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Water management of olive trees (*Olea europaea* L.) in a hilly environment of Central-South Italy

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Abstract. Olive tree is one of the most tolerant species to water stress. The experiment was carried out in Italy on five olive cultivars: Ascolana tenera, Nocellara del Belice, Itrana Maiatica e Kalamata. Four irrigation treatments were compared: a not irrigated control, a treatment fully irrigated during all season and two deficit irrigation levels that received an amount of water of 33 and 66% of ETc from pit hardening stage to fruit veraison. Results showed that a complete replacement of ETc would result in an averaged yield increase of 20% in comparison with 66%, though applying up to two times the seasonal water amount. So starting irrigation at the pit hardening stage supplying the crop with an amount of water of 66% of ETc is feasible for a water saving strategy in this experimental environment. The yield increase was primarily due to the higher fruit weight according to the enhancement in irrigation volume. Yield of the two years was 'off' for all cultivars probably for the high density of plantation that caused difficulties in air circulation. Plantation density was planned under the hypothesis to cut one plant after another within the row after 15–18 years to obtain a final density of 277 plant ha^{-1}. After 15 years of growth this hypothesis become reasonable.

Keywords. *Olea europaea* L. – Deficit irrigation – Irrigation scheduling – Yield.

Gestion de l'eau des oliviers (Olea europea L.) dans un environnement collinaire de l'Italie du Sud

Résumé. *L'olivier est l'une des espèces qui mieux supportent le stress hydrique. Cette expérimentation a été menée en Italie sur cinq cultivars: Ascolana tenera, Nocellara del Belice, Itrana Maiatica et Kalamata. On a comparé quatre régimes d'irrigation: une parcelle témoin non irriguée, une parcelle totalement irriguée pendant toute la saison, deux parcelles recevant respectivement un apport d'eau égal à 33 et 66% de l'ETc à partir du stade de durcissement du noyau jusqu'à la véraison. Si l'on compare la production obtenue et l'eau reçue par la parcelle totalement irriguée et celle recevant 66% de l'ETc on constate que, malgré un apport en eau jusqu'à deux fois supérieur à l'apport saisonnier, la production des plantes totalement irriguées n'augmente que de 20%. En conclusion, dans notre milieu expérimental, un régime d'irrigation apportant 66% de l'ETc pendant la phase de durcissement du noyau s'est démontré faisable et a permis une économie d'eau. L'augmentation de la production a été principalement causée par une augmentation du poids des drupes correspondant à l'augmentation du volume d'irrigation. La production des deux années a été «off» pour tous les cultivars, ce qui probablement dépend de la haute densité de la plantation empêchant une bonne circulation de l'air. La densité de plantation a été conçue se basant sur l'hypothèse que, après 15-18 ans, on effectuerait une coupe alterne dans chaque rangée aboutissant à une densité finale de 277 plantes par ha^{-1}. Cette hypothèse peut être prise en considération après 15 ans de vie des arbres.*

Mots-clés. *Olea europaea L. – Irrigation déficitaire – Pilotage de l'irrigation – Rendement.*

I – Introduction

Mediterranean climate is characterized by dry and hot summers and cold and humid winters. Abiotic stresses combined with climate variability are the limiting factors for quality and yield of agricultural production. Recent previsions of global change climate predict that in the Mediterranean region winter precipitation will increase near the year 2050, while summer precipitation will decrease by 10 to 15%. In addition, the agricultural sector should also bear an increase in water rates caused by the increase in demand, energy costs and distribution. This general situation makes crucial to study irrigation scheduling models that allow avoiding water losses and improving water use efficiency.

It is recognized that olive tree is one of the most drought tolerant fruit trees, but water responses of this species to good soil water supply is higher compared with other fruit species (Xiloyannis *et al.,* 1999) in terms of efficient use. In addition, studies demonstrated that irrigation strategies partially satisfying water consumption in fixed phenological stages (RDI) minimize detrimental effect on fruit yield and on vegetative development (Alegre *et al.,* 2000, Goldhamer *et al.,* 1999, Girona *et al.,* 2002). In Spain, the *cv*. Arbequina showed that irrigation volumes of 75 and 50% of ETc supplied from pit hardening to the beginning of fruit ripening resulted in no significant yield reductions compared with the control, while the water saving was 24 and 35%, respectively. In the same trial 25% of ETc restitution caused a 16% yield loss and a 47% water saving compared with the control due to a lower number of fruit per tree and a lower fruit fresh mass (Alegre, 2001). Thus a rationale irrigation scheduling is essential to reach high quality standard of final production and high and stable yield. Drought adaptations of olive trees depends on several anatomic characteristics such as leaf cuticular waxes, stomata present only in the abaxial position and covered by trichomes and physiological mechanisms such as the ability to withstand low water content and water potential in the tissues. This ability allows establishing a gradient between leaves and roots systems and soil that allows water uptake below the conventional wiling point. This characteristic of olive trees, as reported by Xiloyannis *et al.*, (1999) and Dichio *et al,.* (1994), permits to utilize soil water also at water potential of -2.5 MPa. Under water stress conditions the canopy transpiration rate is higher than root water uptake during the morning independently of soil water conditions (Gucci, 2007). Consequently, the water content in the plant tissues is reduced to satisfy the transpiration flux. Tissues could loss about 60% of water showing high capacitance that permits transpiration when the evaporative demand of the environment is high (Xiloyannis *et al.,* 1999). As a consequence of high water stress, olive tree stops vegetative growth by increasing stomatal resistances and reduce gas exchange to a very low rate. Although, since the fruit yield depends on the time course of vegetative development and reproductive phases during its biennial cycle, the effects of water stress allow negative impacts not only during the season but also in the subsequent years.

The present study summarizes field experiment results of five olive tree cultivars growing in a hilly area of Central-South Italy. The aim of the work was to test the hypothesis that irrigation applied from pit hardening to fruit veraison, in the study area, would allow good crop yield while saving water.

II – Material and methods

The field trial was carried out in the period 2006-2007 in a typical area of southern Italy at CNR-ISAFoM experimental farm (Benevento, 41°06', 14° 43'; 250 m above sea level). The orchards was established in 1992 and trees were planted to a density of 555 plant per hectare (6 x 3 m).

The soil texture is sandy-loam and the soil has a volumetric water content of 35.6% at field capacity (-0.03 MPa) and 21.2% at wilting point (-1.5 MPa), an organic matter content of 1.76%, a CaCO3 of 1% and a pH of 7.2. The experimental orchard was planted in 1992 with one-year-old trees grafted in a nursery on DA-12-Io clonal rootstock (Fontanazza *et al.,* 1992) - patent IRO-CNR no. 1164/NV. Trees were trained using the central leader training system (Fontanazza, 1993) with a planting density of 6 x 3 m. The plantation density was proposed at field establishment as 'dynamic' since after 15th – 18th years of growth one plant on the row should be cut and the final density should become 277 plant ha-1 (6 x 6 m). At field establishment and during the first two years after planting, all trees were irrigated equally to guarantee uniform development. Differentiation of irrigation treatments started in 1994. Irrigation water was delivered daily, using a system with 4 drip nozzles (two per side) of 4 l h^{-1} per tree set in a line along the rows at a distance of 0.50 and 1.00 m from the trunk.

Five olive cultivars for table consumption and double aptitude were tested: Ascolana tenera, Nocellara del Belice, Itrana Maiatica e Kalamata. Four irrigation treatments were applied: a not irrigated control (T0), a treatment fully irrigated (100% of maximum evapotranspiration, ETc) during the all season (T100) and two deficit treatments that received 33 and 66% of ETc (T33 and T66) irrigated from pit hardening to fruit veraison. Reference (ETo) evapotranspiration was estimated adopting Penman-Monteith model and data were adjusted with a crop coefficient equal to 0.65 and a tree ground coefficient of 0.85.

The experimental design was a split-plot, replicated four times with irrigation treatments in the main plots and cultivars in the sub-plots. Each sub-plot consisted of 7 trees.

To assess water regime effect on plant growth, trunk diameter was measured at regular intervals at 0.4 m above the soil level and at pruning time removed wood was collected and weighted. Dry matter of pruned material was determined on a sample after oven dry.

Fruits of each elementary plot were harvested when the cultivars were suitable for table consumption. Yield components were analyzed by determining fruit weight (fresh and dry weight), flesh-to-pit ratio and fruit diameters (longitudinal and equatorial) on a sample of 50 fruits per elementary plot.

Data were analysed using the SAS statistical package. Analysis of variance (ANOVA) was applied by cultivar since the variance was not homogeneous. The interaction between years and irrigation levels was not significant therefore, data presented are means of the two years. Means separation between irrigation treatments was performed with the Least Significant Differences test (LSD) at the 0.05 level.

III – Results and discussion

The climatic conditions of the experimental site were characterized by a mean annual precipitation of 736 mm (1984 - 2007 average) mainly occurring in fall and spring months, while scarce or no rainfall events were generally detected from mid-June to mid September. The yearly mean reference evapotranspiration was about 1233 mm. Differences between the two experimental years were essentially due to precipitation amount and seasonal distribution that influenced the irrigation volume, while temperatures were near the poliannual mean. In the first year, rainfall during the irrigation season accounted for 54.4 mm, with rainy events that occurred at the end of July and first decade of August (Tab. 1).

Table 1. Irrigation volume, crop evapotranspiration (ETc)) and useful rainfall (> 5 mm within 24 h) during the irrigation period of each experimental year.

Treatment	Irrigaton period		ETc	Useful rain	Irrigation volume
	beginning	end			
				mm	
33	27/07/06	14/09/06	117	54.4	21
66	27/07/06	14/09/06	117	54.4	41
100	26/06/06	14/09/06	217	58.0	159
33	24/07/07	07/01/07	191	10.6	57
66	24/07/07	07/01/07	191	10.6	115
100	20/06/07	07/01/07	307	10.6	297

By contrast the second year was drier and only 10.6 mm of useful rain were detected during the all season. Irrigation of T100 started when the soil water content was about the 50% of the total available water for a soil layer of 1.40 m (Fig. 1). These conditions were detected on 20 and 26 June of 2006 and 2007, respectively. For the other two deficit irrigated treatments water was delivered from 27 and 24 July of 2006 and 2007 respectively, when the beginning of pit hardening phase was monitored. Soil water content showed value below 50% of available water at the end of May in all years, while at the time of starting irrigation for treatment T33 and T66 (doy 207) soil water content was near the wilting point. Subsequently the soil profile was gradually replenished by rainfall, with different patterns among years according to the amount of precipitation. Irrigation supply ended in the mid of September in the first year since rainfall replenished the soil layer explored by the root systems while in the second year was necessary to deliver irrigation water until 7 October.

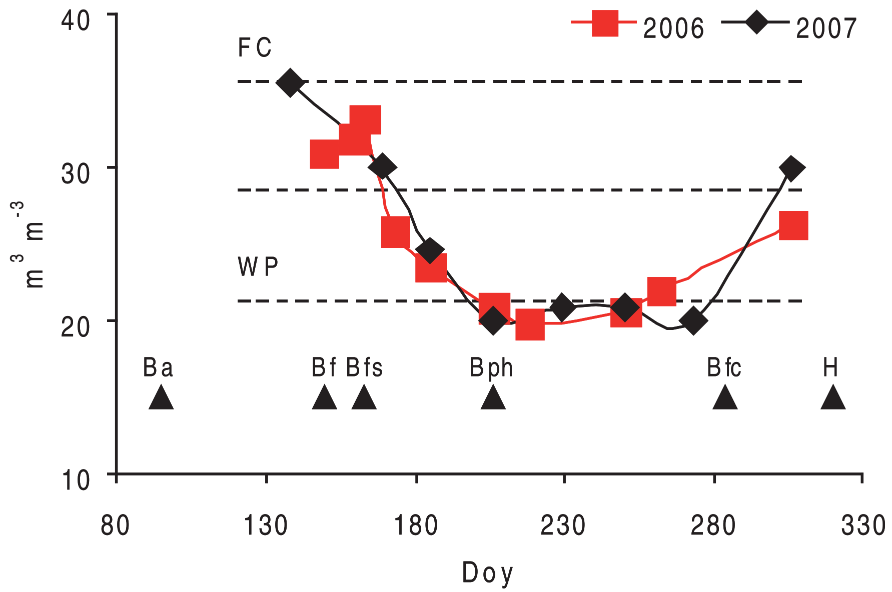

Figure 1. Volumetric soil water content in the top 1.40 m soil layer of rainfed control treatment during the irrigation season of two experimental years (Doy = day of year). Main phenological stages of the cultivars are reported: FC = field capacity, WP = wilting point, Ba = blossom appearing, Bf = beginning of flowering, Bfs = beginning of fruit set, Bph = beginning of pit hardening, Bfc = beginning of fruit veraison, H = harvest.

Across years, cultivars and treatments, stomatal conductance was exponentially related to water potential (Fig. 2).

Stomata are integrators of all environmental factors affecting plant growth, resulting in a wider scattering of stomatal conductance than water potential. These olive trees were able to restrict water loss by modulating stomatal closure at different irrigation levels. The sensitivity of stomata to irrigation might have also reduced the impact of water stress on fruit yield.

Growth patterns of the tested cultivars showed similar behaviour in response to water regime. Pruned wood evaluated as the mean weight of dry matter (DM) removed in the two years, increased according to the increase in irrigation levels (Fig. 3).

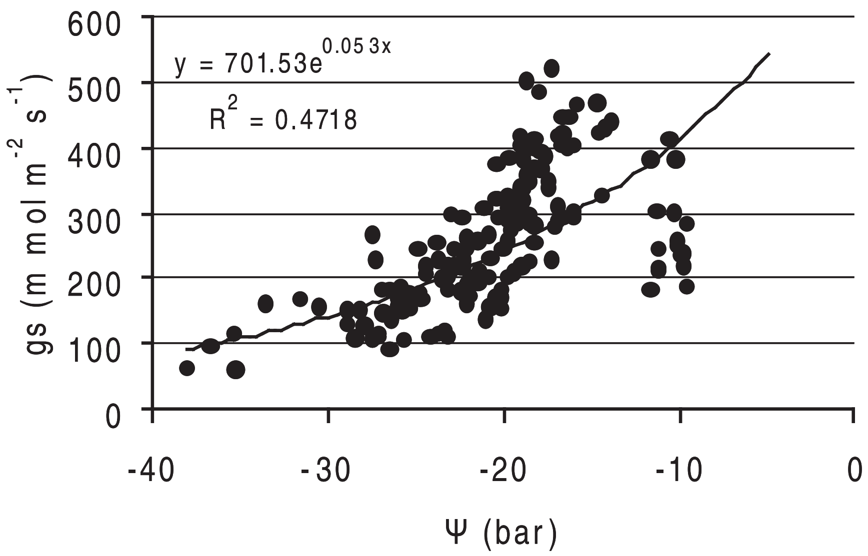

Figure 2. Exponential relation between stomatal conductance (gs) and water potential (?). Relationship between water potential and stomatal conductance for pooled data collected in 2006 2007. Regression parameters of exponential function fitted to data are also reported.

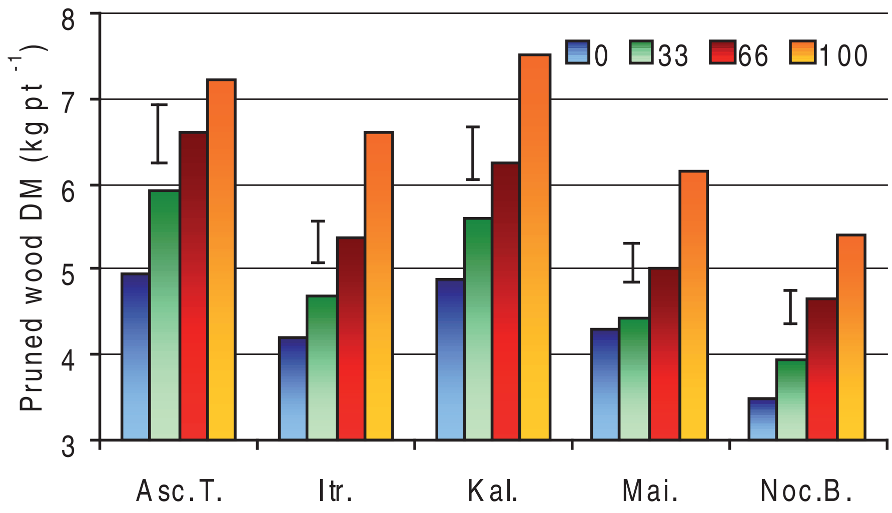

Figure 3. Mean weight of dry matter (DM) of pruned wood removed in the two years as a function of treatments and cultivars. Bars represent LSD value at P = 0.05.

Differences between treatments were significant in all cultivars, while only a trend was found between T0 and T33 for cv. Maiatica. Similar response to watering regime was reported by Magliulo *et al.* (2003) in the same environment for cultivar Frantoio and Leccino and by d'Andria *et al.* (2004) on the same cultivars of the present experiments. In these experiments deficit irrigation (replacing 33% of ETc during the all irrigation season) environment did not show significant increments in comparison with rainfed treatments. These findings are related to present environmental conditions with sufficient spring rainfall that guarantees enough water throughout the vegetative development. By contrast, a restitution of 66 and 100% of water consumption allows significant increments of canopy development. This aspect could have an economic impact since pruning expenses for olive trees generally account for 20-30% of annual cultural costs, being second only to harvesting. Accordingly, the optimisation of deficit irrigation strategy may be economically profitable further limiting tree size and vegetative development with the central leader training system (Gucci and Cantini, 2000). Similar findings were found for trunk area and crown volume (data not shown). Nocellara and Maiatica were the least vigorous cultivars.

Yield of the two years were 'off' for all cultivars (Fig. 4). This behavior was probably due to the high plantation density that caused difficulties in air circulation and high humidity within the canopy, allowing the diffusion of pathogen fungi such as cycloconium. In addition, solar radiation within the canopy was scarce. Itrana, Maiatica and Nocellara del Belice were the most sensitive cultivars to experimental conditions. Plantation density was planned under the hypothesis to cut one plant after another within the row after 15–18 years to obtain a final density of 6 x 6 m (277 plant ha^{-1}).

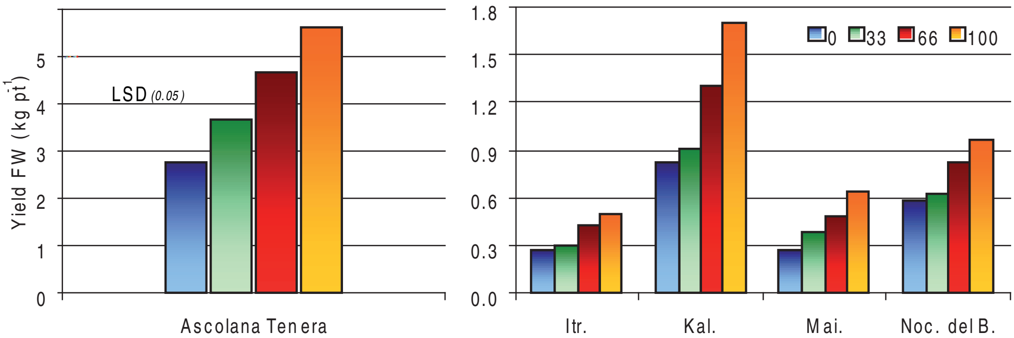

Figure 4. Mean yield of the two years as a function of treatments and cultivars. Bars represent LSD value at P = 0.05.

Besides, yield significantly increased with the increase of irrigation amounts in the most productive cv., Ascolana tenera. Fully irrigated plants during the all season had higher yield than T66 treatment, only for Ascolana tenera and Kalamata. However, in Kalamata, yield was not significantly different between T0 and T33. Itrana, Maiatica and Nocellara del Belice showed effects of irrigation only between T0 and T100. The lack of irrigation effects in these three cultivars was probably due to the generally low productivity in the two experimental years.

The yield increase was primarily due to the higher fruit weight and number according to the enhancement of irrigation volume (Tab. 2). Fruit fresh and dry weights were affected by irrigation treatments, showing marked differences between irrigation levels in all cultivars.

The greatest fruit weight of T100 resulted from the increase in both width and length of fruits, while the shape (polar – equatorial ratio) was not affected by the irrigation regime.

Irrigation favoured the development of fruit flesh. This pattern was due to the increase in flesh–to-pit ratio in all cultivars. In particular, the highest increment was shown by Ascolana tenera between T0 and T100.

Table 2. Fresh and dry weight of fruit, flesh-pit ratio and shape (polar-equatorial diameter ratio) as a function of treatments and cultivars. Data are the mean of two experimental years. The LSD value at P = 0.05 is reported.

Cultivar	Treatment	fresh weight	dry weight	flesh-pit ratio	Diameter pol.-equat. ratio
		g			
Ascolana T.	0	5.03	1.61	3.82	1.29
Ascolana T.	33	5.87	1.82	3.94	1.32
Ascolana T.	66	6.73	1.87	4.91	1.30
Ascolana T.	100	7.73	2.17	5.43	1.24
	$LSD_{(0.05)}$	0.82	0.22	1.03	ns
Itrana	0	3.68	1.35	2.65	1.19
Itrana	33	3.83	1.38	2.91	1.18
Itrana	66	4.67	1.72	2.80	1.18
Itrana	100	4.79	1.77	2.90	1.16
	$LSD_{(0.05)}$	0.38	0.17	ns	ns
Kalamata	0	3.64	1.33	3.72	1.45
Kalamata	33	3.91	1.45	3.86	1.51
Kalamata	66	4.57	1.62	3.63	1.46
Kalamata	100	5.48	1.97	4.48	1.46
	$LSD_{(0.05)}$	0.53	0.14	0.54	ns
Maiatica	0	2.19	0.64	2.53	1.30
Maiatica	33	2.86	0.79	2.86	1.31
Maiatica	66	3.45	0.94	3.15	1.30
Maiatica	100	4.24	1.24	3.57	1.30
	$LSD_{(0.05)}$	0.35	0.13	0.63	ns
Nocellara B.	0	3.93	1.42	3.21	1.15
Nocellara B.	33	4.54	1.62	3.85	1.16
Nocellara B.	66	5.03	1.78	4.51	1.11
Nocellara B.	100	5.74	1.98	4.09	1.18
	$LSD_{(0.05)}$	0.53	0.19	0.76	ns

IV – Conclusions

The increase in fruit size with increasing irrigation levels was primary determined by dry matter accumulation in both endocarp and mesocarp, following similar patterns in each treatment. Bigger fruits had greater equatorial and longitudinal diameter or area; therefore, the overall fruit shape was only marginally affected by deficit irrigation. The yield increase with irrigation was due primarily to a higher fruit weight (d'Andria *et al.* 2004) and fruit number in both cultivars (data not shown).

Between others, one important aspect of irrigation delivered only in the most sensitive phenological phases was a better control of vegetative development, thus reducing plant strength and pruned wood, without high detrimental effects on fruit yield, which should lead to a considerable increase in water use efficiency. This was evident in the most irrigated treatment that yielded a higher vegetative development as compared with T66.

Results implied that a complete restitution of ETc (T100) would result in an average yield increase of 20% in comparison with T66, though applying up to two times the seasonal water amount. This suggests that starting irrigation at pit hardening, supplying the crop with a water amount of 66%

of ETc, is feasible for a water saving strategy in these experimental conditions. In these pedo-climatic conditions, delaying water supply could be achieved particularly considering management costs, such as water, energy and pruning.

Training system adopted (central leader) and plant density (555 plants per hectare) of this olive plantation should be strongly revised according to the present results. After 15 years of growth the hypothesis to cut one plant after another within the row become reasonable, to avoid detrimental effects on yield performances and plant pathology. The central leader training system could be still grantable, in terms of management costs for the varieties of the present experiment.

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