Journal of Horticultural Science (1994) **69** (1) 67–73

Effect of crop load on fruit ripening and olive oil (*Olea europea* L.) quality

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SUMMARY

The influence of individual plant yield on olive fruit ripening, oil accumulation pattern and oil quality was investigated on plants of cv. Cassanese, at full yield (100% = 26.2 kg tree^{-1}), partially reduced yield (70% = 18.4 kg tree^{-1}) and halved yield (50% = 12.5 kg tree^{-1}). Fruits of trees with halved yield were bigger and reached full black maturation stage 30 d earlier than those of the more heavily loaded trees while oil accumulated faster and reached higher final amounts. No differences in acidity, peroxides, alcohol and sterol content were recorded between treatments, but polyphenols, palmitic and linoleic acid contents were highest when the crop load was halved.

COMPETITION between fruits is one of the principal factors affecting fruit growth, ripening and final quality. Fruits compete with each other for assimilates according to their position their relative sink strength, and the availability of assimilates (Ryugo, 1988; Rallo and Fernandez Escobar, 1989). The relationship between yield and fruit quality has been widely investigated in deciduous and evergreen fruit trees (Jackson *et al.*, 1975; Monselise and Goldschmidt, 1982; Testolin, 1990 and Wolpert *et al.*, 1983). Alternate bearing species, such as olive, not only show irregular yields but fruits produced in the 'on' year can be coarse or even valueless (Monselise and Goldschmidt, 1982; Ben Tal and Lavee, 1984). In olive, intense competition between fruits during the earliest stages of their development is primarily responsible for the regulation of crop load (Baratta *et al.*, 1992; Rallo and Fernandez Escobar, 1989). Control of the fruiting potential by heavy winter pruning or early fruit thinning is necessary to achieve a yearly production of optimum sized table olives (Baratta *et al.*, 1992; Martin *et al.*, 1980). It has been reported (Vitagliano, 1969; Zucconi *et al.*, 1978; Shulman and Lavee, 1979; Lavee, 1986 and Lavee and Wodner, 1991) that not only final fruit size, but also the nature of fruit ripening and both rate pattern and final oil accumulation depend on crop load, which varies greatly with location, even within the same orchard (Monselise and Goldschmidt, 1986). Little information is available so far on the influence of crop load on final oil quality. However, recent investigations have demonstrated that oil quality is strictly dependent on the cultivar-environment interaction and, more specifically, on the nature of fruit ripening, which in olive ranges from early and brief to late and extended (Pannelli *et al.*, 1990) and varies according to cultivar, environmental conditions and horticultural practices (Pannelli and Montedoro, 1988). In the present study we investigated the role of crop load as a potential source of variability of olive fruit ripening pattern and oil quality.

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MATERIALS AND METHODS

The experiment was carried out in the coastal plan of Gioia Tauro (RC), 40° 48′ N, on seven year old, self rooted trees of cv. Cassanese irrigated and spaced 6 × 4 m apart. Forty-five trees were selected, according to canopy development and flower load at full bloom. Three distinct crop load levels were compared in a randomized block design with three replicates and five trees per treatment: untouched,

TABLE I
Characteristics (average values of five harvest dates) of fruits of cv. Cassanese as related to crop load

Plant crop load	Fresh Weight g	Flesh to pit ratio	Dry matter %	Oil[z] content % fruit dw
Full load (FL)	3.13a	5.58a	54.80a	39.61a
70% FL	3.56ab	5.93ab	56.60a	41.25a
50% FL	4.00b	6.50b	63.20b	45.75b

Within a column, different letters denote significant differences at $P<0.01$, Tukey's HSD test. [z]Late harvest date, 9 January 1992.

initial, load (FL); partially reduced load (70% FL) and halved load (50% FL). Crop load was reduced 30 d after fruit set when June drop was completed and long before the onset of oil accumulation in the mesocarp (Lavee, 1986); every second fruitlet was removed, from each of the bearing shoots throughout the tree, to halve crop load (50%) and every third fruitlet to reduce the crop load at about 70% of the original load. From 30 September 1991 to 9 January 1992, a sample of 0.7 kg of olives was collected from each tree every two weeks.

At each harvest date oil was extracted using an oil mill able to handle a sample of 5 kg olives per treatment. Oil composition was determined by official EEC methods (Gazzetta Ufficiale CEE, 1991) on four samples per treatment and harvest date. Fresh and dry fruit weight, stone weight and oil content, determined by Soxhlet and expressed on a dry-weight basis, were measured in a sample of 0.5 kg per treatment.

TABLE II
Productive parameters of cv. Cassanese as related to crop load

Plant crop load	Fruit production kg/tree	Yield efficiency kg m^{-3}[y]	Oil production kg/tree	Pre-harvest fruit drop %
Full load (FL)	26.20	2.70	4.75	13.53[z]
70% FL	18.39	1.78	3.50	14.41
50% FL	12.50	1.21	2.63	14.10
Linear coeff.	**	**	**	n.s.
Quadratic coeff.	n.s.	n.s.	n.s.	n.s.
R	0.96	0.93	0.94	—

** = Linear component significant at $P<0.01$; n.s. = not significant.
[y] Fruit yield per canopy volume.
[z] Percent of the total yield.

Flesh to pit ratio was calculated. During the entire period, fruit drop was recorded, for every tree, by collecting and weighting the drupes dropped in nets. Data were analyzed by ANOVA.

RESULTS

The highest values of average fruit fresh weight, percent dry matter, flesh to pit ratio and final oil accumulation were recorded on trees with halved crop load (Table I). The increase in fruit size, due to a greater development of epicarp, and the highest relative oil content only partially compensated for the reduction in fruit number, since the levels of harvested yield were consistent with the expected rates; yield effi-

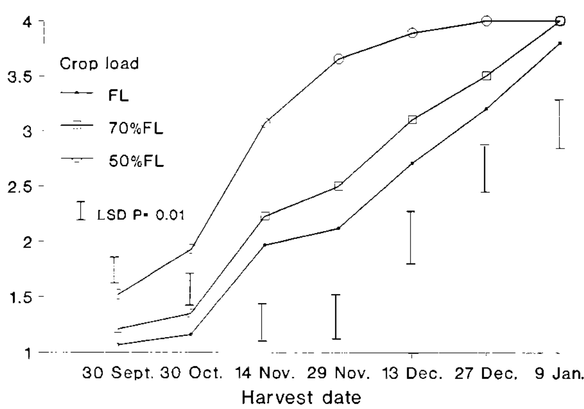

FIG. 1
Ripening pattern of olive fruits in trees with full load (100%), partially reduced load (70%) and halved load (50%). Values on the vertical axis refer to maturation stages as follows: 1 = green ripe stage; 2 = beginning to epicarp blackening; 3 = coloration of epicarp completed; 4 = full black maturation stage (epicarp and mesocarp).

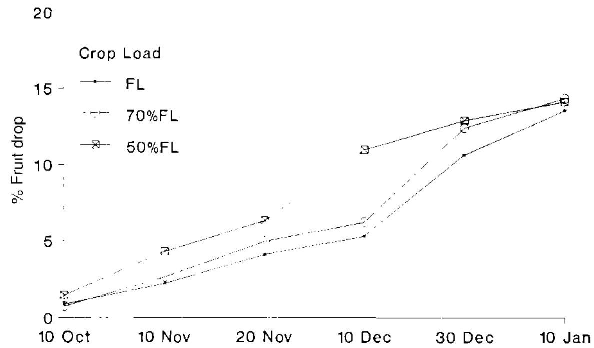

FIG. 2
Cumulative pre-harvest fruit drop as a percentage of total yield in trees with full load (FL), partially reduced load (70% FL) and halved load (50% FL).

ciency (crop load vs. canopy volume) and oil production per tree increased linearly with crop load (Table II). In trees with halved crop load, fruit ripening was advanced and more uniform and drupes reached the black epicarp maturation stage one month earlier than those of FL and 70% FL trees (Figure 1).

The pattern of fruit drop was consistent with that of fruit ripening. Most fruits were shed the second week of December from trees with a halved crop load, a month earlier than in more heavily loaded trees (Figure 2). However, there was no difference in percent fruit drop between treatments at the end of the picking season (Table II). The rate of oil accumulation and the dry weight-relative content in the fruit were the highest at 50% FL; the difference in amount of oil accumulation was significant throughout the ripening period, from green to full black maturation stage (Figure 3). Oil accumulation rate decreased when fruit epicarp became fully black.

Oil characteristics significantly changed with fruit ripening, as the analysis of variance showed for most of the variables taken into account (Tables III and IV); the highest values of oil acidity (0.9%) and number of peroxides (9.18) were reached when olives were fully black (data not shown). Differences in fruit ripening and oil accumulation rate pattern, induced by the different amounts of yield, had no effect on oil acidity, peroxides and alcohol content, while fatty acid, sterol composition and polyphenol content did change with crop load (Tables III, IV). The oil of 50% FL trees had the highest content of palmitic, linoleic acids, and polyphenols (Table V).

Palmitic acid content decreased throughout

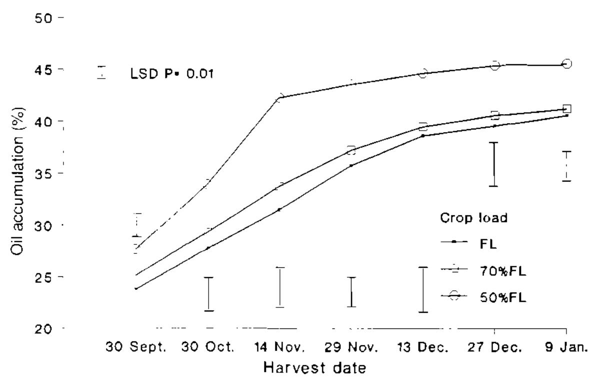

FIG. 3
Percent oil accumulation on fruit dry-weight basis in trees with full load (FL), partially reduced load (70% FL) and halved load (50% FL).

TABLE III
Significance of the effect of harvest date and crop load on the composition of cv. Cassanese olive oil

	Harvest date	Crop load	Interaction
Acidity (% oleic acid)	**	n.s.	n.s.
Peroxides (meq kg^{-1})	*	n.s.	n.s.
Polyphenols (mg kg^{-1})	**	**	**
K232 (absorbance units)	**	n.s.	n.s.
K262	**	n.s.	n.s.
K268	**	n.s.	n.s.
K274	**	n.s.	n.s.

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

ripening, whilst the amount of linoleic acid increased; the time-course was similar in all the treatments, but 50% FL trees showed the highest values until the olives begun to blacken (Figures 4 and 5). Polyphenol content in the oil produced by 50% FL trees reached the highest values towards the end of November, then decreased sharply as fruits rapidly reached the full black maturation stage (Figure 6); the change in polyphenol content of the oil of FL an 70% FL trees was more uniform throughout the maturation period, probably because of the slower fruit ripening (Figure 6).

TABLE IV
Significance of the influence of harvest date and crop load on the composition of cv. Cassanese olive oil

Parameters	Harvest date	Crop load	Interaction
Fatty acid composition (%)			
Palmitic	**	*	**
Heptadecanoic	n.s.	n.s.	n.s.
Stearic	*	n.s.	n.s.
Oleic	**	n.s.	n.s.
Linoleic	**	*	**
Linolenic	n.s.	n.s.	n.s.
Arachic	**	n.s.	n.s.
Oleic/linoleic	**	*	**
Alcohol (mg/100 g)			
Phytol	**	n.s.	n.s.
Docosanol	**	n.s.	n.s.
Tricosanol	**	n.s.	n.s.
Tetracosanol	**	n.s.	n.s.
Pentacosanol	**	n.s.	n.s.
Esacosanol	**	n.s.	n.s.
Heptacosanol	n.s.	n.s.	n.s.
Octacosanol	**	n.s.	n.s.
Cicloartenol	n.s.	n.s.	n.s.
Metilencicloartenol	**	*	**
Citrostadienol	*	n.s.	n.s.
Sterol (mg/100 g)			
Campesterol	*	n.s.	n.s.
Campestanol	n.s.	n.s.	n.s.
Clerostenol	**	n.s.	n.s.
B-sitosterol	**	*	n.s.
Sitostanol	**	*	**
D5-avenasterol	**	n.s.	n.s.

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

DISCUSSION

Lavee (1991) has shown that the genetic control of oil accumulation rate and pattern acts via cultivar-environment interactions. We have shown that plant characteristics such as the amount of yield, strongly affect the nature of fruit ripening, fruit characteristics, rate pattern and final oil accumulation, and, to a lesser extent, oil quality. These differences, however, occur only when the initial crop load and yield efficiency are greatly reduced. Fruit drop in olive is regulated by senescence processes and stalk thickness while the amount of yield has no effect on the attachment force of the fruit (Lavee *et al.*, 1982; Lavee, 1986).

This explains the low percent fruit drop recorded in this experiment, since cv. Cassanese has relatively large fruit, and there is no effect of crop load on pre-harvest percent fruit drop. The effect of harvest date, hence the different degrees of fruit ripeness at picking, was much stronger than the effect of crop load in determining the variability of oil composition (Maestro Duran, 1990). The effect of amount of yield on oil percent yield and oil composition could be related to reduced competition between fruits which resulted in a homogeneous crop with large fruits and shorter duration of fruit ripening in trees with light yield: it might be also an indirect effect resulting from the different environments during fruit ripening in heavily or lightly loaded trees. Average temperature ranged from 15.5°C in November to 13°C in December and 10.5°C in January.

Changes in fruit ripening pattern and timing due to crop load have been reported for various species such as citrus, peach and grape ((Monselise and Goldschimidt, 1982; Caruso *et al.*,

TABLE V
Polyphenols, palmitic and linoleic content (average values of five harvest dates) in olive oil of cv. Cassanese, as related to crop load

Plant crop load	Polyphenols mg/kg	Palmitic acid %	Linoleic acid %	Oleic/ linoleic
Full load (FL)	159.31a	10.87a	8.64a	14.2a
70% FL	151.74a	10.60a	8.88a	12.8a
50% FL	197.16	11.68b	9.65b	10.3b

Within a column, different letters denote significant differences at $P<0.01$: Tukey's HSD test.

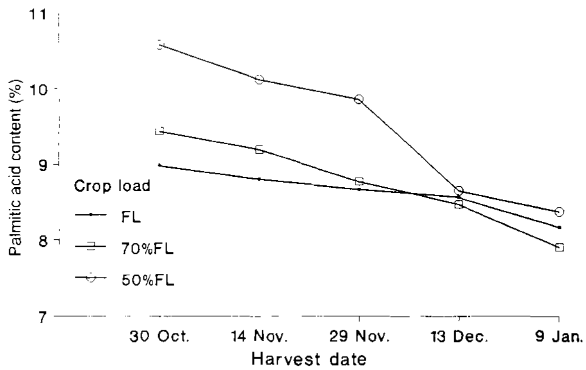

FIG. 4
Time course of palmitic acid content in the oil of fruits produced by trees with full load (FL), partially reduced load (70% FL) and halved load (50% FL).

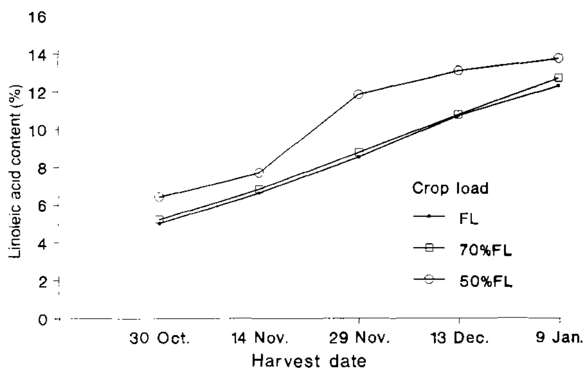

FIG. 5
Time course of linoleic acid content in the oil of fruits produced by trees with full load (FL), partially reduced load (70% FL) and halved load (50% FL).

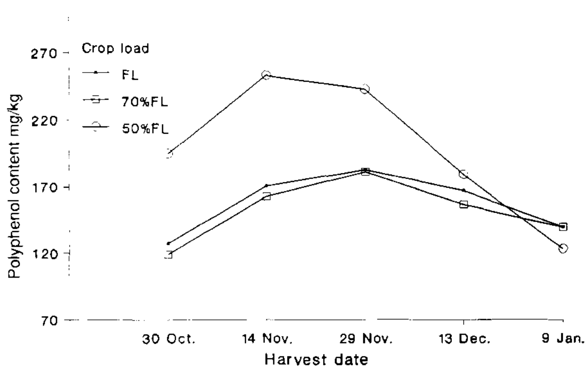

FIG. 6
Time course of polyphenol content in the oil of fruits produced by trees with full load (FL), partially reduced load (70% FL) and halved load (50% FL).

1991 and Eynard and Dalmasso, 1990). Trees with a large crop load might even fail to ripen their fruits, probably because of the strong competition for photosynthates which occurs in heavily loaded trees (Monselise and Goldschimidt, 1982). Optimum harvest time to maximize oil yield and quality changes with plant yield; in trees with a light crop load, it occurs early and lasts for a short period, since fruits rapidly and evenly reach the black epicarp maturation stage. At this time further oil accumulation is small and yield loss by fruit drop is still negligible. Later, fruits ripen rapidly, the alcohol content increases and polyphenols, responsible of oil flavour and stability, decrease; the timing and speed of harvest are therefore crucial in trees with a light yield, whilst the picking season of more heavily loaded trees, with a slower fruit ripening pattern is later and more extended. Finally, large differences in oil quality between off and on years should not be expected, providing differences of the fruit ripening pattern are taken into account in determining the optimum harvest time.

Research supported by the National Research Council of Italy, Project RAISA, Sub-project 2.

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(Accepted 13 May 1993)