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Vegetative, productive and oil quality responses of 'Arbequina' and 'Picual' olive trees to foliar P and K application

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SUMMARY: A completed hedgerow of cv. Arbequina and a youth vase trained orchard of cv. Picual were fertilized with foliar applications of Phosphorus (P) or Potassium (K) throughout four seasons. The orchards were located near Valdepeñas in the dry area of La Mancha (Spain). Vegetative growth, yield and oil quality were evaluated. Foliar treatments did not increase P or K leaf concentration. Most of the evaluated parameters were not significantly affected by treatments. It was observed that the P treatment increased olive growth and oil yield in both orchards and in certain seasons due to an increment in fruit number. P and K application significantly increased 'Arbequina' olive and oil yield in 2008 when spring was wetter than the other years. Oil quality was not modified by fertilizer treatments in the 'Arbequina'orchard. However, oxidative stability was negatively affected by P and K treatments in 'Picual'. Oil extraction could be negatively affected by treatments because of the increase in the water content in the fruit obtained from both orchards.

KEYWORDS: *Fatty acids; Fruit characteristics;* Olea europaea *L.; Phenolic compounds; Phosphorus nutrition; Potassium nutrition*

RESUMEN: ***Respuestas vegetativa, productiva y calidad del aceite a la aplicación foliar de P y K a olivos "Arbequinos" y "Picual"***. Un olivar en seto completamente formado de la variedad Arbequina y otro olivar en vaso joven de la variedad Picual fueron tratados vía foliar con Fósforo (P) y Potasio (K) durante cuatro años. Los olivares estuvieron localizados cerca de Valdepeñas, en la zona árida de La Mancha (España). Se evaluaron el crecimiento vegetativo, el rendimiento y la calidad del aceite. Los tratamientos foliares no aumentaron los niveles foliares de P y K. La mayoría de parámetros de crecimiento y producción evaluados no se vieron afectados por los tratamientos. En ambos olivares y en algún año del ensayo, el tratamiento con P incrementó el crecimiento y el rendimiento, debido al incremento en el número de frutos. Las aplicaciones de P y K aumentaron significativamente el rendimiento en aceituna y aceite en Arbequina en 2008, cuando la primavera fue más húmeda que el resto de años. Los tratamientos no modificaron la calidad del aceite obtenido en 'Arbequina'. Sin embargo, en 'Picual' los tratamientos con P y K afectaron negativamente a la estabilidad oxidativa del aceite. La extracción del aceite podría verse perjudicada por los tratamientos, debido al incremento en el contenido de agua en el fruto obtenido en ambos olivares.

PALABRAS CLAVE: *Ácidos grasos; Características del fruto; Compuestos fenólicos; Nutrición fosfórica; Nutrición potásica;* Olea europea *L.*

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1. INTRODUCTION

The olive tree (*Olea europea* L.) is one of the most important crops in the Mediterranean area, and is mainly used to produce olive oil for human consumption. Interest in establishing new plantations has increased in countries where the olive tree is not a common crop (South America, South Africa, Australia, China, etc.) (IOC 2017). Currently, olive growing is focused on increasing productivity by increasing tree density, improving oil yield and enhancing the olive oil quality. Both irrigation and fertilization are two common horticultural practices that growers use to achieve these purposes and should be adapted to the orchard density and cultivar requirements. In most of the olive growing areas in Spain, fertilization is carried out annually by applying the same fertilization program every year, without prior knowledge of the annual needs of the crop. However, many works confirm that when olive leaves are at adequate level of nutrients, N, P or K fertilization does not always produce increases in productivity, growth or oil quality (Morales-Sillero *et al*., 2007; Fernández-Escobar *et al*., 2009; Therios, 2009; Centeno *et al*., 2017).

Phosphorus (P) is an important macro-nutrient for many plants because of its contribution to root growth and maturation of plant tissues and participates in the metabolism of carbohydrates, lipids and proteins (Therios, 2009). Phosphorous deficiencies in olives are rare probably because these trees have wide and high mycorrhizal roots (Sbrana and Vitagliano, 1999) that optimize the absorption of this element (Therios, 2009) and only small amounts of P are removed every year through pruning and harvesting (Fernández-Escobar *et al*., 2015). For these reasons fertilization with this element is only recommended in calcareous, shallow or poor soils, in orchards fertilized with N for a long time and in intensive irrigation management (Erel *et al*., 2008; Therios, 2009; Fernández-Escobar, 2010). There are few works which monitored the responses to P fertilization in olive trees. Erel *et al*., (2008) did not obtain effects in vegetative growth after applying P by fertigation in young olive trees despite the increase in P-leaf concentration. In this work they obtained increments in flowering intensity, fruit set and the total number of fruits, although the same responses were not always observed (Jiménez-Moreno and Fernández-Escobar, 2017).

Olive trees have high annual Potassium (K) requirements, since this element is removed in high amounts by the fruits (Fernández-Escobar, 2010). This macronutrient is involved in the activation of many enzymes, in the metabolism of carbohydrates and nitrogen, photosynthetic processes, regulation of stomata and in the trees' water balance (Therios, 2009). K deficiencies are common in most olive orchards. The causes of K deficiency are diverse and include poor soil content, low soil temperature and soil moisture, high tree load and interactions with calcium and magnesium (Fernández-Escobar, 2010). Most of the areas where the olive tree is grown are characterized by calcareous, shallow and rain-fed soils and fertilization with K is recommended every year. Previous works have demonstrated a positive relationship between K and olive growth, or productivity, when K was applied to the soil or leaves (Erel *et al*., 2008; Restrepo-Díaz *et al*., 2008b).

In dry lands with low water availability during the growing period, nutrient absorption from the soil may be negatively affected due to the lack of moisture (Zipori *et al*., 2015), which affects the mobility and absorption of the supplied nutrients (Mengel and Kirkby, 2001). In addition, fruit trees have a long and deep root system that hinders the local application of fertilizers effectively. In these conditions, fertilizer application to the leaves is considered a fast and highly effective method to avoid nutritional deficiencies in plants. P and K are compatible with the foliar application method because they are easily absorbed and transferred from the leaves to the rest of the tree (Restrepo-Díaz *et al*., 2008b; Jiménez-Moreno and Fernández-Escobar, 2017). However, factors such as cultivar, salinity, water stress, leaf age, nutritional status of the tree, number of treatments and type of product applied may influence foliar fertilization (Fernández *et al*., 2013).

The aim of this study was to investigate the effect of P and K leaf fertilization on growth, productivity and oil quality in two olive orchards located in the central area of Spain. This area is characterized by an arid climate with high temperatures and low water resources in summer and soils are usually calcareous, clay and/or poor. It is the second most important olive growing area of Spain (MAPAMA, 2017) although there are no studies related to P and K fertilization of the olive trees in this area.

2. MATERIALS AND METHODS

2.1. The site and the experimental orchards

The experiment was conducted between 2007 and 2010 in two commercial orchards located in Valdepeñas (Ciudad Real, Spain) (38°50'N, 3°19'W; altitude 780 m): 11-year-old 'Arbequina' olive trees growing in hedgerow (4 × 1.5 m spacing) and 12-year-old 'Picual' vase-trained olive trees (6 × 8 m). The canopy had not completed its development and the large spaces between trees were not covered in leaves. Both orchards were separated by about 300 m and the soil classification was similar (Typical Rhodoxeralf). In the 'Arbequina' orchard, the soil was sandy loam at the first 0.3 m and clay below this depth. The pH was 7, active lime was < 0.5%, and organic matter was 1.3% in the first 0.15 m of

the soil and < 0.6% below this depth. Available P and exchangeable K were 118 ppm and 484 ppm at the first 0.3 m, and < 1.4 ppm and 247 ppm below this depth, respectively. In the 'Picual' orchard, the soil was sandy loam at the first 0.18 m of the soil and clay below this depth. The pH was 7.1, active lime was < 0.5% at the first 0.48 m and 1.3% below, and organic matter was 1.0% at the first 0.18 m of the soil and < 0.6% below. Available P was 38 ppm at the first 0.18 m and < 1.5 ppm below; whereas exchangeable K was 760.5 ppm in all profiles.

The mean annual temperature, ETo and rainfall (11-year average) registered by a water station located 15 km from the site, were 13.8 °C, 1328 mm and 367 mm, respectively. Irrigation water was scare in the area and so, from 2007 to 2010, 'Arbequina' trees received 0, 78, 84 and 121 mm, respectively, and 'Picual' 0, 15, 21, and 29 mm, respectively. Water was applied by underground drip emitters of 3.5 L/h spaced 1 m apart.

2.2. Experimental design and fertilization treatments

A randomized complete block design with four blocks was established. Each elementary plot consisted of three labelled trees surrounded by two guard trees to avoid interference among treatments.

During the experimental period, the only fertilization applied to the control treatment (CON) corresponded to the one applied by growers during the spring of 2009 and during spring and summer of 2010 to both orchards (Table 1). This fertilization was applied with a sprayer gun adding a non-ionic surfactant (pH-fit, Morera®) at a rate of 0.1% (v/v). The 'Arbequina' CON treatment received mean values of 0.5 kg $P_2O_5 \cdot ha^{-1}$ and 1.4 kg $K_2O \cdot ha^{-1}$; while the 'Picual' CON received mean values of 0.4 kg $P_2O_5 \cdot ha^{-1}$ and 1.1 kg $K_2O \cdot ha^{-1}$.

Total doses of P and K annually applied including the growers' fertilization are summarized in Table 1. The canopy differences between orchards explained the higher amounts of foliar fertilizers applied to 'Arbequina' (5 times) compared to 'Picual'. These treatments were also applied with a sprayer gun and adding the non-ionic surfactant (pH-fit, Morera®) at a rate of 0.1% (v/v). The fertilization treatments were:

P: Phosphorus was applied early in the morning by foliar fertilization with Hakaphos® Violeta from Compo Ltd. (13% N, 40% P_2O_5 and 13% K_2O). In 2007 and 2008, the P-treatments were sprayed at the beginning of July and September; and in 2009 and 2010 at the end of June, July and September.

K: Potassium was applied by foliar fertilization with NKplus® from Compo Ltd. (11% N and 39% K_2O). In 2007, the K- treatments were sprayed at the beginning of September and October, and the rest of years at the end of June, August and September.

The treatments were applied by wetting the whole canopy. Both commercial products used were authorized and tested as foliar fertilizers to increase P and K concentrations in olive leaves (De Liñán, 2017).

2.3. Leaf analysis

Leaf nutrient concentration was determined each year from 100 mature leaves sampled in July from the middle of the basal portion of non-bearing, current season shoots around the trees and at about 1.5 m above ground. Leaves were collected from each plot in three blocks per treatment and CON. Once in the laboratory, the leaves were rinsed with de-ionized water, dried at 60 °C, and mineralized at 450 °C. After that, the ashes were digested with acid and the extract was measured by a ICP-OES spectrometer (Perkin Elmer, Massachusetts, USA) to determine P, K and Ca, Mg, Na, Fe, Mn, Cu, Zn, Mo, Sulfates and B. Nitrogen was determined with a LECO TruSpec®N Nitrogen Protein Analyzer System (LECO, Michigan, USA. The methodology was described by Fernández-Escobar *et al*., (2009)).

TABLE 1. Foliar fertilizer applied ($kg \cdot ha^{-1}$) each year in 'Arbequina' and 'Picual' orchards to control (CON), P and K experimental trees

	2007		2008		2009		2010	
Treatments	**P_2O_5 ($kg \cdot ha^{-1}$)**	**K_2O ($kg \cdot ha^{-1}$)**	**P_2O_5 ($kg \cdot ha^{-1}$)**	**K_2O ($kg \cdot ha^{-1}$)**	**P_2O_5 ($kg \cdot ha^{-1}$)**	**K_2O ($kg \cdot ha^{-1}$)**	**P_2O_5 ($kg \cdot ha^{-1}$)**	**K_2O ($kg \cdot ha^{-1}$)**
'Arbequina'								
CON	0.93	0.55	0.13	0.13	0.13	3.13	0.90	1.90
P	7.50	2.67	6.50	2.20	8.40	5.82	8.00	4.20
K	0.93	8.88	0.13	25.50	0.13	30.00	0.90	32.90
'Picual'								
CON	0.93	0.55	0.14	0.14	0.13	3.13	0.30	0.60
P	2.14	0.96	1.60	0.61	1.73	3.65	1.80	1.10
K	0.93	3.72	0.14	7.40	0.13	8.31	0.30	6.10

2.4. Vegetative growth and reproductive components

From 2008 to 2010, before the beginning of the vegetative growth stage (March), the trunk perimeter of the 3 labeled trees per experimental plot were measured at 35 cm above the soil surface. In each of these labeled trees, 3 shoots were tagged on the S-side. Vegetative growth was evaluated by measuring shoot length and number of node increments from budburst (March) to harvest (end of October for 'Arbequina' and end of November for 'Picual'). In May number of inflorescences was counted in these tagged shoots and the number of fruits per shoot was determined at harvest. From these determinations, the percentages of buds which burst from initial budbreak, buds that developed an inflorescence (buds initiated) and percentage of inflorescence having at least one fruit (fertile inflorescence) were calculated.

2.5. Production

Two olive trees per treatment and block were harvested individually by hand. From each repetition production per hectare was calculated. 'Arbequina' olives were picked from early to mid-November with a maturity index between 0 and 1 (skin color between deep green and yellow-green), except in 2007, when olives were harvested at the end of November with a maturity index between 3 (skin color with more than half of the surface turning red, purple or black) and 4 (skin color all purple or black with less than half of the flesh turning purple) (Ferreira, 1979). 'Picual' olives were picked at the end of November with a maturity index between 3 and 4. From the harvested fruits, six subsamples of around 25 g of 'Arbequina' and 'Picual' were weighed fresh and again after drying at 105 °C, and fruits were counted to determine fruit weight. Oil content was determined by nuclear magnetic resonance (MiniSpec MQ−10, Bruker, Madison, USA) using the method described by Del Rio and Romero, (1999).

Additional subsamples of 2.5 kg were taken for oil extraction with the Abencor system (MC2 Ingeniería y Sistemas S.L., Seville, Spain) in 2009 and 2010 (Martínez *et al*., 1975). The samples were crushed in the hammer mill at 3000 rpm. The resulting olive paste was placed in stainless steel 1-L containers and malaxated for 45 min in the thermobeater at 26 °C, using four stainless steel cross blades at 54.5 rpm (radius 53 mm). After that, the paste was centrifuged in a pulp centrifuge for 1 min at 3,500 rpm (radius 100 mm) to separate the liquid phase (oil and wastewater) from the solid waste. Then, the oil was decanted into graduated tubes until complete separation of the water and oil phases was obtained. The oil volume was determined after decantation and the extractability index was calculated as the percentage of olive oil extracted from the total oil content of the fruit (on a fresh matter basis) considering 0.916 $kg \cdot L^{-1}$, the olive oil density at ambient temperature. After measurement, the oil was filtered through filter paper and stored in a N_2 atmosphere at -20 °C until analysis.

2.6. Oil analysis

Free acidity, peroxide index value, and coefficients of specific extinction at 232 and 270 nm (K_{232} and K_{270}) were evaluated over the two latest years according to the Regulation EEC/2568/91. An automated Methrom Rancimat 679 apparatus (Methrom Co., Basel, Switzerland) was used to determine the oxidative stability of a 2.5 g oil sample warmed to 98 °C and an air flow of 10 $L \cdot h^{-1}$. The results were expressed as induction time in hours (Gutiérrez, 1989). The composition of fatty acids was determined by gas chromatography in a Perkin-Elmer Autosystem (CT, USA). The fatty acids (carbon number:unsaturation) analyzed were myristic (14:0), palmitic (16:0), palmitoleic (16:1), margaric (17:0), margaroleic (17:1), stearic (18:0), oleic (18:1), linoleic (18:2), linolenic (18:3), arachidic (20:0), gadoleic (20:1) and behenic (22:0). Different variables were determined from the fatty acid composition: saturated fatty acids (SAFA), including fatty acids without unsaturations; unsaturated fatty acids (UNFA), including fatty acids with one, two or three unsaturations; monounsaturated fatty acids (MUFA), including fatty acids with only one unsaturation; and polyunsaturated fatty acids (PUFA), including fatty acids with two or three unsaturations. The phenolic fraction of the oil samples was isolated by solid-phase extraction and analyzed by reversed-phase HPLC using a diode array UV detector (Mateos *et al*., 2001). The quantification of phenolic compounds (except ferulic acid) was carried out at 280 nm using *p*-hydroxyphenylacetic acid as an internal standard; whereas that of flavones and ferulic acid was made at 335 nm using *o*-coumaric acid as an internal standard. The results were expressed in ppm.

Sensorial analysis. A sensorial evaluation of the oils was performed according to the Panel test method (European Union Commission, 1991) using two trained tasters from the Panel Test of the Comunidad de Madrid (Spain). Two replications per treatment were tested by the panelists.

2.7. Statistical analyses

Analysis of variance was carried out using MSTAT-C (University of Michigan, USA). Least significant differences ($P \leq 0.05$) tests (protected LSD) were used to compare P and K treatments with CON. The margin of error for LSD was calculated from the residual of the ANOVA. All percentage values were transformed using the arcsin of the square root before analysis.

3. RESULTS

3.1. Climate conditions

The average temperature and rainfall of the experimental period are shown in Fig. 1. The maximum temperature was registered in July and varied between 39 °C in 2008 and 40 °C in 2010. The absolute minimum temperature was registered in November and December at −10 °C, −6 °C, −12 °C and −8 °C, respectively in 2007, 2008, 2009 and 2010. Annual rainfall was 321, 416, 392 and 652 mm, respectively. In spring vegetative growth occurs and rainfall in this season was different among years with 157, 167, 50 and 116 mm, respectively. The rainfall in 2010, the wettest year, fell in winter and autumn with 38 and 36.5% of total annual rainfall, respectively.

3.2. Nutritional status

Leaf N, P and K concentrations were above the threshold limits for deficiency for adult olive trees (1.5–2.0% N, 0.1–0.3% P and > 0.8% K) (Fernández-Escobar, 2010) (Table 2). There was no significant

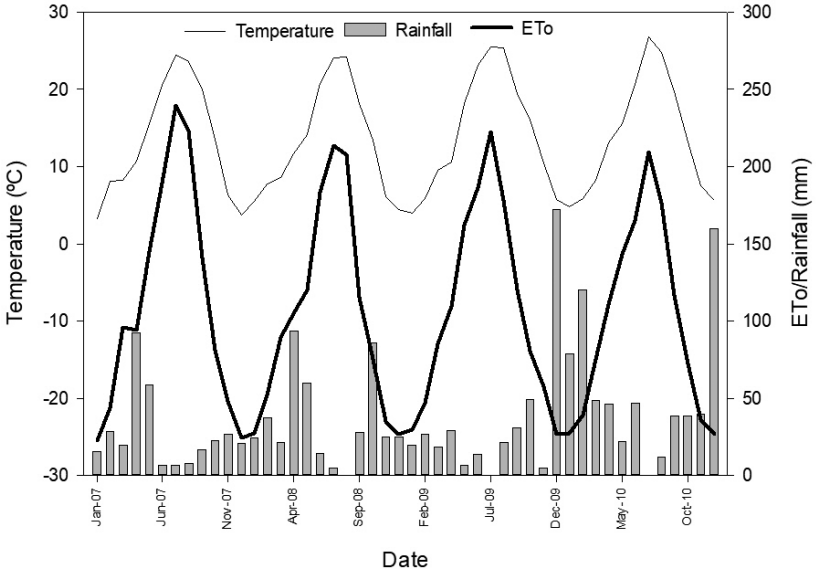

FIGURE 1. Monthly rainfall (mm), ETo (mm) and average temperature (°C) from January 2007 to December 2010 at the experimental orchards located in Valdepeñas (Ciudad Real, Spain).

TABLE 2. Leaf N, P and K concentration in 'Arbequina' and 'Picual' olive trees for each year in control trees (CON) and fertilization treatments

	'Arbequina'				'Picual'			
Year	**Treat**	**N (%)**	**P (%)**	**K (%)**	**Treat**	**N (%)**	**P (%)**	**K (%)**
2007	**CON**	1.82±0.05	0.18±0.02	1.09±0.09	**CON**	1.99±0.18	0.14±0.01	0.76±0.01
	P	1.83±0.06	0.18±0.03	1.11±0.06	**P**	2.02±0.11	0.13±0.02	0.77±0.13
	K	1.74±0.09	0.16±0.02	1.12±0.04	**K**	2.03±0.14	0.13±0.01	0.74±0.02
2008	**CON**	1.57±0.11	0.16±0.01	1.22±0.12	**CON**	1.80±0.04	0.14±0.02	0.92±0.11
	P	1.62±0.05	0.17±0.02	1.19±0.13	**P**	1.69±0.04	0.17±0.01	1.05±0.15
	K	1.91±0.62	0.15±0.02	1.27±0.20	**K**	1.82±0.01	0.14±0.00	0.99±0.07
2009	**CON**	1.43±0.13	0.12±0.01	0.92±0.13	**CON**	1.62±0.10	0.09±0.01	0.72±0.05
	P	1.39±0.15	0.13±0.01	0.97±0.09	**P**	1.64±0.08	0.10±0.01	0.75±0.07
	K	1.37±0.12	0.12±0.01	1.01±0.05	**K**	1.65±0.02	0.09±0.01	0.77±0.09
2010	**CON**	1.93±0.07	0.20±0.01	1.39±0.08	**CON**	2.04±0.08	0.15±0.00	0.95±0.04
	P	1.92±0.05	0.21±0.02	1.92±0.05	**P**	2.17±0.20	0.15±0.00	0.97±0.04
	K	1.78±0.04*	0.18±0.01*	1.78±0.04*	**K**	2.01±0.00	0.15±0.01	0.95±0.10

Values are reported as means ± SEM based on 100 mature leaves sampled in July in three blocks per treatment. * significant differences ($P \leq 0.05$) with CON according to ANOVA/protected LSD test.

effect of the fertilizer treatment on the leaf nutrient content in any of the orchards or experimental years. Mean values were 1.69, 0.16, 1.18, and 1.87, 0.13 and 0.86 for N, P and K (%) for 'Arbequina' and 'Picual'. respectively.

3.3. Hedgerow 'Arbequina' orchard

Vegetative growth was significantly different among years and trunk perimeter and shoot elongation were lower in 2009 than the rest of the years (Table 3). The mean values for shoot elongation and developed nodes were 13.2 cm and 8.9, respectively. The application of P produced increased shoot elongation and the number of developed nodes significantly in 2010 with respect to CON by 93 and 70%, respectively. Reproductive components were also significantly different among years (Table 3). The percentage of budburst was higher in 2010 and initiated buds were higher in 2009. Fertilizer application did not significantly modify any of these evaluated parameters in the experimental years. Mean values of 54 and 89% budburst and initiated buds were measured, respectively. Fertile inflorescence was 53% (data not shown). Interactions among treatments and years was significant for shoot elongation and node development but not for the other parameters.

TABLE 3. Vegetative and reproductive components of the control (CON), P and K experimental trees in the 'Arbequina' orchard

	Vegetative growth		Reproductive components	
Year and treatment	**Shoot elongation (cm)**	**Node developed (number)**	**Budburst (%)**	**Initiated buds (%)**
2008				
CON	16.8±5.5	14±3	37.7±2.8	68.6±7.8
P	18.6±8.2	14±6	37.4±9.7	67.4±19.6
K	12.5±6.0	10±4	42.1±10.9	79.3±11.1
2009				
CON	7.2±3.0	4.5±1.4	46.7±16.0	100.0±0.0
P	9.3±5.7	5.0±2.4	42.2±16.4	95.2±9.6
K	6.7±2.7	4.1±1.4	48.5±12.4	98.7±2.6
2010				
CON	10.8±8.2	7.3±4.8	74.3±12.5	99.4±1.2
P	20.9±18.8*	12.4±9.0*	77.4±13.7	94.3±8.7
K	16.0±9.5	9.0±4.1	78.1±12.2	97.3±1.8
2008-2010				
CON	11.6±9.1	8.5±7.1	52.9±15.1	89.3±15.9
P	16.3±7.3	10.5±7.3	52.3±19.2	86.7±19.1
K	11.7±5.5	7.7±5.5	56.3±19.5	91.9±11.6
Year (*Sign.*)	**	**	**	**

Values are reported as means ± SEM based on 12 olive trees and 36 shoots per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to ANOVA/protected LSD test. Budburst: percentage of buds from initial budbreak; Initiated buds: percentage of buds that developed an inflorescence; fertile inflorescence: percentage of inflorescence having at least one fruit.

In the 'Arbequina' orchard fruit characteristics were significantly affected by the season (Table 4). The values for fruit number, fruit oil content per fresh weight and MI were higher in 2007. In these two last parameters this increment could be explained by the fact that in this season the olives were harvested at the end of November whereas in the rest of seasons they were picked during the first fortnight of this month. Meanwhile oil content per dry weight was higher in 2008 even though higher fruit water content was observed that year. Furthermore, both olive yield and oil production were significantly higher in 2010. In 2008, P- and K-trees produced significantly higher numbers for kg of fruit and oil content than CON, while in the mean values of the experimental years no significant effect of fertilizer treatment was observed (mean values were: 7192 fruits/tree, 8468 kg olive/ha and 1519 kg oil/ha). The interaction among treatments and years was not significant for any production parameter.

There was no influence of fertilizers on fruit oil content (mean values of 17.4 and 37.6% f.w. and d.w., respectively) according to the mean values of the four seasons, but fruit water contents were increased in both P and K compared to CON.

All quality parameters of the extracted olive oils showed values under the limits established for the "Extra" quality, the best level of commercial quality for virgin olive oils (Commission Regulation EC No. 640/2008, of 4 July 2008) (Table 5). However, year significantly affected those values. In 2009, the oil presented higher acidity, K_{232}, K_{270} and oxidative stability, but peroxide values were higher in 2010. Fertilizer application did not affect any of these parameters. Mean values were 0.1%, 4 meq O_2 kg^{-1}, 1.49, 0.14 and 28 h for acidity, peroxide, K_{232}, K_{270} and oxidative stability, respectively.

The composition of fatty acids remained at the limits accepted for extra virgin olive oils (data not shown). Mean values for oleic, palmitic, linoleic, estearic and palmitoleic acids were 71.7, 14.2, 8.9, 2.0 and 1.4%, respectively (data not shown). Fatty acid contents significantly changed with the different seasons, but not due to the fertilizer treatments (Table 5). In 2009 SAFA, PUFA and linoleic acid showed higher values than in 2010.

The phenolic compounds of the oils were significantly modified by year but not by the fertilization treatments (Table 5). Only *p*-Cumaric acid and pinorresinol contents were not affected as a consequence of the different seasons (data not shown). The more simple phenolic molecules such as hydroxytyrosol, tyrosol, vanillic acid, vanilline, acetoxy-pinoresinol,

TABLE 4. Fruit characteristics and yield of control (CON), P and K experimental trees in the 'Arbequina' orchard

Year and treatment	Oil content (% f.w.)	Oil content (% d.w.)	Fruit water content (%)	Maturity index MI	Fruit number (n°/tree)	Olive yield (kg.ha^{-1})	Oil yield (kg.ha^{-1})
2007							
CON	18.6±1.7	34.0±3.7	45.2±1.0	3.81±0.4	9335±998	8012±1178	1501±349
P	19.2±1.8	35.6±3.5	46.1±0.9	4.25±0.35*	9949±296	9340±1051	1801±327
K	19.2±1.0	35.4±2.3	45.8±1.7	4.10±0.31	8321±1419	7735±1154	1485±220
2008							
CON	16.8±1.7	38.0±4.0	55.8±0.6	0.35±0.17	7305±2330	6758±737	1140±107
P	17.8±2.3	40.9±5.0	56.5±0.5	0.82±0.58*	8746±1493*	9376±946*	1683±361*
K	17.6±1.3	40.4±3.4	56.4±0.8	0.76±0.37*	7692±912	8444±476*	1502±95*
2009							
CON	14.8±2.5	33.5±5.3	56.0±1.1	0.58±0.44	4112±921	5246±518	782±155
P	16.3±2.7	37.0±5.9	56.3±0.2	0.74±0.6	4110±634	6207±2031	1045±491
K	15.2±2.6	34.8±6.4	56.5±1.5	0.70±0.1	3527±830	5151±1069	795±227
2010							
CON	17.7±1.1	38.7±1.8	54.4±1.8	0.64±0.49	7706±1517	11304±1206	2098±293
P	17.5±1.0	39.7±2.5	55.8±1.0	0.60±0.25	7858±1259	12368±1837	2275±405
K	17.4±1.5	39.6±2.7	56.1±0.9	0.47±0.28	7649±1418	11669±1579	2125±358
2007–2010							
CON	17.0±2.4	36.0±4.7	52.9±4.7	1.35±1.51	7115±2443	7830±2546	1380±568
P	17.7±2.2	38.3±4.6	53.7±4.6*	1.60±1.61*	7665±2579	9323±2811	1701±604
K	17.4±2.4	37.6±5.1	53.7±4.6*	1.52±1.56	6797±2398	8250±2759	1477±572
Year (*Sign.*)	**	**	**	**	**	**	**

Values are reported as means ± SEM based on 12 olive trees per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to the ANOVA/protected LSD test.

luteoline and apigenine showed higher contents in 2010, whereas more complicated molecules such as hydroxytyrosol acetate, tyrosol acetate, 3,4 DHPA-EDA, *p*-HPEA-EDA, 3,4 DHPA-E and *p*-HPEA-EA exhibited higher contents in 2009 (data not shown). As a consequence, the contents of the most important groups of phenolic molecules (total phenols, ortodiphenols and secoiridoids derivatives) were also significantly higher in 2009 (Table 5). The mean values of these groups were 476, 301 and 423 mg·kg$^{-1,}$ respectively.

Taste descriptions showed that these fertilizations did not affect the sensory quality of the oils (data not shown). In 2009, the oils were fruitier, more bitter and more pungent than in 2010. The mean values for the intensities of these sensory attributes were 6.0, 3.1 and 3.2, respectively.

3.4. Vase 'Picual' orchard

Vegetative and reproductive components were significantly affected by the year (Table 6) but interaction between treatment and year was not significant. The values for vegetative growth were higher in 2008. The application of P increased trunk perimeter significantly in 2009 (data not shown) and shoot elongation in 2010 by 37 and 22%, respectively. Mean values for the increment of trunk perimeter, shoot elongation and number of nodes were 3.2 cm, 8.2 cm and 6.7, respectively. The percentage of budburst and initiated buds were higher in 2010 and 2009, respectively. Foliar fertilization with P significantly affected reproductive components in 2008 throughout the experimental period. P-trees presented lower budburst, initiated buds and fertile inflorescence (data not shown) with respect to r CON by 38, 38 and 39%, respectively in 2008 and by 17, 13 and 40%, respectively throughout the experimental period. Mean values for budburst, initiated buds and fertile inflorescence were 54, 87 and 34%, respectively.

In this orchard, the fruit characteristics were significantly affected by season and fertilization treatments (Table 7) but interaction between treatment and year was not significant. Fruit oil content per fresh weight was higher in 2009; while per dry weight was higher in 2008 and water content in 2010. Considering the mean values for all the experimental years, The P treatment significantly increased oil content per d.w. and fruit water content by 5 and

TABLE 5. Oil quality parameters. fatty acid relationships and total phenolic compounds (ppm) of extra virgin olive oil extracted from the control (CON), P and K experimental trees in the 'Arbequina' orchard

Year and treatment	Acidity (% oleic acid)	Perox. val. (meq O_2 kg^{-1})	K232	K270	Oxidative stability (h)	MUFA/ PUFA	UNFA/ SAFA	C18:1/ C18:2	Total Phenols (ppm)	Total Ortodiphenols (ppm)	Total Secoiridoids (ppm)
2009											
CON	0.2±0.0	3±1	1.77±0.07	0.18±0.04	36±2	6.6±0.1	4.5±0.1	6.9±0.1	835.2	537.6	784.6
P	0.2±0.1	3±1	1.75±0.16	0.16±0.03	36±4	6.4±0.3	4.5±0.1	6.7±0.4	597.1	377.8	543.5
K	0.1±0.0	3±1	1.61±0.13*	0.16±0.05	33±4	6.7±0.1	4.5±0.0	6.9±0.1	700.9	472.4	643.9
2010											
CON	0.1±0.0	6±1	1.28±0.09	0.11±0.02	21±2	9.1±0.9	5.4±0.2	9.5±1.0	220.3	125.2	157.9
P	0.1±0.0	5±1	1.28±0.08	0.11±0.01	22±5	9.3±0.6	5.5±0.1	9.7±0.7	223.6	125.7	178.6
K	0.1±0.0	5±0	1.28±0.04	0.11±0.01	22±4	9.9±0.8	5.5±0.0	10.3±0.9	283.5	167.7	227.9
2009–2010											
CON	0.1±0.1	4±2	1.52±0.34	0.14±0.05	29±11	7.8±1.8	5.0±0.6	8.2±1.9	527.7	331.4	471.3
P	0.1±0.1	4±2	1.51±0.33	0.13±0.04	29±10	7.9±2.0	5.0±0.7	8.2±2.1	410.3	251.7	361.0
K	0.1±0.0	4±2	1.44±0.23	0.14±0.04	27±8	8.3±2.3	5.0±0.7	8.6±2.4	492.2	320.1	435.9
Year (*Sign.*)	**	**	**	**	**	**	**	**	**	**	**

Values are reported as means ± SEM based on 4 olive oils per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to the ANOVA/protected LSD test. MUFA: Monounsaturated fatty acids. PUFA: Polyunsaturated fatty acids. UNFA: Unsaturated fatty acids. SAFA: Saturated fatty acids. C18:1: Oleic acid. C18:2: Linoleic acid. Phenols: Total phenols. Ortodi: Total ortodiphenols. Secoiri: Total Seco-iridoids

4%, respectively. In 2009, the fruit number and olive and oil yield of P-trees were significantly higher than CON by 42, 31 and 27%, respectively. The number of fruits from P-trees was significantly lower than CON in 2008 by 49%.

All the quality parameters of the extracted oils showed lower values than the limits established for the extra level of commercial quality (Commission Regulation EU No. 1348/2013, of 16 December 2013) (Table 8). Year significantly induced changes in oil quality. In 2009 the oil presented higher acidity, K_{232}, K_{270} and oxidative stability, but peroxide values were higher in 2010. Both P and K applications coincided with a significant reduction in the oxidative stability in 2009. Mean values for acidity, peroxide, K_{232}, K_{270} and oxidative stability were 0.2%, 3 meq O_2 kg^{-1}, 1.48, 0.14 and 59 h, respectively.

Just as 'Arbequina' oils, all the fatty acid compositions of 'Picual' oils showed contents in accordance with the ones established for the extra virgin olive oils (data not show). Mean values for oleic, palmitic, linoleic, estearic and palmitoleic acids were 81, 10, 3, 3 and 1%, respectively (data not shown). Fatty acid contents were significantly modified by year but not by fertilizer treatments (Table 8). In 2010 the oleic and linoleic acid contents were higher and lower, respectively than in 2009. Therefore, the ratios MUFA/PUFA, UNFA/SAFA and Oleic/Linoleic acid in 2010 were higher than the previous year.

Phenolic compounds were significantly modified by the particular conditions of each season, but not as a consequence of the fertilization treatments applied (Table 8). Thus, in 2010 almost all the phenolic molecules of the extracted oils showed significantly higher contents (data not shown). Only hydroxytyrosol and *p*-HPEA-EA contents were higher in the oils of the 2009 season, whereas tyrosol, *p*-HPEA-EDA contents did not show significant differences in the two years tested (data not shown). Total phenols and ortodiphenols were significantly higher in 2010, while the secoiridoid derivatives did not exhibit significant differences (Table 8). The mean values for these parameters were 799, 510 and 747 $mg \cdot kg^{-1}$, respectively. Taste descriptions showed that fertilizer did not affect sensory oil quality (data not shown). In 2009 the oils were fruitier, more bitter and more pungent than in 2010. The mean values for these sensory attributes were 6.0, 3.7 and 3.3, respectively.

4. DISCUSSION

In our experiment, growth, production and oil quality were significantly affected by the conditions of the particular year. In 2008 vegetative growth was higher in both orchards probably due to the high water availability (40% of total year's rainfall occurred in April and May). The highest production was registered in 2010 most likely because of the low

TABLE 6. Vegetative and reproductive components of control (CON), P and K experimental trees in the 'Picual' orchard

	Vegetative growth		Reproductive components	
Year and treatment	**Shoot elongation (cm)**	**Node developed (number)**	**Budburst (%)**	**Initiated buds (%)**
2008				
CON	8.3±3.6	7.9±2.9	48.1±21.0	86.3±19.3
P	9.3±3.7	10.2±3.9	29.8±14.6*	53.3±30.2*
K	10.3±4.1	10.9±5.9	48.5±12.2	70.1±35.9
2009				
CON	6.2±1.6	4.9±0.7	44.5±18.6	100.0±0.0
P	7.1±2.7	5.1±1.5	43.4±4.2	98.1±2.2
K	12.0±6.7	7.0±2.3	48.2±26.1	90.1±7.5
2010				
CON	6.8±5.8	4.4±3.0	80.8±14.9	93.3±7.3
P	8.3±6.4*	5.8±3.3	69.7±15.9	92.0±14.2
K	5.2±4.5	4.1±2.5	74.5±10.3	95.0±5.2
2008–2010				
CON	7.1±5.5	5.7±3.8	57.8±25.3	93.2±12.9
P	8.2±5.6	7.0±4.9	47.7±26.3*	81.2±29.4*
K	9.2±7.2	7.3±5.6	57.1±22.3	86.1±23.8
Year (*Sign.*)	**	**	**	**

Values are reported as means ± SEM based on 12 olive trees and 36 shoots per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to ANOVA/protected LSD test. Budburst: percentage of buds from initial bud break; Initiated buds: percentage of buds which developed an inflorescence; fertile inflorescence: percentage of inflorescence having at least one fruit.

TABLE 7. Fruit characteristics and yield of control (CON), P and K experimental trees in the 'Picual' orchard

Year and treatment	Oil content		Fruit water content (%)	Maturity index (MI)	Fruit number (n°/tree)	Olive yield ($kg.ha^{-1}$)	Oil yield ($kg.ha^{-1}$)
	(% f.w.)	(% d.w.)					
2007							
CON	20.7±1.5	36.2±3.1	42.8±1.0	4.99±0.01	12844±751	3398±199	707±81
P	21.9±0.5	39.9±1.4	45.0±1.3	4.98±0.02	13351±2948	3919±493	856±87*
K	21.1±1.8	37.2±0.0	43.3±1.1	4.97±0.05	13706±1537	3621±424	772±136
2008							
CON	22.0±1.6	38.7±3.4	43.1±1.1	3.11±0.17	14858±3618	3733±299	818±22
P	23.3±1.1	44.3±0.7	47.3±1.9	3.29±0.15*	7587±2088*	3362±675	778±139
K	22.3±0.8	39.3±0.7	43.1±1.7	3.13±0.15	13859±3655	3751±622	837±129
2009							
CON	23.5±0.3	39.5±1.1	40.4±2.1	3.99±0.01	9311±1845	3314±711	778±160
P	23.1±1.2	40.0±1.9	42.4±1.3	3.98±0.02	13183±2754*	4327±849*	991±154*
K	23.7±0.5	40.2±0.0	41.1±1.7	4.00±0.01	9609±1493	3183±383	758±92
2010							
CON	20.1±0.9	41.6±1.3	51.5±2.8	3.36±0.58	11000±3234	6010±1060	1216±258
P	20.2±0.8	40.2±2.0*	49.7±1.6	3.34±0.53	12668±2384	6295±740	1265±120
K	21.2±0.3*	41.0±1.3	48.4±1.3	3.31±0.28	11176±1491	5511±1036*	1167±227
2007–2010							
CON	21.6±1.8	39.0±3.3	44.5±2.0	3.86±0.79	12004±3297	4114±1270	880±254
P	22.1±1.6	41.1±2.7*	46.1±2.9*	3.90±0.74	11697±3611	4476±1388	973±247
K	22.1±1.7	39.4±3.0	44.0±1.9	3.85±0.75	12087±3176	4016±1213	884±256
Year (*Sign.*)	**	**	**	**	**	**	**

Values are reported as means ± SEM based on 12 olive trees per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to ANOVA/protected LSD test.

Table 8. Oil quality parameters, fatty acid relationships and total phenolic compounds (ppm) of virgin olive oil extracted from control (CON), P and K experimental trees in the 'Picual' orchard

Year and treatment	Acidity (% oleic acid)	Peroxide value (meq O_2·kg^{-1})	K232	K270	Oxidative Stability (h)	MUFA/ PUFA	UNFA/ SAFA	C18:1/ C18:2	Total Phenols (ppm)	Total Ortodiphenols (ppm)	Total Secoiridoids (ppm)
2009											
CON	0.3±0.0	2±0.6	1.63±0.03	0.16±0.00	63±2	15.5±0.8	5.8±0.1	17.9±1.1	755.9	419.3	743.9
P	0.2±0.0	2±0.2	1.60±0.10	0.15±0.02	59±2*	16.0±1.7	5.9±0.1	18.4±2.1	663.6	350.7	616.2
K	0.2±0.0	2±0.6	1.61±0.04	0.16±0.01	60±1*	15.3±0.9	5.8±0.1	17.5±1.2	693.6	380.1	680.2
2010											
CON	0.1±0.0	4±0	1.36±0.05	0.13±0.01	57±2	27.0±0.7	6.6±0.2	33.4±0.7	986.4	724.7	897.0
P	0.1±0.0	4±1	1.35±0.06	0.13±0.01	53±9	27.9±1.4	6.6±0.1	34.9±1.9	896.7	631.0	818.9
K	0.1±0.0	4±1	1.35±0.07	0.13±0.01	59±5	27.0±2.7	6.7±0.2	33.1±4.0	799.1	557.1	725.9
2009–2010											
CON	0.2±0.1	3±1	1.50±0.19	0.14±0.02	60±3.9	21.3±8.1	6.2±0.6	25.7±11.0	871.2	572.0	820.5
P	0.2±0.1	3±2	1.47±0.17	0.14±0.01	56±4.3	22.0±8.5	6.2±0.5	26.6±11.7	780.2	490.8	717.4
K	0.2±0.1	3±1	1.48±0.18	0.14±0.02	60±0.5	21.1±8.3	6.2±0.7	25.3±11.0	746.4	468.6	703.1
Year (*Sign.*)	**	**	**	**	**	**	**	**	**	**	ns

Values are reported as means ± SEM based on 4 olive oils per treatment. * significant differences ($P \leq 0.05$) with CON; ** significant differences ($P \leq 0.01$) among years according to ANOVA/protected LSD test. MUFA: Monounsaturated fatty acids. PUFA: Polyunsaturated fatty acids. UNFA: Unsaturated fatty acids. SAFA: Saturated fatty acids. C18:1: Oleic acid. C18:2: Linoleic acid. Phenols: Total phenols. Ortodi: Total ortodiphenols. Secoiri: Total Seco-iridoids

olive yield of the year before and the high rainfall from October 2009 to March 2010 (474 mm), which would have increased floral induction and fruit set (Ulger *et al*., 2004). MUFA/PUFA and oleic/linoleic relationships in 2010 were significantly higher than in 2009 for both cultivars. This was mainly due to the increase in oleic acid and decrease in linoleic acid obtained the previous year. The lower fruit ripening in 2010 could explain this MUFA/PUFA increase with respect to the previous year (Dag *et al*., 2011), even though this is less evident in 'Arbequina' than in 'Picual'. In olive and other oleaginous species, it has been suggested that water availability and environmental conditions may influence the synthesis or activation of the oleate desaturase and therefore the fatty acid composition as well (Morales-Sillero *et al*., 2007; Flagella *et al*., 2002).

Foliar fertilization did not increase the foliar concentration of P or K throughout the experiment in any of the orchards and responses to treatments were scarce. This lack of response to fertilizers has been reported by other authors for olive trees (Restrepo-Díaz *et al*., 2009; Jiménez-Moreno and Fernández-Escobar, 2017). In all these works the olives had adequate leaf levels of P and K as in our experiment. However, Erel *et al*., (2008) after applying different rates of P and K to olives with adequate leaf-levels of nutrients, observed increases in P- and K-leaf composition as a function of P- and K-solution concentration, probably because the nutrients were applied by fertigation and the olives were grown in containers with granular perlite substrate.

The application of nutrients to the leaves is complex and involves many factors that influence treatment efficiency. Their effects may explain the differences among experimental results. These factors include: the type of formulation applied, the atomization of the spray solution, drop size and retention on the leaf surface and the level of penetration into the leaf (Fernández *et al*., 2013). When a spray solution is applied to a leaf, rapid penetration occurs, which decreases as the solution dries up (Sargent and Blackman, 1962). This drying is influenced by the formulation of the foliar solution and by the prevailing environmental conditions. The interaction between temperature and relative humidity surrounding the plant directly affect the physic-chemical characteristics and solubility of deposited materials and therefore the efficiency of foliar nutrient sprays (Fernández *et al*., 2013). When relative humidity is low the permeability may be reduced because of cuticular dehydration and the drying of the solution deposited onto the leaves. These environmental conditions may limit the availability of adequate energy and metabolic substrates to drive the uptake, transport and assimilation processes (Fernández *et al*., 2013). In this sense a humectant product was added to foliar fertilizers for increasing the time of contact between leaf

and sprayed solution during treatments and foliar treatments were made early in the morning, when temperature and humidity were adequate for foliar applications. However, sharp increases in temperature (mean maximum temperature above 33 °C were registered in June, July and August and above 28 °C in September) and an important decrease in relative humidity (below 45, 30, 38 and 55%, respectively) occurred. These conditions could have accelerated the evaporation of sprayed solutions and could explain why the leaf concentration did not increase even when P and K doses were increased by two and three times higher in 2008 than in 2007. Moreover, the low irrigation applied during the experiment (lower than 33% of ETo in 'Arbequina' and 8% of ETo in 'Picual') probably had a negative effect on P and K penetration into leaves since water stress could affect leaf expansion (Restrepo-Díaz *et al*., 2009), reduce stomatal opening (Fernández *et al*., 2014), and damage or slow down diffusion through the tree (Arquero *et al*., 2006).

K application slightly modifies olive growth or production. In the 'Arbequina' orchard, fertilization with K significantly increased olive and oil yields in 2008. Vegetative growth and oil quality were not significantly affected by K applications, as was also observed by Rufat *et al*., (2014) and Dag *et al*., (2009) in 'Barnea' olive trees. However, in the 'Picual' orchard oxidative stability was negatively affected by the K treatment. This could be due to the decrease in the phenol composition obtained, even though significant differences were not found, and to the low MUFA/PUFA and Oleic/Linoleic ratios, which have been directly linked with the oxidative stability of olive oil (Gutiérrez *et al*., 1999). A highly positive correlation between oil oxidative stability and polyphenol content, and between the former and Oleic/Linoleic fatty acid ratio have been observed by other authors (Morales-Sillero *et al*., 2007; Aparicio *et al*., 1999). Fruit water content was significantly increased in 'Arbequina' with K. It is known that the consumption of this element induces osmotic adjustment and water absorption in cells and plant tissues (Mengel and Kirkby 1987). Toplu *et al*., (2009) also observed an increase in fruit water content by fertilizing with P and K without affecting oil quality or fatty acid composition. This fruit water increase could negatively affect oil extraction (Pastor *et al*., 2005). Restrepo-Díaz (2008b) observed a positive effect of K application on olive fruit size in olive trees which was close to the deficiency level of 0.4% K, and Erel *et al*., (2008) obtained higher olive yield and number of fruits by applying K by fertigation. Inglese *et al*., (2002) obtained higher yields by applying K foliarly in different phases of fruit development, because of a significant increase in fruit fresh weight and a high pulp/stone ratio, however oil quality was not influenced by treatments. In this work leaf nutrient levels were not reported. The treatments with K only increased fertile inflorescence in Picual in 2009. The low water availability in these orchards could explain this lack of responses as previously pointed out by Restrepo *et al*., (2008a).

The application of P increased growth or production during certain experimental years. In the 'Arbequina' orchard, P-fertilization increased yield in 2008 and growth in 2010 (Tables 3 and 4). The intense spring rains fell in 2008 and winter rains fell in 2010, which could have increased the responses. In other experiments where P was applied by fertigation, positive effects on yield were observed. Erel *et al*., (2008) and Erel *et al*., (2016) observed enhanced perfect flower formation, final fruit set and fruit number by increasing P nutritional status, when young olives showed low (< 0.1%) and adequate (0.1–0.3%) P-leaf levels. Morales-Sillero *et al*., (2007) obtained oil yield increases with the amount of fertilizer applied by irrigation due to the increase in the number of fruits per tree. However, Jiménez-Moreno and Fernández-Escobar (2017) did not find responses to P applied to the leaves in vegetative growth or flowering in 'Arbequina' young olives. In the 'Picual' orchard P fertilization increased oil yield when CON registered the lowest olive yield (Table 7). The greater P availability could have improved oil synthesis as P is a constituent of the phospholipids, which are substrates for unsaturated fatty acid synthesis (Chesworth *et al*., 1998); although there were no significant differences in the oil content of the fruits. This treatment has reduced fertile inflorescence but this significant effect was not observed for fruit production. As for K, in 2009, oxidative stability was reduced in this orchard probably due to a reduction in total phenols, even though significant differences were not found. Dag *et al*., (2009) also observed a decrease in polyphenols and oxidative stability by increasing P in the irrigation solution. These authors obtained a negative correlation between MUFA and fruit P concentrations. In both orchards, treatments with P increased fruit water content in the experimental period (2007–2010). This increase was also obtained by Toplu *et al*., (2009) and Morales-Sillero *et al*., (2007) by fertilizing with N, P and K. In our case, the K content (13% K_2O) in the fertilizer used in the P treatment could explain this fruit water increase after osmotic adjustment.

5. CONCLUSIONS

In our experimental conditions, year characteristics seem to have had a greater effect on olive development than P or K fertilization treatments. Water availability determined production and olive trees only responded to fertilizer application in the rainy years. Despite that, P foliar application increased growth and production parameters for one year

in the 'Arbequina' and two years in the 'Picual' orchard. These results indicate that P foliar application could have a positive effect on olive trees in low rainy and scare irrigation conditions. However, it would be necessary to extend this type of trial in order to assess these positive results. Furthermore, responses to K foliar applications were not significant. Neither P nor K modified oil quality but oil stability may have been reduced in 'Picual' by reducing phenolic composition and MUFA/PUFA and Oleic/Linoleic acid ratios. Moreover, oil extraction could be negatively affected by treatments because of the increase in the fruit water content obtained in both orchards.

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