

# Effect of Fertigation on the ‘Manzanilla de Sevilla’ Table Olive Quality Before and After “Spanish-style” Green Processing

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**Abstract.** Table olive quality was analyzed in adult ‘Manzanilla de Sevilla’ olive trees subjected to different N–P–K fertigation treatments through five years (1999–2003). A randomized block design with four fertigation treatments was established: irrigated without fertilizer (control), and T200, T400, and T600 treatments, in which each tree was respectively fertigated with 200, 400, and 600 g N per irrigation season of a complex 4N–1P–3K fertilizer applied daily. Fruit yield and fruit physical characteristics and chemical composition were studied in 2002 and 2003. Fruit analysis realized in 2002 showed that the fruit pulp/stone ratio and water content increased with the amount of applied fertilizer. In 2003, a similar trend was found for fruit yield, weight, pulp/stone ratio, volume, longitudinal and transversal diameters, and fruit water and potassium concentrations. On the contrary, the concentration of reducing sugars; Ca, Na, and B; and the fruit texture decreased linearly with the fertilizer dose in 2003. No differences between treatments in fruit and stone shape, or stone volume or polyphenols concentration were found. On the other hand, the effect of the treatments on fruit browning damage was studied in 2003, as well as the fruit quality after “Spanish-style” green processing. In spite of the differences in fruit composition and texture, the fertigation treatments did not affect browning damage. After Spanish-style processing, differences between treatments in fruit weight and texture were again observed, but color, brown spots, and blistering incidence were not modified.

Oil and table olive have been the major products of the olive tree for centuries. Table olive means just the 10% of the world production (Civantos, 2004) and its consumption, as well as that of the oil, has increased in recent years because of the recognized nutritional value of the Mediterranean diet (Patumi et al., 2002).

The consumer and the processing industry request fruits with good size, proper shape,

high pulp/stone ratio, good texture and color, and ease in releasing the pit. The nutritional and biological value of the fruit depends on the chemical composition of the pulp, with water and oil as the main components, and reducing sugars, polysaccharides, polyphenols, and minerals present in lower amounts. Together with their nutritional value, reducing sugars are also important because they are the raw material for fermentation during fruit processing (Garrido et al., 1997). Cell wall structure seems to be harmed by the partial solubilization of polysaccharides, influencing fruit texture (Jiménez et al., 1997). Phenolic compounds contribute significantly to table olive quality because of their recognized antioxidant capacity. They are also related, between others, to organoleptic characteristics such as bitterness, color of natural black olives and olives darkened by oxidation in alkaline medium (Vázquez and Janer, 1977), and to the palatability of processed fruits (Vinson et al., 1998). A high concentration in polyphenols can also inhibit lactic

bacteria growth and activity during fermentation (Vázquez and Janer, 1977).

Agronomic practices, in particular fertilization and irrigation, modify table olive quality. It is known that an excess of nitrogen fertilization can negatively affect olive production and delay fruit ripeness. A deficit of nitrogen, however, may lead to a decrease in fruit number, size, and color, as well as an early fruit ripeness (Hidalgo and Pastor, 2005; Lavee, 1986). Concerning irrigation, this practice increases fruit fresh weight, volume, pulp/stone ratio, and mesocarp water content (d’Andria et al., 2004; Proietti and Antognozzi, 1996), but may also negatively affect fruit quality by decreasing the firmness and sugar concentration (Proietti and Antognozzi, 1996). The effect of irrigation on sugar concentration is, however, not clear yet. Although an increase of sugars was observed by Marsilio et al. (2006) in ‘Ascolana Tenera’ fruits from trees irrigated with 66% crop evapotranspiration (ET<sub>c</sub>), d’Andria et al. (2004) and Patumi et al. (2002) observed no effect of irrigation on the concentration of sugar in the fruits. On the other hand, it seems that polyphenol concentration, bitterness, flavor, color, and aromatic potential characteristics decrease during fruit ripening with water availability (Marsilio et al., 2006; Patumi et al., 2002). However, little is known of the effect of fertigation on table olive quality, despite it being a common practice in most high-density olive orchards. Troncoso et al. (1997) observed an increase in yield but not in fruit weight when they fertigated a ‘Manzanilla de Sevilla’ adult tree orchard with 2 kg of urea per tree during irrigation season. In a recent study made with trees of the same cultivar, Morales-Sillero et al. (2007) studied the effect of fertigation with increasing doses of a 4N–1P–3K fertilizer on the oil quality and oil yield. Although oil yield increased with the fertilizer dose, due to an increase on the number of fruits, the oil quality was negatively affected in trees fertilized with 400 and 600 g of nitrogen per tree and irrigation season compared with control trees and trees with 200 g of nitrogen. The aim of this work, carried out in the same orchard and with the same experimental setup, was to evaluate the effects of the treatments on table olive quality. Fruit yield, physical characteristics, and chemical composition of fruits, as well as the appearance of brown spots on the fruit surface before and after the Spanish-style green olive processing and fruit quality only after processing, were studied.

## Materials and Methods

**Plant material.** The field experiment was carried out between 1999 and 2003 in an olive orchard (*Olea europaea* L. ‘Manzanilla de Sevilla’) near Alcalá de Guadaíra (Seville, lat. 37°18’N, long. 5°54’W), a typical olive-growing area of southwest Spain. The orchard was planted at 7 m × 7 m in 1989 and was clean cultivated. The soil, a Calcic Rhodoxeralf, is characterized by sandy clay

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loam texture at the first 0.35 m and sandy loam or loam below this depth; with a calcareous horizon at  $\approx 0.65$  m, and a fine and noncontinuous calcareous crust generally found at a depth of  $\approx 0.4$  m. Other characteristics included bulk density, measured in the field, of  $1.55 \text{ Mg}\cdot\text{m}^{-3}$  ( $\pm 0.03$ ) for the 0.10- to 0.14-m soil layer and  $1.47 \text{ Mg}\cdot\text{m}^{-3}$  ( $\pm 0.04$ ) for the 0.60- to 0.64-m soil layer; a pH of  $\approx 8.2$ ; a  $\text{CaCO}_3 \approx 30\%$  at the top 0.35 m and  $\approx 70\%$  below 0.55 m, organic matter of 2.5% at the top 0.35 m but 0.29% below 0.55 m; total nitrogen content of 0.16%; and low soil phosphorous and potassium concentrations (4 and 94  $\text{mg}\cdot\text{kg}^{-1}$ , respectively) at the start of the experiment.

Four fertigation treatments were applied in a randomized block design, with six blocks per treatment and four trees per plot, surrounded by guard trees. Irrigation amounts were the same for all trees, as described below, but the amount of fertilizer applied was different depending on the treatment. No fertilizer was supplied to trees of the control treatment; each tree of treatments T200, T400, and T600 received 100, 200, and 400 g of nitrogen per year, respectively, of a 4N-1P-3K complex fertilizer in 1999, 2000, and 2001; in 2002 and 2003, these amounts were increased to 200, 400, and 600 g of nitrogen per tree, respectively, to account for the increase in tree size. Nitrogen was derived from urea,  $\text{NH}_4$ , and  $\text{NO}_3$  (2:1:1 mixture), phosphorous was derived from  $\text{H}_3\text{PO}_4$ , and potassium was derived from KCl.

All trees were irrigated daily from April to May and from September to October to replace the  $\text{ET}_c$  (in millimeters) estimated with the crop coefficient approach (Allen et al., 1998). The values of the  $K_r$  and  $K_c$  coefficients were those estimated according to Fernández et al. (2006) for a similar orchard of the same area ( $K_r = 0.7$ ;  $K_c$  values were 0.76 in May, 0.70 in June, 0.63 in July and August, 0.72 in September, and 0.77 in October). The irrigation system consisted of a lateral per tree row with four 8  $\text{L}\cdot\text{h}^{-1}$  compensating drippers per tree, 1 m apart. For each treatment, equal daily doses of a liquid fertilizer were injected into the irrigation system toward the end of each irrigation event, allowing for a 15-min rinse of the laterals.

Water for irrigation was sampled several times during the experimental period. Analyses of the samples gave average values of pH and EC of 7.17 ( $\pm 0.12$ ) and  $0.838 \text{ dS}\cdot\text{m}^{-1}$  ( $\pm 0.04$ ), respectively. The average  $\text{NO}_3\text{-N}$  concentration was  $15.3 \text{ mg}\cdot\text{L}^{-1}$  ( $\pm 1.34$ ), which supposed an additional nitrogen supply of 60 g of nitrogen per tree and irrigation period. Concentrations of magnesium and potassium were  $4.25 \text{ mg}\cdot\text{L}^{-1}$  ( $\pm 0.55$ ) and  $0.44 \text{ mg}\cdot\text{L}^{-1}$ , respectively. No phosphorous was detected in the irrigation water.

Olive trees were picked by hand in September, when the ripening index was 1 (yellowish green skin color). This index was determined according to the skin (epicarp) and pulp (mesocarp) colors of the olive drupes (Beltrán et al., 2004). The effect of the

treatments on fruit yield and on the physical characteristics and chemical composition of the fruits, as well as on the appearance of brown spots in the fruits was studied in 2002 and 2003. In addition, fruit volume and fruit quality after Spanish-style green processing were analyzed in 2003.

No significant differences in trunk perimeter and canopy volume were found between the fertigation treatments. Trunk perimeter mean values, measured at 0.2 m above-ground, were 0.62 m ( $\pm 0.04$ ) in 2002 and 0.67 m ( $\pm 0.05$ ) in 2003. Canopy volume mean values, determined from tree heights and transversal and longitudinal diameters, were  $33 \text{ m}^3$  ( $\pm 5.6$ ) in 2002 and  $48 \text{ m}^3$  ( $\pm 6.0$ ) in 2003. On the other hand, foliar analyses realized in July indicated leaf nitrogen concentrations below 1.4%, a threshold value for deficiency (Fernández-Escobar, 2004) in the control treatment in 2002 and 2003, and in T200 in 2003. For the same treatments and years, leaf potassium concentrations were below optimum levels ( $>0.8\%$ ) but were above deficiency levels ( $<0.4\%$ ). For all treatments and dates, leaf phosphorous concentrations were above 0.1%, i.e., they were adequate. In addition, leaf nitrogen and potassium concentrations showed linear and significant increases with respect to the amount of fertilizer in both years.

*Fruit physical characteristics.* The average fruit weight (in grams) and the pulp/stone ratio were determined from randomly chosen samples of 0.5 kg fruits per tree (2 kg per plot) and 0.5 kg per plot, respectively. Pulp weight was determined as the difference between fruit and stone weight. Fruit and stone shapes were obtained from the major longitudinal and transversal diameters in samples of 50 fruits per plot. Fruit and stone volume (in milliliters) were determined in samples of 20 fruits per plot.

Fruit texture ( $\text{N}\cdot\text{g}^{-1}$  of pitted fruit) was measured with a texturometer (model 1011; Instron, Norwood, MA) fitted with a Allo-Kramer shear-press cell (Allo Precision Metals Engineering, Rockville, MD). The operating speed was  $200 \text{ mm}\cdot\text{min}^{-1}$  and the force scale was 0 to 500 N. Samples were of 10 fruits per plot in 2002 and 20 fruits per plot in 2003.

*Fruit chemical composition.* Fruit mineral concentrations were determined in samples of 100 g of pitted fruit per plot. Samples were dried at  $80^\circ\text{C}$  for 48 h and were then milled. Nitrogen concentration was determined by spectrophotometry in an AA-3 autoanalyzer (Bran+Luebbe, Norderstedt, Germany) after digestion with concentrated sulfuric acid using the Kjeldahl method. Metal concentrations were determined by Inductively Coupled Plasma-Optical Emission Spectrophotometry (model IRIS ADVANTEGE, ThermoJarrell, Franklin, MA) after dry ashing (at  $550^\circ\text{C}$ ) a solution of the ashes in concentrated hydrochloric acid (Walinga et al., 1995). Results were expressed as grams per kilogram on a dry weight basis for nitrogen, phosphorous, potassium, Ca, Mg, Na, and sulfur concentrations, and as milligrams per kilogram of

dry weight for Fe, Cu, Mn, Zn, and boron concentrations.

Fruit water content was determined by desiccation at  $105^\circ\text{C}$  for 24 h in a sample of 40 g of milled fruit. Reducing sugars concentration (percentage of fruit fresh weight and dry weight) was analyzed in 10 g of fresh milled pulp following the Lane Eynon method, using Fehling reagent, as described in Association of Official Analytical Chemist's Official Methods of Analysis (1995). Total polyphenol concentration ( $\text{mg}\cdot\text{kg}^{-1}$  caffeic acid) was determined in other sample of 10 g of fresh milled pulp by extraction with a 75:25 water:ethanol mixture. The Folin-Ciocalteu reagent was added and colorimetric measurement at 725 nm was made with a spectrophotometer ultraviolet-vis (HP8452A; Hewlett Packard, Waldbrook, Germany) (Vázquez et al., 1971).

*Browning damage.* In 2002, an experiment was carried out to analyze the effect of treatments on the appearance of brown spots in 100 fruits per block randomly chosen from three blocks per treatment. The fruits had similar weight, a ripening index of 1 (yellowish green skin color), and no visual damage at the exocarp. Fifty fruits were dropped from a height of 1 m and the rest were dropped from 2 m onto a wood surface, where the rebound was minimum. The appearance of brown spots at the exocarp was recorded at 0.5, 1, 2, 4, 6, 12, and 24 h after the beating. According to the damage suffered, fruits were classified into four categories: big-size, medium-size, small-size, and very small-size brown spots. In 2003, we repeated the experiment, but each fruit was dropped from a 1-m height into a pot filled with earth and covered with a plastic net. According to the appearance of brown spots at 0.5, 1, 2, 6, 9, and 24 h, three categories were established: fruits with big-size, medium-size, and small-size brown spots.

*Olive processing.* In 2003, a 5 kg fruit sample was taken from three randomly chosen blocks of the six of each treatments and was processed as are Spanish-style green olives. The fruits, completely green and without visual damage in the exocarp, were immersed in a 1.96% solution of NaOH (lye) for 6.5 h and then washed with 3.5 L of water for 3 h. They were then transferred to a brine solution (10% NaCl), where lactic fermentation took place at room temperature for 7 months. Due to the low weight:volume ratio of the fruits, sugar was added to the fermentation medium of four fruit samples. For this reason, it was not possible to study the influence of the treatments on fermentation (e.g., pH and lactic acid evolution). Free acidity, combined acidity, and the pH of brine samples were periodically measured in a titroprocessor (Metrohm 670; Herisau, Switzerland). Analyses of free and combined acidity were made by titrating up to pH 8.3 with 0.2 N OHNa, and down to pH 2.6 with 2 N HCl. The concentration of NaCl was determined by titrating with 0.1 N silver nitrate and 0.5% potassium chromate as an indicator (Fernández-Diez et al., 1985). At the end of the olive processing (7 months

after the lye, washing, and brine immersion treatments), a sample of 1 kg fruits was taken for determining fruit number and weight, texture, color and percentage of fruits with brown spots, and blistering. Texture ( $\text{N}\cdot\text{g}^{-1}$  of pitted fruit) was measured as explained above, in 15 replicates of three fruits each. A color index was determined based on the percentages of reflectance of the fruit skin at 560, 590, and 635 nm, measured in a spectrophotometer (Color-View model 9000; BYK-Gadner, Silver Spring, MD) (Sánchez et al., 1985). The fruits with brown spots and blistering were classified as fruits with big brown spots, fruits with little brown spots, fruits without brown spots, and fruits with blistering.

**Statistical analysis.** We made an analysis of variance in all cases, except for the yield. This was analyzed by covariance using the canopy volume. Polynomial contrasts were obtained when a significant F test was observed.

### Results and Discussion

In 2003, the vapor pressure deficit of the air was generally higher than in 2002 (Fig. 1), which explains the different values of reference crop evapotranspiration calculated for

both irrigation periods (620.9 mm in 2002 and 695.7 in 2003). In 2002, the mean temperature increased from 18 °C to 20 °C at the end of April to 24 °C to 26 °C in the middle of July, decreasing to 19 °C to 21 °C in September; in 2003, the mean temperature increased from 16 °C to 17 °C in April to 32 °C to 35 °C at the beginning of August, and decreased to 23 °C to 24 °C in September. The annual rainfall (624 mm in 2002 and 551 mm in 2003) generally occurred in spring and autumn. As is shown in Fig. 1, rainfall during both irrigation periods was negligible, although a 105 mm rainfall event occurred in Sept. 2002 just before harvest.

Most of the fruit characteristics recorded in 2002 showed no response to the fertigation treatments, whereas in 2003, differences were more evident (Tables 1, 2, and 3). Apart from trees in 2003 having been one more year affected by the treatments than in 2002, the different weather conditions recorded in both years with differences in pruning and other management practices could explain these results.

The fertigation treatments did not modify nutrient composition in 2002 (Table 1). Although potassium concentration increased with the fertilizer dose, and Na concentration decreased, these trends were not significant.

In 2003, the potassium concentration showed a linear and positive response when the amount of fertilizer increased. Ca, Na, and boron concentrations were also affected by the fertigation treatments, showing negative linear trends with the increase of fertilizer dose.

Low yields were recorded in both years, particularly in 2003 (Table 2), likely because a severe shoot defoliation occurred in all treatments at the end of the spring, caused by an infection of *Spilocaea oleagina*, the olive leaf spot. In addition, in 2002, a severe pruning was made in January, which probably caused an imbalance between vegetative and reproductive development. No significant differences between treatments were found in the fruit yield or weight that year (Table 2), but the pulp/stone ratio increased linearly with the amount of fertilizer. In 2003, these parameters, as well as fruit volume, increased linearly with the fertilizer dose; the volume of the stone was not modified by treatments, with the mean value of all of them at  $0.5 \pm 0.03$  mL. In other reports, no effect on fruit weight was found when different fertilizers were applied to olive orchards. Troncoso et al. (1997) did not find fruit weight response when applied by fertigation 2 kg of urea per irrigation season to ‘Manzanilla de Sevilla’ adult trees, yet fruit yield was positively affected. Nor did Frega et al. (1995) find a response when foliar fertilizers based on urea, biammonia phosphate, and potassium sulfate were applied in young ‘Leccino’ trees.

Texture is an important organoleptic characteristic in table olives. In fact, a nonappropriate fruit texture can be one of the main reasons for rejection by the consumer. In addition, a lack of fruit texture may cause high economic losses to the processing industry because of difficulties in fruit pitting and stuffing after lactic fermentation (Garrido et al., 1997). In 2002, we found no effect of the treatments on the fruit texture (Table 2). On the contrary, in 2003, texture decreased when increasing the fertilizer dose, with T600 about 16% lower than in the control. The loss of texture could have been from a partial solubilization of the cell wall polysaccharides as a result of the increase in the fruit water content (Table 3). It is known that texture is related to these compounds (Jiménez et al., 1995). In addition, a decrease of Ca in the fruits associated with the increase of the fertilizer doses was found (Table 1), which may have contributed to the mentioned loss of texture. The cell wall structure depends on the presence of Ca, which constitutes complexes with the pectic polysaccharides from the middle lamella. In fact, the addition of Ca to the brine during the olive fermentation causes an important increase in fruit texture (Jiménez et al., 1997).

Data from 2002 show no differences between treatments in fruit and stone diameters or in fruit shape (Table 4). The longitudinal and equatorial diameters of the fruits increased with the fertilizer dose in 2003, although the shape remained unchanged.

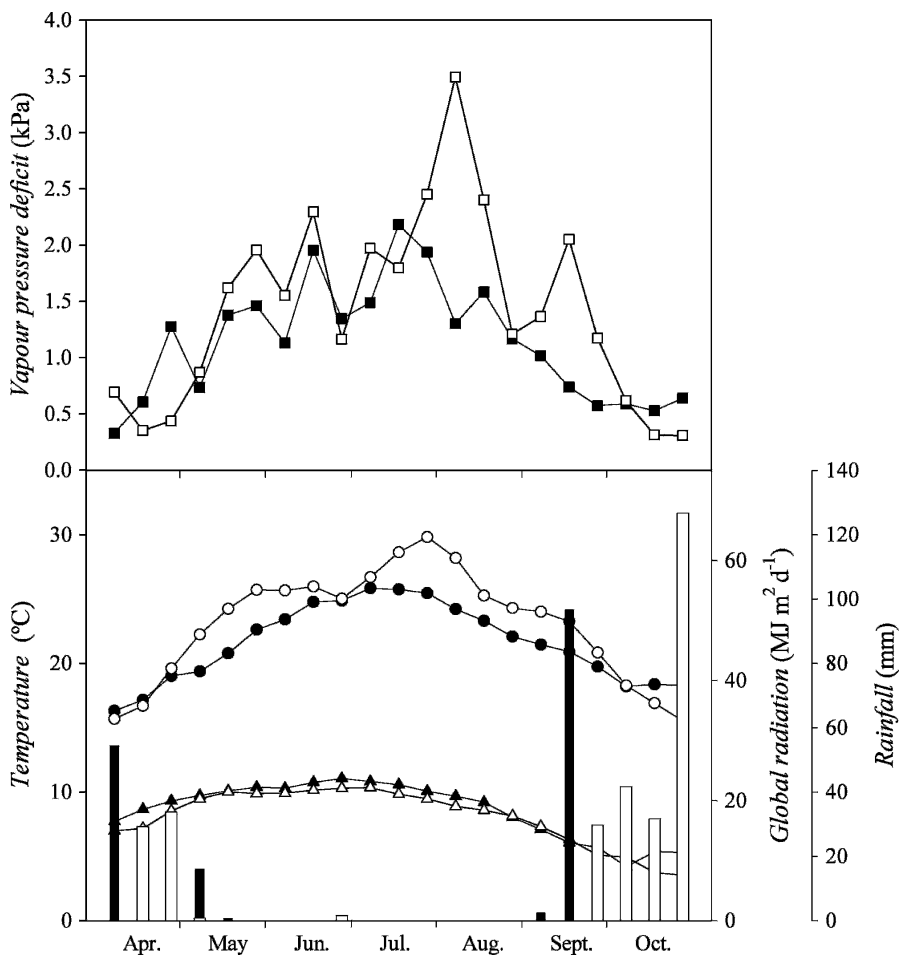


Fig. 1. Vapor pressure deficit, temperature (circles), global radiation (triangles), and rainfall (bars) recorded with a weather station next to the orchard. Data points are 10-day averages. Filled symbols correspond to data recorded in 2002 and open symbols correspond to data recorded in 2003.

Table 1. Effect of the fertigation treatments on nutrient composition in fruit samples (n = 6) taken on the last two experimental seasons.<sup>z</sup>

Yr & Treatment	N	P	K	Ca	Mg	Na	S	Fe	Cu	Mn	Zn	B
	(g·kg <sup>-1</sup> )							(mg·kg <sup>-1</sup> )				
2002												
Control	6.1	1.2	9.2	1.3	0.2	0.3	0.3	11.6	3.4	2.6	13.4	—
T200	7.3	0.9	9.7	2.0	0.2	0.2	0.3	43.8	2.7	3.7	22.3	—
T400	7.2	0.9	10.5	1.6	0.2	0.2	0.3	18.7	2.1	1.8	11.8	—
T600	6.9	0.9	10.9	0.8	0.2	0.1	0.3	19.0	0.9	1.7	12.7	—
Significance	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	15.2	30.7	10.8	85.7	33.7	67.3	24.1	100	100	70.1	53.8	—
2003												
Control	6.9	1.4	13.5	1.7	0.3	0.3	0.2	18.6	10.0	5.2	15.0	22.6
T200	7.4	1.3	13.6	1.6	0.3	0.1	0.2	16.6	9.6	4.6	11.6	17.2
T400	8.4	1.2	15.5	1.2	0.3	0.1	0.3	19.3	4.7	4.2	10.7	9.8
T600	7.7	1.3	16.2	1.2	0.3	0.1	0.3	18.0	6.6	4.4	11.4	9.7
Significance	NS	NS	L**	L*	NS	L**	NS	NS	NS	NS	NS	L**
CV (%)	9.2	19.5	10.2	18.1	23.1	56.4	17.3	29.4	65.8	23.89	19.29	39.7

<sup>z</sup>See text for details on the treatments.

ns,\*,\*\* Nonsignificant or significant at  $P \leq 0.05$  and  $0.01$ , respectively.

CV = Coefficient of variation; L = linear.

Table 2. Effect of the fertigation treatments on fruit yield, weight, pulp/stone ratio, and texture in fruit samples (n = 6) of the last two experimental seasons. Data on fruit volume recorded in 2003 are also shown.<sup>z</sup>

Yr & Treatment	Fruit yield	Weight	Pulp/stone	Volume	Texture
	(kg ha <sup>-1</sup> )	(g)	ratio	(mL)	(N g <sup>-1</sup> )
2002					
Control	1791	5.02	7.57	—	48.9
T200	2713	5.09	8.30	—	52.9
T400	2811	5.42	8.92	—	45.0
T600	2083	5.70	9.77	—	45.5
Significance	NS	NS	L***	—	NS
CV (%)	39.4	10.4	9.7	—	21.65
2003					
Control	692	4.25	5.12	4.02	92.1
T200	1189	4.21	5.83	4.33	86.6
T400	1705	4.81	6.41	4.75	77.8
T600	1736	5.03	6.65	4.94	77.0
Significance	L*	L***	L****	L***	L**
CV (%)	34.2	5.3	6	7.6	6.3

<sup>z</sup>See text for details on the treatments.

ns,\*,\*\*,\* Nonsignificant or significant at  $P \leq 0.05$ ,  $0.01$ ,  $0.001$ , and  $0.0001$ , respectively.

CV = Coefficient of variation; L = linear.

Table 3. Effect of the fertigation treatments on water, reducing sugars, and polyphenol concentration in fruit samples (n = 6) of the last two experimental seasons.<sup>z</sup>

Yr & Treatment	Water content (%)	Reducing sugars (%)		Polyphenol (mg·kg <sup>-1</sup> caffeic acid)	
		Fresh weight	Dry weight	Fresh weight	Dry weight
2002					
Control	64.7	3.5	9.8	16,159	45,794
T200	67.5	3.3	10.1	16,569	50,940
T400	68.6	3.0	9.6	15,746	50,062
T600	69.4	3.1	10.0	16,230	53,191
Significance	L***	NS	NS	NS	NS
CV (%)	1.8	9.5	10.7	7.2	2.5
2003					
Control	58.7	4.4	10.6	27,228	66,000
T200	58.3	4.7	11.2	27,303	65,675
T400	62.4	3.4	8.9	25,411	67,782
T600	63.1	3.2	8.9	24,155	65,348
Significance	L***, C**	L**, C**	L*	L***	NS
CV (%)	2.3	13.4	13.0	5.5	2.1

<sup>z</sup>See text for details on the treatments.

ns,\*,\*\*,\* Nonsignificant or significant at  $P \leq 0.05$ ,  $0.01$ , and  $0.001$ , respectively.

CV = Coefficient of variation; L = linear; C = Cubic.

A significant increase in the fruit water content with the amount of fertilizer was found in both experimental years; the water content in fruits from the T600 treatment were 6.9% and 6.8% greater than in the control in 2002 and 2003, respectively (Table

3). As reported by Morales-Sillero et al. (2007), the increase in fruit potassium concentration with the fertilizer dose (Table 1) probably induced water absorption, following an osmotic adjustment. In any case, this increase in fruit water content with the

amount of fertilizer applied is of relevance for the table olive industry because the lye treatment must be shorter at greater fruit water contents (water in the fruit favors lye penetration). If this is not taken into account, brown spots may appear close to the stone first and then diffuse to the skin, depreciating the fruits' value (Fernández-Díez et al., 1985). In fact, fruits from irrigated and nonirrigated orchards are usually processed separately.

Sugars are important because they are the raw material for fermentation during processing. Changes in these compounds affect greatly the processing of Spanish-style green olives because their preservation is highly dependent on a strong lactic acid fermentation (Garrido et al., 1997). We found that reducing sugars concentration, the most abundant sugars in the fruit flesh, was unaffected by the fertigation treatments in 2002 (Table 3). However, in 2003, the reducing sugars concentration, expressed as a dry weight, were about 17% lower in T400 and T600 than in the control and T200. In addition, the concentrations of the two highest doses were lower than 4%, which ensures an appropriate acidity (0.8%–1%) in the brine of the Spanish-style green olives. This acidity threshold, together with the NaCl concentration and the anaerobic conditions, preserves the processed fruits for a long time (Balatsouras et al., 1996). The concentration of reducing sugars in fruits and reserve organs is related to plant photosynthetic activity and the translocation rate of assimilates of these organs. In potassium-deficient plants, accumulation of reducing sugars instead of starch is common, which can be related to the function of potassium as a starch synthetase enzyme activator (Salisbury and Ross, 1985). This could explain the higher reducing sugars concentration that we have found in the control and T200 treatments. As mentioned in "Materials and Methods," foliar analyses indicated that leaf potassium concentrations were low in the control treatment in 2002 and 2003 and in T200 in 2003.

No differences between treatments in polyphenol concentration were found when

the data were on a dry weight basis (Table 3). When the polyphenol concentration was expressed on a fresh weight basis, data from 2002 showed no differences between treatments, but a linear decrease with the increasing fertilizer dose was observed in 2003.

Browning damage is a specific problem of Spanish-style green olives, related to the hits in the fruits at harvesting. Brown spots usually appear on the fruit surface, and it extends inside into the fruit with time, with fruit quality greatly affected. This is one of the main limitations of mechanical harvesting (Garrido et al., 1997). Our experiment for evaluating browning damage before Spanish-style green olive processing, described in the "Materials and Methods," showed no effects of the fertigation treatments on the browning damage (data not shown) at any of the sampled times after throwing.

After Spanish-style green olive processing, fruit weight and texture (Table 5) showed similar trends to those mentioned above: the fruit weight increased with the amount of fertilizer, thus the number of fruits per kilogram decreased. The fruit texture decreased linearly from 40.8 N·g<sup>-1</sup> in the control treatment to 31 N·g<sup>-1</sup> in T600 one, i.e., 24% lower in the highest fertigation treatment. All of these values are considered acceptable for table olive commercialization; however, the two highest fertigation treatments would

likely reduce the period of commercialization because texture usually decreases with time. Processing resulted in a loss of texture, probably because of the lye treatment. Marsilio et al. (1995) observed that the lye dissolves the epicuticular waxy coating and the intercellular cement in the middle lamella. At the same time, the fruit texture and the amount of pectic substances decreased. Jiménez et al. (1995) found that fermentation of 'Hojiblanca' olive fruits produce marked changes in cell wall polysaccharides, particularly uronic acid-containing fractions, and degradation of neutral polysaccharides, mostly from hemicellulose A, hemicellulose B, and  $\alpha$ -cellulose, likely by enzymatic action. Color was not affected by treatments (Table 5). The mean value of the color index, 28, corresponds with a "good" color according to Sánchez et al. (1985). No differences were observed in the brown spot or blistering incidence, which is an alteration in 'Manzanilla de Sevilla' fruits due to the lye treatment. Fruits often appear peeled, and sensory characteristics can be negatively altered, therefore affecting table olive quality (Fernández-Díez et al., 1985). The percentage of fruits with brown spots or blistering was always below 26 for brown spots and 13 for blistering. The brown spots in most affected fruits were classified as small-size.

Morales-Sillero et al. (2007) showed that olive oil quality was negatively affected in the T400 and T600 treatments; they concluded that doses similar to the T400 treatment could lead to the best equilibrium between the olive oil quality, fertilization costs, and environmental impact. In this article, we show that fruit yield, weight, pulp/stone ratio, longitudinal and equatorial fruit diameters, and fruit volume increased with the amount of fertilizer. The fruit water concentration also increased with the fertilizer dose, whereas reducing sugars concentration and texture decreased. These results suggest that the most profitable dose for table olive could be T600, because fruit size is one of the most important parameters for fruit commercialization. This recommendation, however, may be biased by uncontrolled effects due to the sanitary problems occurring in the last two experimental years, as mentioned above. In addition, the risk for soil and groundwater contamination under this high fertigation dose should be taken into account. Because olive growers often apply higher fertilizer doses than that of our experiment on the perception that this may insure higher yields, our results suggest that particular attention should be paid to the effects of this practice on the fruit quality to ensure an adequate process and final quality product after Spanish-style processing.

Table 4. Effect of the fertigation treatments on fruit and stone shapes (n = 6) observed in the last two experimental seasons.<sup>z</sup>

Yr & Treatment	Fruit			Stone		
	Longitudinal diameter (mm)	Equatorial diameter (mm)	Shape	Longitudinal diameter (mm)	Equatorial diameter (mm)	Shape
<b>2002</b>						
Control	23.0	19.2	1.2	13.6	8.0	1.7
T200	23.3	19.4	1.2	13.5	7.9	1.7
T400	23.8	20.0	1.2	13.4	7.9	1.7
T600	23.7	20.3	1.2	13.2	8.1	1.7
Significance	NS	NS	NS	NS	NS	NS
CV (%)	2.9	4.8	2.3	1.7	3.1	2.3
<b>2003</b>						
Control	21.0	18.1	1.2	13.4	8.7	1.5
T200	21.5	18.4	1.2	13.4	8.5	1.6
T400	22.2	18.9	1.2	13.4	8.5	1.6
T600	22.6	19.3	1.2	13.5	8.5	1.6
Significance	L**	L***	NS	NS	NS	NS
CV (%)	2.6	2.6	1.4	2.7	3.3	1.7

<sup>z</sup>See text for details on the treatments.

NS, \*\*, \*\*\* Nonsignificant or significant at  $P \leq 0.01$ , and 0.001, respectively.

CV = Coefficient of variation; L = linear.

Table 5. Fruit quality after "Spanish-style" green processing (n = 3) for each fertigation treatment. The processing was made in 2003.<sup>z</sup>

Treatment	Fruit number (No kg <sup>-1</sup> )	Fruit weight (g)	Texture (N·g <sup>-1</sup> )	Color	Brown spots (%)		Blistering (%)
					Big	Small	
Control	251	4.2	40.8	26.9	1.8	22.5	12.8
T200	251	4.3	38.4	28.1	2.4	20.5	6.1
T400	214	4.8	33.6	28.5	2.3	25.3	8.3
T600	219	4.9	31.0	28.4	2.1	20.5	7.0
Significance	L*	L**	L****	NS	NS	NS	NS
CV (%)	4.7	8.7	5.1	6.5	53.4	35.3	60.3

<sup>z</sup>See text for details on the treatments.

NS, \*\*, \*\*\* Nonsignificant or significant at  $P \leq 0.05$ , 0.01, and 0.0001, respectively.

CV = Coefficient of variation; L = linear.

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