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Productive and vegetative response to different irrigation and fertilization strategies of an Arbequina olive orchard grown under super-intensive conditions

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ABSTRACT

The rise in olive oil consumption in most of the world's leading markets in recent years has forced the producers to seek for ways of increasing the productivity of their olive groves. Intensive and super-intensive orchards allow reducing production costs per liter, but largely depend on water and fertilizer supplies. Since olive is traditionally cultivated in regions where water is a scarce resource, stating the optimal irrigation doses for vegetative and productive response is essential. In this piece of work, super-intensive Arbequina tree behavior was found to be affected by water, nitrogen and potassium availability. Full irrigation led to the highest vegetative growth and yield, while reducing water supply to 25% of the needs from July to September 10th resulted in lower growth and in a yield reduction of 9.6% in the most productive year. Reducing also the water supply to 70% of the needs during the rest of the year (but using subsurface drip irrigation) resulted in an even lower productive response. Nitrogen fertilization had a straight effect on enhancing productivity, but potassium was only useful if soil and tree reserves had been depleted.

1. Introduction

The traditional extensive systems, with low production per hectare and high labor requirements, result in high production costs per liter that reduce olive oil competitiveness in the international market (Proietti et al., 2012). At this point, it seems that the sustainability of olive oil production is linked to the use of new managing techniques of irrigation-based, high-density plantations (Rufat et al., 2013). Intensive and super-intensive olive orchards, in which trees are trained to form hedgerows, allow the mechanization of any operation, even pruning or harvesting. In addition, these systems can enter full production in only a few years.

Selecting the appropriate olive variety is one of the most important issues to be defined when planning a brand-new super-intensive plantation. According to several studies, Arbequina, Arbosana and Chiquitita (from Spain) and Koroneiki (from Greece) are the most suitable cultivars due to their vegetative (low vigor and erected habit) and productive behavior, as well as the excellent sensorial features of their oil (Allalout et al., 2011; Rallo et al., 2007; Proietti et al., 2012; Tous et al., 2011). Among these, Arbequina is commonly admitted to be the one that provides the best results (Proietti et al., 2012; De la Rosa et al., 2007; Tous et al., 2008).

Notwithstanding this fact, the study of the optimal irrigation and fertilization strategies to be applied to a certain cultivar should also be a matter of discussion, since they depend on a number of factors such as plant-soil-ambient interaction or water availability, which is scarce in many olive-producing regions (Rufat et al., 2012). In traditional (rainfed) orchards of adult Arbequina olive transformed into support-irrigated, it has been proved that deficit irrigation techniques during pit hardening do not pose adverse effects on oil production, although in some cases the number of fruits and oil yield may be reduced (Alegre et al., 2002; Iniesta et al., 2009). In a trial with a high-density plantation (1709 trees ha^{-1}) with young trees (less than 3 years), Grattan et al. (2006) kept irrigation doses below 71% of the water needs, leading to a significantly lower vegetative growth and achieving a similar yield to the control.

Besides water, nutrition is the other key factor for fruit production and quality (Weinbaum et al., 1992). In the last decades, more than 55% of the increase in crop production, especially in

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Table 1
ET_0, rain and irrigation and fertilization values for the three years.

Year	Month	ET_0 (mm)	Rain (mm)	Irrigation (mm)			Fertilization (kg/ha)	
				T-100	RDI	SDI-70	N-50	K-100
2010	April	95	27	11	7	7		
	May	137	45	43	34	30	21	46
	June	151	70	69	62	47	21	46
	July	183	2	70	33	19		
	August	154	24	77	18	20		
	September	101	45	65	35	32	11	21
	October	66	37	3	4	3		
2011	April	110	15	37	35	20		
	May	147	45	58	48	46	22	41
	June	157	6	83	80	63	17	31
	July	171	21	90	24	25		
	August	166	0	111	29	33		
	September	114	6	63	54	46	16	35
	October	73	11	34	34	29		
2012	April	96	52	12	8	8		
	May	151	13	77	64	52	8	29
	June	173	16	61	51	44	24	8
	July	170	6	88	33	32	14	23
	August	166	4	103	26	29		
	September	102	38	69	48	46	9	37
	October	54	92	12	12	10		

emerging countries, comes from the use of chemical fertilizers, with nitrogen and potassium fertilizers being dominant (Gonzalez-Dugo et al., 2010). Such macronutrients have a great influence on plant and fruit growth and quality and on several aspects of plant water regime. The aim of this three-year study was to determine the productive response and vegetative development of an adult super-intensive Arbequina olive plantation to deficit irrigation, applied by surface and subsurface drip irrigation and in combination to the application of nitrogen and potassium. This fact would provide new insights to the suitability of super-intensive orchards and the possibility of applying long-term deficit-irrigation procedures to adult olive trees in the climatic conditions of the Lleida horticultural area.

2. Materials and methods

2.1. Experimental site and climate, soil and irrigation water properties and soil determinations

The trial was conducted on a commercial adult olive plot (cv. Arbequina) in Torres de Segre (Lleida) during the years 2010, 2011 and 2012. The climate is continental Mediterranean-type, with average rainfall of 350 mm per year, irregularly distributed. The trees were planted in summer 2002 at 4.5 m × 2.2 m, resulting in a density of 1010 trees ha^{-1}. In 2010 the ETo was 1068 mm and the rainfall 403 mm. In 2011, the values were 1120 and 308 mm for ETo and rainfall, respectively, and in 2012, 1137 mm for ETo with 292 mm of rainfall.

The soil was moderately deep, calcareous with a pH of 8 and an organic matter content of 1.5%, with a silty-loam texture and an electrical conductivity (EC 1:5) of 1.4 dS/m (due to the presence of gypsum). Initial contents of nitrate-nitrogen ($N\text{-}NO_3^-$), phosphorus (P) and potassium (K) in the soil were 23, 50 and 131 ppm, respectively.

The irrigation system consisted of auto-compensated drip emitters every 60 cm and a flow rate of 2.3 L/h, used for both surface and subsurface systems. The lines were placed at a distance of 50 cm from the tree trunk and, in the case of subsurface irrigation, the lines were buried at 20 cm. Irrigation water came from the Segre river and was managed by the irrigation district of Carrassumada. Water conductivity was 0.9 dS/m, chloride 2.25 meq/L and sodium 2.14 meq/L, with boron content below 0.15 ppm and 9 ppm for nitrate.

Soil moisture was monitored continuously with ECH2O-10 capacitance probes (Decagon Devices Inc., Pullman, Washington, USA) that were installed in 2009. Two trees from two elementary plots were selected representing each irrigation treatment. Three ECH2O probes were inserted into the soil at a distance of 70 cm from one side of the trunk and at depths of 20, 40 and 60 cm, within the wetted soil volume. The average soil volumetric water content was recorded based on hourly readings, being determined based on the recharge level (50%) and field capacity level (100%) (Ferrer et al., 2011).

At the beginning and the end of each growing season, a composite soil sample was taken from each elementary plot to a depth of 0.25 m to determine soil $N\text{–}NO_3$ content.

2.2. Experimental design and irrigation and fertilization treatments

The trial consisted of 48 plots as a result of crossing the irrigation treatments (3) with the fertilizing treatments (4) with four replicates, randomly distributed in blocks. Each plot consisted of 18 trees distributed into three adjacent rows, in which the 4 central trees were monitored. Vegetative growth was assessed by means of two parameters: canopy volume, estimated in December, and pruning weight, measured in April. Meanwhile, fruit yield, oil yield and oil content on a fresh matter basis were used as productive indicators.

Table 1 shows the values of monthly ET_0, rain and the applied irrigation and fertilization treatments. The irrigation treatments, daily-applied, were:

(1) T-100: 100% of the water requirements throughout the year, according to the FAO methodology (Allen et al., 1998) and Kc values from Girona et al. (2002).
(2) RDI: Application of different amounts of water according to the following scheme:
    March to June, 100% of the requirements.
    July, August and until September 10th, 25% of the requirements.
    September and October, 100% of the requirements.