

# The effect of complementary irrigation on fruit growth, ripening pattern and oil characteristics of olive (*Olea europaea* L.) cv. Carolea

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## SUMMARY

Complementary irrigation, 80 mm, distributed only during the third stage of fruit development, delayed ripening time and increased fruit size and oil content for fruits of the olive cv. Carolea. Prolonged water deficit reduced fruit growth, oil accumulation rate, K content of the fruit and enhanced ripening and pre-harvest fruit drop. Harvest time affected oil characteristics more than the water availability. Fatty acid composition was not affected by the water regime but polyphenol content increased and alcohol content decreased in the oil produced by irrigated trees.

THE response of olive (*Olea europaea* L.) to prolonged water deficits has been widely investigated in terms of adaptive behaviour, i.e. gas exchange and stomatal functioning (Deidda *et al.*, 1990; Xiloyannis *et al.*, 1988), tree growth and dry-matter partitioning within root and canopy components (Nuzzo *et al.*, 1994), fruit growth and ripening pattern (Agabbio, 1977; Dettori and Russo, 1993; Lavee and Wodner, 1991; Spiegel, 1955).

Complementary irrigation, distributed during critical stages of fruit growth, particularly during the enlargement of mesocarp cells, increases fruit weight, percent flesh, overall tree production and oil yield (Baratta *et al.*, 1985; Dettori *et al.*, 1990; Dettori and Russo, 1993; Lavee *et al.*, 1990). However, percent oil content in the pericarp usually decreases under fully irrigated conditions because of a proportionally larger increase of the water content of the fruit (Lavee *et al.*, 1990; Lavee and Wodner, 1991; Spiegel, 1955; Vitagliano, 1969). Indeed, a water deficit lasting up to the third stage of the fruit development period (FDP) may change the rate pattern of oil accumulation and fruit ripening (Lavee and Wodner, 1991; Vitagliano, 1969) and result in a sharp reduction of final oil content in fruit pericarp (Dettori *et al.*, 1990; Rotundo *et al.*, 1992).

Despite the large influence that water availability has on fruit growth and ripening and oil accumulation, the possible relationship between water availability and oil characteristics has been merely investigated so far.

In this study we investigated the effect of different water regimes, imposed during the third stage of the FDP, on fruit growth and ripening and oil characteristics.

## MATERIALS AND METHODS

The research was carried out during 1992 at Lamezia Terme (CZ) 39° 00' Lat N, on nine year old own rooted trees of olive cv. Carolea, trained to a globe shape and spaced 7 × 5 m apart. The orchard is on a clay-loam soil (sand 48%, silt 15%, clay 37%) which reaches field capacity and wilting point respectively at 22.3% and 8.4% soil water content.

Two water regimes were imposed to 15 trees per treatment, distributed in three replicates laid out in a randomized block design. Trees were irrigated only during the third stage of the FDP: 60 (3 August), 80 (23 August), 100 (13 September) and 120 (4 October) days after full bloom (1 June). The irrigated plots received 80 mm of irrigation water, supplied through a drip irrigation system, with two on-line drippers (4 l h<sup>-1</sup>) per tree, each placed 0.75 cm from the tree-trunk base. Control trees

were left unirrigated throughout the FDP. Annual rainfall was 480 mm and no rains occurred from 21 May to 28 October. Soil water content was measured on soil samples taken every 20 d at depths of 30, 60 and 90 cm and 1.2 m from the tree-trunk base. During the irrigation period samples were taken one-day before the water was supplied. Samples were fresh weighted and then dried to constant weight, in a ventilated oven at 105°C, to measure dry weight. Stomatal conductance was measured at 0900 hours with a Li-Cor 6200 diffusive porometer (L-Cor, Lincoln, NE, USA) on five fully exposed leaves on fruitless branchlets of two trees per treatment. Measurements were taken to coincide with irrigation supply dates, but last measurement (4 October) is not reported because of data failure. Fruit fresh weight was measured every second week on 100 fruits per treatment. Oil was extracted by Soxhlet from five samples of 20 fruits per treatment, and oil content was calculated on a fruit dry-weight basis. Fruit ripening was monitored, fortnightly, from 105 d (15 September) to 225 d (5 January 1993) after full bloom, according to the development of colour in both epicarp and mesocarp. Pre-harvest fruit drop was measured from 135 d (15 October) to 225 d after full bloom, collecting and weighing the fruits shed in nets placed under each of 15 trees per treatment.

From the end of October (30 October) and every second week until the end of December (30 December), a sample of 1 kg of drupes was randomly collected from each tree. The oil was then extracted with an oil mill from three samples of 5 kg of drupes per treatment. Fruit fresh weight, flesh to pit ratio and fruit ripening stage were measured on each sample.

Oil composition was determined, 30 d after extraction, according to the official EEC methods and analytical parameters (Gazzetta Ufficiale, 1991). Fruit were harvested and yield per tree measured 225 d after full bloom.

To smooth the effect of discrepancies of pre-harvest fruit drop and relative oil content related to the different ripening pattern of irrigated and rainfed trees, fruit and oil yield per tree were calculated on the basis of fruit fresh weight, oil relative content and pre-harvest fruit drop measured at the date of beginning of epicarp blackening (150 and 165 d after full bloom for rainfed and irrigated trees respectively).

Data were analyzed by two-way analysis of variance and standard errors (SE) were calculated for any set of data.

#### RESULTS

Soil water content at 30, 60 and 90 cm depth was significantly affected by the irrigation regime (Table I). In mid-July (15 d before the first irrigation was applied) the soil water content at 30–60 cm had fallen to 40% of the total available water (TAWC). During the irrigation period, in the irrigated plots the soil water content never dropped below 60% of TAWC. In the dry plots and at 30–60 cm depth, it remained close to the wilting point throughout the third stage of the FDP. Differences between plots were significant even at 90 cm soil depth. Only after October rains did the soil water content show the same values in dry and irrigated plots (Table I). At this stage fruit on non-irrigated trees had already begun to ripen. Stomatal conductance was significantly lower in unirrigated trees on all measurement dates, showing a higher degree of plant water stress during the third stage of the FDP (Table II).

TABLE I  
Soil water content (%) measured at 30, 60 and at 90 cm soil depth, during the fruit development period of 'Carolea' olive (*Olea europaea*) trees

	Soil depth (cm)	Days after full bloom						
		40	60	80	100	120	140	160
<i>Irrigated trees</i>								
	30	14.0	17.0	16.3	16.5	15.7	17.0	20.1
	60	14.5	17.5	17.0	16.8	16.7	17.2	20.5
	90	17	18.5	19.1	20.4	20.6	20.8	21.3
<i>Non-irrigated trees</i>								
	30	14.3	9.0	8.6	7.5	7.0	6.9	20.1
	60	14.7	10.7	8.9	8.6	8.6	8.6	20.9
	90	16.3	14.3	12.7	12.3	11.9	11.7	21.9

TABLE II  
Stomatal conductance ( $\text{cm}^2 \text{s}^{-1}$ ) measured at 0900 hours in fully exposed leaves of irrigated and non-irrigated 'Carolea' olive (*Olea europaea*) trees

	Measurement dates		
	3 Aug	23 Aug	13 Sept
Irrigated	0.64	0.62	0.68
Non-irrigated	0.48	0.39	0.37
	**	**	**

\*\*denote significant differences at  $P \leq 0.01$ .

Irrigation had a major effect on the extent of fruit growth determined on a fresh-weight basis (Figure 1). On irrigated trees fruit growth was basically linear throughout the third stage of the FDP and ceased at the beginning of epicarp blackening (Figures 1 and 2). Water deficit significantly reduced fruit growth, particularly mesocarp development (Table III), and the slight decrease of fruit fresh weight, apparent in September when the soil water content in the dry plots reached the lowest values, indicates a temporary loss of water by the fruit pericarp. In October, the lower evaporative demand and then the first rains resulted in a further growth of the fruit even at an advanced stage of ripening (Figures 1 and 2).

Indeed, most of the fruit which grew on non-irrigated trees completed epicarp blackening within the second week of November, more

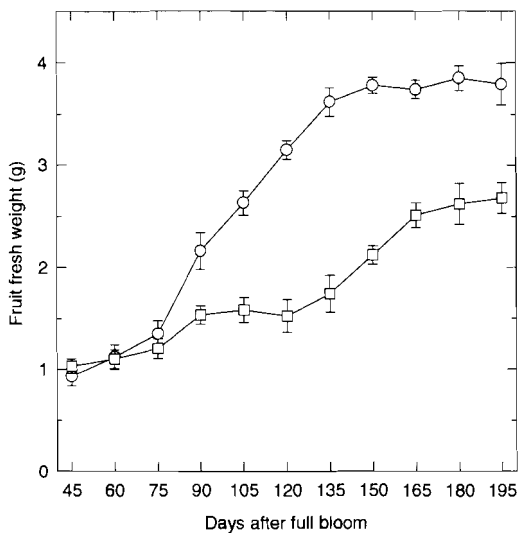


FIG. 1

Fruit growth pattern in terms of fresh weight, for irrigated (○) and rainfed (□) trees of the olive cv. Carolea. Points are means  $\pm$  SE.

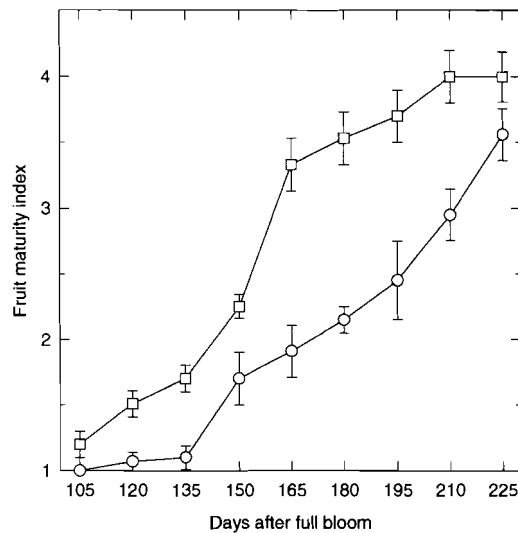


FIG. 2

Ripening pattern of fruits in irrigated (○) and rainfed (□) trees of the olive cv. Carolea. Values on the vertical axis refer to maturation stages as follows: 1 = green ripe fruits; 2 = beginning of epicarp blackening (5% of the drupes); 3 = colouration of epicarp completed; 4 = mesocarp blackening completed in 50% of the drupes. Data are mean  $\pm$  SE.

than four weeks earlier than those growing under non-stressed conditions (Figure 2). Moreover, the time-lapse between the beginning and end of pericarp blackening was much shorter under non-irrigated conditions (Figure 2).

The oil accumulation on a dry-weight basis showed a similar basic pattern for irrigated and non-irrigated trees except for the reduction of oil accumulation which was apparent under non-irrigated conditions consistently with the lag phase of fruit growth which occurred from 90 to 120 d after full bloom (Figures 1 and 3). The linearity of the oil accumulation pattern in fruit of irrigated trees was apparent until the onset of fruit ripening, marked by the change in epicarp colour. Under non-irrigated conditions the oil accumulation showed a higher rate until the beginning of the stress period early in September, then oil accumulation decreased significantly. October rains had no effect on oil accumulation, on a dry-weight basis, since they occurred when fruit ripening in dry plots was fairly advanced and oil accumulation was nearly completed (Figure 3). Oil accumulation on commercially mature

TABLE III

Yield, pre-harvest fruit drop, percent oil and fruit characteristics of cv. Carolea under irrigated and non-irrigated conditions

	Fruit <sup>1</sup> production kg/tree	Pre-harvest <sup>2</sup> fruit drop %	Oil <sup>1</sup> production kg/tree	Oil <sup>2</sup> content % fruit fw	Fruit <sup>2</sup> weight g	Flesh to pit ratio <sup>3</sup>
Non-irrigated	41.6 ± 3.3	18.5 ± 1.9	8.5 ± 0.7	20.5 ± 1.5	2.6 ± 0.2	3.9 ± 0.2
Irrigated	51.4 ± 5.6	14.4 ± 1.3	11.4 ± 0.5	22.0 ± 1.3	3.7 ± 0.2	5.8 ± 0.6

<sup>1</sup>At the date of beginning of epicarp blackening, i.e. 150 d and 165 d after full bloom for non-irrigated and irrigated trees, respectively.

<sup>3</sup>Percent of the total yield at harvest.

fruits was significantly higher for irrigated than non-irrigated trees, on a dry-weight (Figure 3) but not on a fresh-weight basis (Table III).

The pattern of pre-harvest fruit drop was basically similar for both irrigated and non-irrigated trees (Figure 4), whereas the final extent changed with water availability (Figure 4, Table III). Under non-irrigated conditions the highest rate of fruit drop occurred from 150 to 165 d after full bloom, consistent with the onset of mesocarp blackening for most of the drupes. At harvest time (225 d after bloom), fruit drop was higher for non-irrigated than for irrigated trees. However, fruit drop measured at stage 2 and 3 of fruit ripening (from the beginning to end of epicarp blackening) was unaffected by the water regime (Figure 4).

The irrigation supply resulted in a significantly higher (ca. 20%) fruit yield per tree, due

to a significant increase in fruit fresh weight (Table III). Indeed, pit weight did not increase with irrigation (data not shown), which favoured flesh development as shown by the higher (ca. 50%) flesh to pit ratio measured on irrigated trees (Table III). The increase in fruit yield per tree should not be related to any difference in pre-harvest fruit drop since it was calculated at the beginning of epicarp blackening, when fruit drop was still negligible and unaffected by treatment.

Irrigation increased the oil yield per tree by 35% (Table III). The potassium concentration in the drupes was higher for irrigated than non-irrigated trees, particularly during the third stages of fruit growth (90–180 days after full bloom) (Figure 5).

Changes in fruit growth and ripening pattern, final fruit characteristics and oil accumulation which were imposed by the different

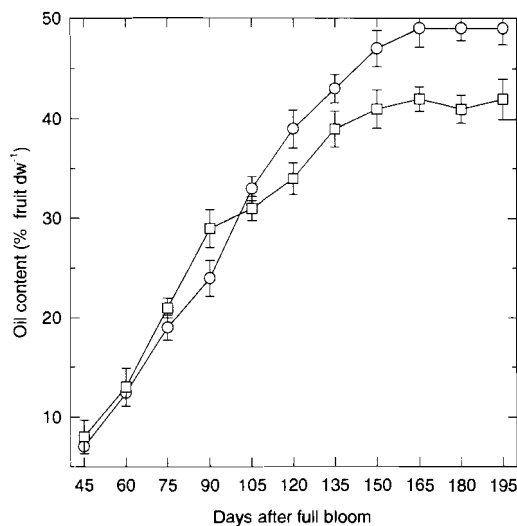


FIG. 3

Percent oil accumulation pattern, on dry-weight basis, in irrigated (○) and rainfed (□) trees of the olive cv. Carolea. Data are means ± SE

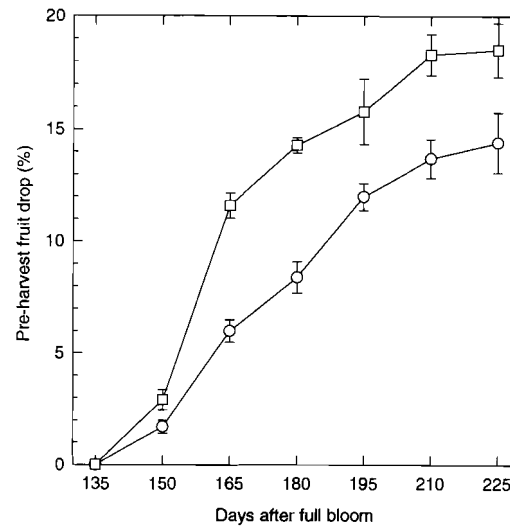


FIG. 4

Cumulative pre-harvest fruit drop pattern as a percent of total yield in irrigated (○) and rainfed (□) trees of the olive cv. Carolea. Data are means ± SE.

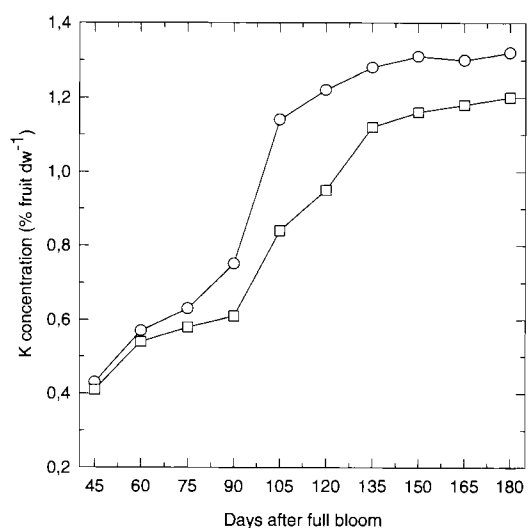


FIG. 5

Time course of potassium concentration in fruit of irrigated (○) and rainfed (□) trees of the olive cv. Carolea.

water regimes had no significant effect on fatty acid composition (Table IV), oleic to linoleic ratio and the peroxide number (Table V)

TABLE IV

Significance of the influence of harvest date and water regime on the composition of cv. Carolea olive oil

Parameters	Harvest date	Water regime	Interaction
<i>Fatty acid</i>			
Palmitic	**	n.s.	**
Heptadecanoic	*	n.s.	n.s.
Stearic	*	n.s.	*
Oleic	*	n.s.	*
Linoleic	n.s.	n.s.	**
Linolenic	n.s.	n.s.	*
Arachic	**	n.s.	n.s.
<i>Alcohol</i>			
Phytol	**	**	*
Docosanol	*	**	*
Tricosanol	*	n.s.	n.s.
Tetracosanol	n.s.	*	n.s.
Pentacosanol	*	*	**
Hexacosanol	n.s.	n.s.	n.s.
Heptacosanol	**	n.s.	*
Octacosanol	n.s.	n.s.	n.s.
Cicloartenol	*	n.s.	*
Citrostadienol	*	*	*
Amirine	n.s.	*	*
<i>Sterol</i>			
Campesterol	*	**	*
Campestanol	*	n.s.	*
Clerosterol	n.s.	n.s.	n.s.
B-sitosterol	n.s.	**	*
Sitosterol	*	*	**
D5-avenasterol	*	*	n.s.

(\*), (\*\*) denote significance of the treatment at  $P < 0.05$  and  $P < 0.01$  respectively. n.s. = not significant.

TABLE V

Polyphenols and peroxides content and oleic/linoleic ratio (means  $\pm$  SE of five harvest dates) in olive oil of cv. Carolea, as related to water regime

	Polyphenols mg kg <sup>-1</sup>	Peroxides meq O <sub>2</sub> kg <sup>-1</sup>	Oleic/ linoleic
Non-irrigated	148.8 $\pm$ 7.5	9.6 $\pm$ 0.09	11.8 $\pm$ 0.30
Irrigated	175.6 $\pm$ 11.0	9.5 $\pm$ 0.12	12.7 $\pm$ 0.36

measured in the oil produced by irrigated and non-irrigated trees. Polyphenol content increased (Table V), and alcohol content decreased, with irrigation (Table VI).

Fatty acid, alcohol and sterol composition were largely affected by harvest time and the interaction between water regime and harvest time was highly significant for most of the fatty acids, alcohols and sterol considered (Table IV).

## DISCUSSION

The pattern of oil accumulation and fruit ripening determines the timing and efficiency of mechanical harvesting as well as olive oil characteristics (Barone *et al.*, 1994; Zucconi *et al.*, 1976; Lavee and Wodner, 1991). Based on data measured under highly differentiated environmental and cultural conditions and on different genetic pools, Lavee and Wodner (1991) demonstrated that the pattern of oil accumulation does not depend on genetic specificity but rather on environmental conditions, particularly water availability and fruit yield (Barone *et al.*, 1994).

In this study the water stress produced direct effects on fruit growth, on oil accumulation patterns and on the final oil content in the fruit. A distinct lag phase of fruit growth was apparent under dry conditions during the

TABLE VI

Alcohol and sterol content (mg 100 g<sup>-1</sup> means  $\pm$  SE of five harvest dates) in olive oil of cv. Carolea, as related to water regime

Chemical	Non-irrigated	Irrigated
Phytol	21.5 $\pm$ 0.2	10.9 $\pm$ 0.2
Docosanol	1.9 $\pm$ 0.2	0.9 $\pm$ 0.07
Tetracosanol	3.9 $\pm$ 0.4	1.7 $\pm$ 0.2
Pentacosanol	0.4 $\pm$ 0.1	0.3 $\pm$ 0.1
Amirine	24.7 $\pm$ 0.5	18.3 $\pm$ 0.3
Citrostadienol	26.8 $\pm$ 0.6	20.4 $\pm$ 0.3
Campesterol	3.7 $\pm$ 0.1	3.0 $\pm$ 0.1
B-sitosterol	151.2 $\pm$ 0.5	131.0 $\pm$ 0.2
Sitosterol	0.8 $\pm$ 0.1	0.6 $\pm$ 0.1
D5-avenasterol	16.4 $\pm$ 0.4	11.8 $\pm$ 0.5

period of highest fruit growth and oil accumulation rate measured in irrigated trees. This lag phase of fruit growth was accompanied by a reduction of stomatal conductance and oil metabolism in the fruit and was not fully recovered after the autumn rains. Indeed, the low potassium assimilation, whose concentration in the fruit is highly correlated with oil accumulation (Deidda, 1968), indicates a sharp reduction of fruit sink strength induced by the water stress. Water shortage usually imbalances the sink strength of the canopy and the roots, in favour of a larger root development (Nuzzo *et al.*, 1994). On the other hand potassium availability to roots usually decreases with water shortages (Marschner, 1986). Furthermore, the diversity of the oil accumulation pattern from linearity indicates the degree of a water stress and the cultivar sensitivity to it (Lavee and Wodner, 1991); thus the marked effect that the water deficit had on the fruit growth and oil accumulation pattern indicate the trees' poor ability to recover from water shortage, probably because of a relatively small root system which had developed under routinely drip-irrigated conditions in the previous growing seasons. Indeed a marked effect of water deficit on fruit growth and oil accumulation has been reported for young olive trees characterized by a reduced root volume (Dettori *et al.*, 1990).

Fruit ripening was advanced by the water shortage, and oil accumulation had stopped by the onset of epicarp blackening regardless the water availability. Oil characteristics were highly influenced by harvest time. In other words, the pattern of fruit ripening deeply affects oil quality. The high significance of the

harvest time per water regime interaction indicates that when the ripening stage of the entire population of the fruits in the tree changes rapidly and uniformly, this will necessarily result in deeper changes in the oil characteristics by time. Eventually, the optimum harvest time to increase yield and optimize oil quality will differ considerably according to the ripening pattern induced by the water availability.

Differences in oil characteristics measured for irrigated and non-irrigated trees could then develop as a direct effect of water shortage occurring during the phase of oil assimilation but might also largely depend on the frequency, during commercial harvest time, of populations of fruits highly differentiated in terms of ripening stages. These differences increase with time because fruits on non-irrigated trees mature earlier and faster. The higher content of alcohols and sterol as well the lower content of polyphenols in rainfed trees reflect the advanced stage of ripening that the fruit had already reached at the first harvest date, 150 d after full bloom.

Finally, the different speed of the fruit ripening pattern requires different strategies of fruit harvest to couple optimum yield and oil quality. As for trees with low yield (Barone *et al.*, 1994) timing and speed of harvest are crucial for water-stressed trees, whilst the slower fruit ripening pattern under irrigated conditions require a later and more flexible optimum harvest time.

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#### REFERENCES

- AGABBIO, M. (1977). Influenza dell'intervento irriguo sul ciclo produttivo dell'olivo. 1. Influenza del regime idrico sull'accrescimento delle drupe della cv 'Ascolana Tenera'. *Annali della Facoltà di Agraria dell'Università di Sassari*, **25**, 266–72.
- BARATTA, B., CARUSO, T., DI MARCO, L. and INGLESE, P. (1985). Effetti dell'irrigazione sulle caratteristiche delle olive nella cv. 'Nocellara del Belice'. *Frutticoltura*, **3/4**, 61–6.
- BARONE, E., GULLO, G., ZAPPÀ, R. and INGLESE, P. (1994). Influence of crop load on fruit ripening and olive oil (*Olea europaea* L.) quality. *Journal of Horticultural Science*, **69**, 67–73.
- DEIDDA, P. (1968). Osservazioni sull'accrescimento delle drupe nell'olivo: variazioni di alcuni macroelementi nelle foglie e nei frutti ed andamento dell'inolizione. *Studi Ssassaresi, Sez. III Annali della Facoltà di Agraria dell'Università di Sassari*, **16**, 1–15.

- DEIDDA, P., DETTORI, S., FILIGHEDDU, M. R. and CANU, A. (1990). Water stress and physiological parameters in young table-olive trees. *Acta Horticulturae*, **86**, 255–58.
- DETTORI, S., FILIGHEDDU, M. R. and PALA, M. (1990). Influenza del regime idrico su sviluppo e maturazione delle drupe di olivo. *Proceedings Problematiche Qualitative dell'olio di Oliva, Sassari*, 169–78.
- DETTORI, S. and RUSSO, G. (1993). Influenza della cultivar e del regime idrico su quantità e qualità dell'olio di oliva. *Olivae*, **49**, 36–43.
- GAZZETTA UFFICIALE CEE (1991). *Regolamento CEE no. 25/68 relativo alle caratteristiche degli olii di oliva e degli olii di sansa d'oliva nonché ai metodi ad essi attinenti*, No. 381.
- LAVEE, S., NASHEF, M., WODNER, M. and HARSHMESH, H. (1990). The effect of complementary irrigation added to old olive trees (*Olea europaea* L.) cv Souri on fruit characteristics, yield and oil production. *Advances in Horticultural Science*, **4**, 135–38.
- LAVEE, S. and WODNER, M. (1991). Factors affecting the nature of oil accumulation in fruit of olive (*Olea europaea* L.) cultivars. *Journal of Horticultural Science*, **66**, 583–91.
- MARSCHNER, H. (1986). *Mineral nutrition of higher plants*. Academic Press, London.
- NUZZO, V., XILOYANNIS, C., ROTUNDO, A. and ROMANO, M. (1994). Effetto della disponibilità idrica sullo sviluppo e conformazione della chioma e dell'apparato radicale dell'olivo. *Proceedings Giornate II Scientifiche SOI*. S. Benedetto del Tronto, 357–58.
- ROTUNDO, A., RUGGIERO, C. and D'ANTONIO, P. (1992). Riflessi dell'irrigazione sull'efficienza produttiva dell'olivo e sui parametri qualitativi dell'olio. *Proceedings Olive Oil Quality*, Firenze, 369–71.
- SPIEGEL, P. (1955). The water requirement of the olive trees, critical period of moisture stress and the effect of irrigation upon the oil content of its fruits. *Proceedings 14th International Horticultural Congress*, **2**, 1363–73.
- VITAGLIANO, C. (1969). Osservazioni comparative sull'olio prodotto da oliveti intensivi irrigui ed in coltura tradizionale asciutta. *Scienza e Tecnica Agraria*, **6/7**, 169–76.
- ZUCCONI, F., KASSIMIS, D. and CORVOUNIS, G. (1978). Considerazioni sulla maturazione commerciale delle olive. *Italia Agricola*, **115**, 105–12.
- XILOYANNIS, C., PEZAROSSA, B., JORBA, J. and ANGELINI, P. (1988). Effects of soil water content on gas exchange in olive trees. *Advances in Horticultural Science*, **2**, 58–63.

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