These results are accordance with those previously reported in Arbequina variety [7,9,10].

3.2.3. Water Use Efficiency

The amount of water applied in postharvest period in RDI-75 was 215.8 mm while in the control it was 431.6 mm, in the first experiment. In the second experiment the RDI-75 received 325 mm and the control 650.1 mm of water from pit hardening to harvest. Water use efficiency (WUE) measured as fruit yield or oil yield (kg) per mm of irrigation water, was greater for both periods when RDI-75 was applied, reaching values of 0.83 during pit hardening to harvest period (**Table 7**). These values are less that those reported by Vita *et al.* [7] for a six years old intensive Arbequina olive orchard. By other side, RDI-75 could save until 12.4% (163 mm) when RDI is applied during pit hardening to harvest period. Goldhamer [8] suggests that the RDI regime that saves about 25% (200 mm) of full ETc may be useful in conserving water while maintaining top yield and high fruit quality.

4. Conclusion

A regulated deficit irrigation applying 75% ETc during the postharvest period allows saving water without affecting table olive yield and quality, while the same wa-

Table 4. Olive table yield and fruit quality in different RDI applied during postharvest.

Treatments	Yield ($kg \cdot ha^{-1}$)	Fruit weight (g)	Fruit diameter (cm)	Pulp-pit ratio
Control	11040 ± 2212 a	4.3 ± 0.26 b	1.6 ± 0.08 b	3.9 ± 0.12
RDI-75	10280 ± 1520 a	4.5 ± 0.22 b	1.6 ± 0.07 b	3.8 ± 0.08
RDI-50	7920 ± 11230 b	4.9 ± 0.18 a	1.8 ± 0.07 a	3.8 ± 0.10
Significance	**	**	*	ns

Means followed by same letter in a column do not differ significantly (LSD 0.05); ns = non significant; *Significant at 0.05 probability level and **Significant at 0.01 probability level.

Table 5. Oil yield and oil content in different RDI applied during pit hardening to harvest period.

Treatments	Oil yield ($kg \cdot ha^{-1}$)	Oil content (%)
Control	1020 ± 71.2 a	10.5 ± 0.22 b
RDI-75	956 ± 62.5 a	10.6 ± 0.24 b
RDI-50	750 ± 55.3 b	11.5 ± 0.21 a
Significance	**	**

Means followed by same letter in a column do not differ significantly (LSD 0.05); **Significant at 0.01 probability level.

Table 6. Oil quality in different RDI applied during pit hardening to harvest period.

Treatments	Peroxide value (meq O_2 kg^{-1})	Acidity (% oleic acid)	Polyphenols (ppm of caffeic acid)
Control	15.2 ± 0.90	0.45 ± 0.02	153 ± 12.8
RDI-75	14.8 ± 0.59	0.48 ± 0.01	174 ± 14.3
RDI-50	15.6 ± 0.73	0.43 ± 0.02	180 ± 22.0
Significance	ns	ns	ns

Means followed by same letter in a column do not differ significantly (LSD 0.05); ns = non significant.

Table 7. Water applied and water use efficiency (WUE) during postharvest period and pit hardening to harvest period.

Treatments	Experiment 1		Experiment 2	
	Water applied (mm)	WUE (kg of fruit. mm^{-1})	Water applied (mm)	WUE (kg of oil. mm^{-1})
Control	1416.4	7.79	1305.0	0.78
RDI-75	1308.5	7.85	1142.5	0.83
RDI-50	1200.6	6.60	980.0	0.76

ter application from pit hardening to harvest also saves water without affecting oil yield. Under that water management, the highest water-use efficiency was achieved in this study.

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