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Effects of different fertilization sources on *Olea europaea* (Oleraceae). Impact on olives and oil yield and quality. Considerations on environmental sustainability and soil use. A review

Revisión sobre los efectos de diferentes fuentes de fertilizantes en *Olea europaea* (Oleraceae). Impacto sobre el rendimiento y calidad de aceitunas y aceite. Consideraciones sobre la sustentabilidad ambiental y uso del suelo

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ABSTRACT

This review highlights the importance of olive trees growing in the southwest of Buenos Aires, Argentina. It also discusses the importance (1) of the different fertilizations forms in the determination of the various soil physicochemical and leaf chemical properties, olives yield, oil yield and quality, and (2) oil quality parameters. Cover crops can be beneficial to soil properties. The incorporation of organic manures is also beneficial to improve plant and soil physical and biological properties, which allows a better root development and longevity, and nutrient absorption. Additionally, organic crops can increase the oil yield and quality in comparison to non-organic treatments. Foliar fertilization can be a very efficient system for supplying N, P and K to olive trees. However, several applications are required to meet the needs of the crop. Olive yield decreases significantly when soil fertilization with N is eliminated for several consecutive years in comparison to the fertilization that is carried out annually. Nutrient overfertilization can lead to several negative effects

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from the environmental point of view. Fertilization with P might be unnecessary due to the extensive root system of the olive trees. Olive have a high K requirement since large amounts of K are removed each year at harvest. However, fertilization with different levels of K had negligible effects on oil quality. Oil quality parameters were first associated with N concentrations in leaves and fruits. The phenolic content of the oil decreased linearly in relation to the increase of N in the leaves, which indicates a competition between the synthesis of proteins and the phenolic compounds.

Palabras clave — Fertilization; oil; olive; polyphenols; yield.

RESUMEN

Esta revisión (1) destaca la importancia del crecimiento de olivos en el sudoeste de Buenos Aires, Argentina, y de diferentes (2) formas de fertilización en la determinación de varias propiedades fisicoquímicas del suelo y químicas de las plantas, del rendimiento de aceitunas, y del rendimiento y calidad del aceite, y (3) parámetros de calidad del aceite. Los cultivos de cobertura pueden beneficiar las propiedades del suelo. Los abonos orgánicos al suelo pueden mejorar las propiedades físicas y biológicas de las plantas y del suelo, y permiten un mejor desarrollo y longevidad de raíces, y de absorción de nutrientes. Los cultivos orgánicos pueden incrementar el rendimiento y calidad del aceite en comparación a los tratamientos no orgánicos. La fertilización foliar puede ser un sistema muy eficiente para abastecer N, P y K a los árboles de olivo. Sin embargo, se necesitan varias aplicaciones para satisfacer las necesidades de la cosecha. El rendimiento de los olivos disminuye significativamente cuando la fertilización con N del suelo es eliminada por varios años consecutivos en comparación a la fertilización producida anualmente. La excesiva fertilización con nutrientes puede producir varios efectos negativos desde el punto de vista ambiental. La fertilización del suelo con P podría no ser necesaria debido al sistema radical extensivo del árbol de olivo. Los frutos del olivo tienen un alto requerimiento de K por lo que grandes cantidades de K son removidas cada año con la cosecha; sin embargo, la fertilización con diferentes niveles de K tuvo efectos despreciables en la calidad del aceite. Los parámetros de calidad del aceite se asocian mayormente con las concentraciones de N en hojas y frutos. El contenido de fenoles en el aceite disminuyó linealmente en función del incremento de N en las hojas, indicando una competencia entre la síntesis de proteínas y compuestos fenólicos.

Keywords — Aceite; fertilización; olivos; polifenoles; rendimiento.

INTRODUCTION

1.1. The olive in Argentina and in the southwest of the Buenos Aires Province

Currently, Argentina is the major producer and exporter of olive oil in South America and the tenth to a worldwide level (COI, 2015). The southwestern region of the province of Buenos Aires is made up of the semi-arid, arid and sub-humid-dry pampas, with 6,500,000 ha, divided into 12 districts. Its agricultural productivity is lower than that of the rest of the Pampas, a consequence of the prevailing agroecological conditions (Cincunegui, *et al*., 2019). The Region has competitive advantages derived from its proximity to the largest port in the country (Ingeniero White port), an adequate transport system and the provision of related services necessary for the commercialization and general development of the activity (Cincunegui *et al*., 2019).

The National University of the South (UNS) is linked to the group of regional olive growers in order to generate, in an interdisciplinary way, information of a technological nature. This information should provide a firm basis for the development of a modern olive growing, that promotes and supports the production of quality oil in the arid and sub-humid zones of the province of Buenos Aires. Therefore, a group characterized by its high capacity for innovation, adequate treatment of the fruit, search for quality and collaborative action by different agents has been formed in the region (Rueda, 2016).

The oil produced in the area is distinguished by an oleic acid content with values greater than 70%, widely higher than the national average percentage. If its low levels of campesterol and free acidity are added to this data, the extra virgin oil from the south of Buenos Aires is chemically among the best at the national level, having received several national and international awards for its high quality (Cincunegui *et al*., 2019). This is due to characteristics such as the type of soil, the proximity to the sea, cold winters and a temperature range that favor the slow ripening of the fruit, high levels of phenols and a high proportion of oleic acid. These factors definitely influence the aromatic and chemical profile of the oils.

1.2. Fertilization systems and challenges for southwestern Buenos Aires Province

A large part of the producers of olive groves in the southwest of Buenos Aires use foliar fertilization with macronutrients (N, P and K) as the only method to increase the production of olive groves. This type of application is only recommended, however, for fertilizing with micronutrients (e.g., B, Fe, Mn, etc.). In addition, if one takes into account that: (1) depending on the quantities in which these nutrients are necessary for the olive tree (if high, their absorption must be via roots), (2) the very low absorption efficiency via the leaves (caused by the presence of leaves with pubescent undersides), (3) the large amount of fertilizer that is not absorbed due to dripping, evaporation, drift, etc., several foliar applications should be made throughout the cycle. Annually, most of the regional producers do not make more than two or three foliar applications, assuming that the crop is well nourished. In this framework, more efficient fertilization methods should be found that not only incorporate inorganic nutrients to the olive grove but also provide organic matter to the soils where this species is grown. This is important to not only have current fertility (inorganic nutrients), but also potential fertility (i.e., organic matter that slowly releases inorganic nutrients).

A study is currently being conducted at the Agronomy Department UNS to determine which of different fertilization sources is the best to improve (1) different soil physicochemical or leaf chemical properties, (2) fruit quantity, and (3) oil quantity and quality. The different fertilization sources include a (1) nitrogen-fixing grass-legume consociated cover crop (*Avena sativa* L. – *Vicia villosa* L.) between the rows of olive trees, (2) commercial organic fertilizer, or (3) an inorganic fertilization of the leaves or the soil with macronutrients (N, P and K). In addition, a zonal harvest time will be determined that optimizes the quantity and quality of the obtained oil. The originality of such study consists in using organic fertilizers and nitrogen fixation through cover crops (e.g., *Vicia faba*) in order to obtain alternative ways to foliar or soil fertilization with macronutrients.

The incorporation of alternative intensive crops such as olive trees by the producer will contribute to carbon sequestration and reduction of soil losses due to erosion, common in agricultural production, increasing sustainability and reducing the degradation of the agroecosystem. Although the SOB is characterized by developing agricultural and livestock activities, olive growing has become highly relevant, even more in times of drought. This is due to the great resistance to drought of *Olea europaea* (Mechri *et al.*, 2019).

A review on the effects of different fertilization systems on soil and plant properties, olives yield, and oil yield and quality follows:

FERTILIZATION SYSTEMS ON SOIL AND LEAF. PLANT RESPONSES IN TERMS OF OLIVE AND OIL YIELD AND QUALITY

2.1. Soil management systems in olive orchards: Traditional system versus cover crops between the rows of olive trees

Soil tillage is the traditional soil management in olive orchards. The effect of tillage on infiltration varies according to the location and type of soil, and the methods used for tillage (Gómez *et al.*, 1999). In many cases, the greatest infiltration of water only occurs for a short period of time immediately after the passage of the machinery (Pastor *et al.*, 2000). Tillage, however, could result in the degradation of the soil structure which can significantly reduce the rate of water infiltration causing runoff and erosion processes (Abid & Lal, 2009). Such undesirable effects are especially evident in olive trees present on steep slopes (Romero *et al.*, 2007; Gómez *et al.*, 2009a). Therefore, the environmental, hydrogeological, and socioeconomic consequences can be serious at both farm and basin scales (Xiloyannis *et al.*, 2008). In addition, the combination of intensive tillage and high air temperature induce an oxidative metabolism in the soil, determining a high rate of mineralization of organic matter.

A significant loss of soil organic carbon leads to a further deterioration of the soil and its hydraulic properties, precisely those that allow a better recharge and storage of rainwater within the soil (Strudley *et al*., 2008).

An alternative opportunity to manage the soil in olive orchards is given by the use of cover crops that eliminate most of the disadvantages of conventional tillage. This practice reduces runoff and soil erosion by interception of raindrops, thus reducing their erosive impact on the soil and accelerating the infiltration of excess surface water. Furthermore, soil cover, ensured by the resulting litter (cover crop residues left on the soil surface), conserves soil moisture and reduces water evaporation from the soil surface. Some studies indicated an increase in soil moisture in olive orchards with cover crops as a result of an increase in the infiltration rate and in the content of organic carbon in the soil (Durán-Zuazo *et al*., 2009; Gómez *et al*., 2009a, 2009b). At present, there are contradictory results on the effects of soil management on the productive performance of olive trees. Gomez *et al*. (1999), in a 15-year trial, did not observe differences in yield between mature olive plants that grew according to the conventional soil management systems and no-till (weed control using the herbicide simazine). The differences were recorded in a very dry experimental year (67% of the average annual rainfall) in which the non-tillage of the soil produced almost twice as much as the conventional soil management system. The authors suggested that the presence of roots in the topsoil in the no-tillage system favored water uptake by trees rather than evaporation of water from the soil. Ferreira *et al.* (2013) compared three management systems for mature olive orchards during 2002-2011: glyphosate, soil tillage, and sheep walking. These authors reported the highest cumulative olive yields in the glyphosate treatment applied once a year in April.

Different results were reported by Gucci *et al*. (2012) who obtained a higher fruit and oil yields in young olive orchards managed with soil tillage compared to orchards that grew with a permanent natural cover. However, the same authors suggested that the negative effect on yield could be attributed to an early establishment of the permanent cover and recommended delaying its adoption to the third or fourth year after orchard planting depending on tree growth

Soil and water conservation are essential for ecosystems to be sustainable in the long-term (Mirsky *et al*., 2013). Cover crops are increasingly recognized as a critical part of a sustainable agricultural production, based on the combination of productivity with the reduction of environmental risks (e.g., less use of herbicides due to less presence of weeds) (Schipanski, *et al*., 2014). The inclusion of cover crops (e.g., legumes) can increase the amount of particulate organic matter in the soil (Restovich *et al*., 2011). As a result, it is expected that it will also affect the dynamics of N in the soil (Beltrán *et al*., 2014).

The organic matter of soils is their most important nutrient reserve (Rani Sarker *et al*., 2018). The availability of these nutrients is a function, at least in part, of soil pH (Mengel & Kirkby, 2001). Soils with a pH between 5.5 and 7.5 are those that determine a greater availability of macro and micronutrients (Mengel & Kirkby, 2001). Therefore, the reduction of soil organic matter directly affects its quality and productivity (Beltrán *et al*., 2018). Thus, a permanent or semi-permanent organic cover of the soil is necessary to ensure the maintenance of its quality (Fuentes *et* *al.*, 2009). Cover crops increase carbon levels in the soil and enhance its accumulation in the first layer of the soil due to deposition of crop tissues. This represents a greater stability for the soils since higher levels of carbon on the surface reduce erosion processes (Duval *et al.*, 2016). The scarce or null contribution of residues could cause negative balances of the organic matter of the soil (Mazzilli *et al.*, 2014), reducing the contribution of nutrients (Cruzate & Casas, 2012) and increasing their losses. This is due to the erosive processes that determine the lack of a soil coverage (Duval *et al.*, 2017). Cover crops are not incorporated as green manures or harvested, and can fulfill many functions such as: (1) physical protection of the soil from solar radiation, wind and rain, (2) weed control (Alonso-Ayuso *et al.*, 2018), (3) a greater contribution of organic carbon (Álvarez *et al.*, 2005), (4) prevention of erosion, (5) increase in infiltration, (6) promotion of the capture of mobile nutrients (N and S), (7) reduction of their losses by leaching and (8) pest and disease control (Quiroga *et al.*, 2009; Rimski Korsakov *et al.*, 2015). It should also be considered that the presence of cover crops stimulates microbial activity in the soil and thus affects the availability of some nutrients (Kunze *et al.*, 2011) and their distribution in the soil profile. The latter is the result of the absorption of water and nutrients from deeper layers in the soil, and their re-incorporation into the soil at the surface once the cover crop tissues dry out and decompose, producing a marked stratification and an increased soil nutrient density (mainly those that are not very mobile) at the soil surface. For example, in the case of phosphorus (P) and potassium (K), due to their low mobility, cover crops have an effect of stratifying their concentrations. As a result, there is an increase in them on the surface (Tiecher *et al.*, 2012).

The cover crop fixes nitrogen during the autumn-winter season and releases it in spring-summer, after incorporating its biomass into the soil (Kramberger *et al.*, 2009; Tosti *et al.*, 2012). This situation allows the substitution of inorganic nitrogenous fertilizers, which is very important from the environmental point of view, contributing to the sustainability of the production systems (Da Silva *et al.*, 2007). Although a significant amount of N may exist in the aerial part of cover crops, the actual amount of N that will remain available will depend on the amount of waste that decomposes and the dynamics of mineralization/immobilization of each type and amount of waste contributed to the soil (Sá Pereira, 2013). The N maintained in the organic form is, compared to that provided by fertilizers, less prone to losses due to leaching, volatilization or denitrification, since it is made available slowly, according to the mineralization of plant residues (De Sá Pereira *et al.*, 2014). Furthermore, N incorporated into the soil from plant biomass is more efficiently used by plants than N derived from fertilizers (Reicosky & Archer, 2005). The availability of N from cover crop residues will depend on their rate of decomposition, which is directly related to environmental conditions (e.g., water, light) and their C/N ratio.

If the C/N ratio is low, a high net mineralization will occur (Mengel & Kirkby, 2001). Soil fertility management requires an integrated strategy to maintain long-term nitrogen stocks while managing short-term nitrogen dynamics (Lawson *et al.*, 2013). Species belonging to the *Fabaceae* family (e.g., vetch, *Vicia* spp.) are important sources of nitrogen used to meet these goals (Spargo *et al.*, 2016). Vetch is an annual, winter species that is widely adapted to most areas and has a very satisfactory natural reseeding. In addition, it has a low C/N ratio (generally 10:1 to 15:1) that results in a rapid biomass decomposition, with most N mineralization occurring during the first 4 to 8 weeks of spring (Poffenbarger *et al*., 2015); it can produce more than 150 kg ha^{-1} of total N (Teasdale *et al*., 2012). Vetch has the ability to fix atmospheric N and recycle soil N, supplying it with very relevant amounts (Benincasa *et al*., 2008) and increasing crop productivity (Baigorria & Cazorla, 2009).

2.2. Soil commercial organic fertilizers

Organic production is a new agricultural production system that avoids the use of synthetic and chemical fertilizers applied to the soil. The environmental effects on human health encourage agricultural producers to replace the use of these chemical fertilizers with organic ones (Fayed, 2005). In addition, the incorporation of organic manures matter will help create favorable conditions for root development and nutrient absorption, since they provide elements that allow a better soil structure, managing to improve infiltration, drainage, aeration, moisture and nutrient retention (Bueno & Oviedo, 2014).

Relevant organic materials incorporated into olive orchards include chopped pruned material, raw organic manure, olive mill wastewater, compost and non-composted organic manures. Although the direct application of non-composted organic manures is common, it is not recommended because of the risk of spreading pathogens, parasites and weed seeds, all of which are eliminated during the composting process (Larney & Hao, 2007). Different composts have varying nutrient concentrations depending on the source materials used for their preparation (Cayuela *et al*., 2004). Concentrations of 1.4-2.5% total N, about 0.3-1% P and 2.1-2.9% K are common in the dry matter (Sánchez-García *et al*., 2016). In a study conducted by Cayuela *et al*. (2004), 40 kg compost $tree^{-1}$ was applied in an irrigated orchard. The potential contribution of the compost to N, P and K tree nutrition in that study was 75-84, 11-17, and 100-120 kg ha^{-1}, respectively. These amounts are about 50% of the recommended levels of 150 (N), 30 (P) and 250 (K) kg ha^{-1}, respectively (Erel *et al*., 2018). In an orchard fertilized with compost there were increases in (1) organic matter content, (2) cation-exchange capacity, (3) soil hydraulic conductivity, (4) soil water retention (Cayuela *et al*., 2004), (5) the humic fraction of the soil, (6) aggregate stability (Whalen *et al*., 2003), (7) soil organic carbon content (Palese *et al*., 2014), and (8) mineral N content in compost was usually one order or magnitude lower than total N (Sánchez-García *et al*., 2016). Most of the N in the compost is in organic form, which makes it less liable to migrate downward through the soil because of heavy rains or irrigation (Dahan *et al*., 2014).

Organic matter is not only necessary for plant nutrition as slow-release fertilizer but also essential for efficient plant production systems (Steve, 2009). Composting is recommended for olive cultivation in arid and semi-arid regions, especially in sandy soils, which are limited by water resources (Abdel-Nasser & Harash, 2001). The increase of soil organic matter is a slower and more complex process than its decomposition, making thus necessary the addition of organic manure if the main objective is a sustainable production (Diacono & Montemurro, 2010). The integrated nutrient management sustains an appropriate use of the combinations of organic and inorganic fertilizers, addressed to restore the soil organic matter, improve the availability and efficiency of soil nutrient use, and maintain or improve the soil biological, chemical and physical properties (Hernández *et al*., 2014).

The traditional organic fertilizers (residues of agricultural and feeding processes) have maintained the soil productivity for thousands of years. In the modern horticultural systems, friendly with the environment, organic fertilizers are often used to improve the soil physical and biological properties. Use of the organic matter in the fertilization of plants contribute to improve the soil chemical and biological properties. The organic matter increases the (1) organic carbon content, (2) soil biological properties (microflora and microfauna), (3) cation exchange capacity, and (4) soil structural stability (Giusquiani *et al*., 1995; Bravo *et al*., 2012), and reduce the (5) apparent density and (6) formation of crusts in the soil surface area (Chang *et al*., 2010). This improves the water retention, the water infiltration rate, and the soil hydraulic conductivity (Chang *et al*., 2010; Bravo *et al*., 2012) conducing to a greater harvest yield (Kwabiah *et al*., 2003; Chang *et al*., 2010; Jha *et al*., 2011; Marzouk & Kaseem, 2011). In addition, the organic manure can be beneficial to the harvest and soil on the long-term (Tirol-Padre *et al*., 2007). This is because the organic matter is mineralized during the growing season, gradually providing nutrients for plant uptake, more slowly than the mineral fertilizers. Baldi *et al*. (2010) observed that repeated applications of compost in a peach orchard increased root proliferation and longevity compared to soil without aggregates.

However, according to Aisueni *et al*. (2009), Amoah *et al*. (2012) and Bravo *et al*. (2012), the sole use of organic fertilizers as substitutes for chemical fertilizers is not enough to maintain the productivity of high-yielding crops. In turn, Lu *et al*. (2011) observed that the partial replacement of inorganic fertilizers with organic ones met the nutrient demands of crops and maintained the efficacy of macronutrients. This suggests that the combination of the organic and mineral fertilizers could be more efficient than the application of any of them separately.

Organic fertilizer application or compost amendment resulted in (1) lower pH values, (2) higher cation exchange capacity, (3) an increase of olive tree yields, (4) adequate mineral contents in leaves during the growing cycle of olive trees for obtaining an economical yield, (5) increases of the percentage of fruit establishment, (6) reductions in times of fruit fall, (7) increases in the soil N, P and K availabilities, (8) an increase of soil organic matter content, and (8) an increase in the soil water content and olive tree performance compared with the control (Roussos *et al*., 2017; Chehab *et al*., 2019).

Anastasopoulos *et al.* (2011) found that overall, olive oil from organic cultivation was of superior quality in comparison to the non-organic treatment. The utilization of compost improved significantly the oil yield by about 100% (Chehab *et al.*, 2019). The organic olive virgin oil was of a superior quality in comparison to the conventional olive virgin oil: lower values of acidity and of peroxide index, greater stability and a greater value from the organoleptic point of view (Gutiérrez *et al*., 1999; AL-Kahtani & Ahmed, 2012).

The optimal pH values for olive cultivation are between 7 and 8.5 with respect to the availability of nutrients necessary for its correct growth and fruiting (Porta Casanellas & López Acevedo, 2005). Since the pH values found in the southwest of Buenos Aires are close to neutrality (Aguirre *et al*., 2011), they would not be restrictive for soil fertilization with macronutrients (N and K).

2.3. Inorganic foliar fertilizers

On numerous occasions, especially in dry years and very limestone soils, foliar fertilization can be a very efficient system for supplying nutrients to the olive tree. N and K are very well absorbed when applied by this method and P does so acceptably (Vega *et al*., 2018). However, such macronutrient fertilization is not recommended because these elements are needed in high quantities by the plant and the absorption by the leaves is not enough to supply the demand (Christensen, 2005). The amounts of macronutrients applied in this way is small, so several applications are required to meet the needs of the crop.

Foliar fertilization during plant growth has been a topic of recent research (Erel *et al*., 2013; Haytova, 2013). It is known that supplemental foliar nutrients can correct the mineral status of plants, improve fruit yields and quality, resistance to diseases, pests and drought tolerance (Haytova, 2013). However, the use of foliar fertilizers based on N, P and K led to a significant decrease in the content of phenolic compounds in the oil, although they seemed to significantly improve the level of most volatile compounds, especially hexanal (Dabbaghi *et al.*, 2019).

In fact, several studies have focused on the effects of foliar fertilization on the antioxidant profile and fatty acid composition of the olive oil (Fernández-Escobar *et al*., 2006; Dag *et al*., 2009; Tekaya *et al*., 2013). Single and combined applications of the macronutrients N, P and K via foliar fertilization from 2.5 to 7.5 g/L have increased the weight, size and oil percentage of the fruits compared to unfertilized olive trees (Hussein & Abd Elall, 2018). Foliar fertilization with N applied at the end of the winter break, and B, Mg, S and Mn at the beginning of flowering, caused a significant decrease in phenols, tocopherols and carbohydrates in olive fruits. Thus, a high correlation was observed between the concentration of nutrients in the plant and the chemical composition of those fruits (Tekaya *et al*., 2014). Ben Mimoun *et al.* (2004) reported that foliar fertilization improves the quality of olive oil. The seasonal pattern of foliar macro and micronutrients of olive cultivation is affected by environmental, varietal and management effects that must be considered in the preparation of nutritional standards (Fernández-Escobar *et al*., 1999). Foliar nutrient analysis is the best method to diagnose the nutritional status of a tree and represents an important tool to determine future fertilization requirements.

2.4. Inorganic fertilizers applied to the soil

Morales-Sillero *et al*. (2007) studied the effect of fertilizing the water for irrigation on the oil quality and yield with different dosages of the fertilizer 4N-1P-3K. The oil yield increased as the fertilizer dosage also increased. This was due to an increased number of fruits. However, the oil quality was negatively affected on trees fertilized with 400 and 600 g of N per tree during the irrigation season in comparison to the control trees and those fertilized with 200 g of N.

Among the mineral elements of the soil that the olive tree requires the most are N, P and K (Bueno & Oviedo, 2014). These authors suggested which are the best moments to apply nitrogenous and phosphorous fertilizers during the crop cycle. When the olive tree is young, the greatest needs are N and P (Bueno & Oviedo, 2014). However, when the olive grove is in full production and without any limitation to its growth, the highest mineral requirements are fundamentally of N and K.

The way to estimate the need for fertilization is by carrying out a soil analysis. This practice must be taken into account by the olive grower as the main tool for nutritional diagnosis before planting the olive grove. Over the years and as the olive grove grows and develops, the soil analysis must be complemented with the corresponding foliar analysis, for an efficient nutritional management. The amount of nutrients removed annually in the olive harvest is relatively low, suggesting that fertilizer applications could be more conservative than those usually recommended by soil and leaf tissue analysis laboratories. Thus, with a fruit yield of 2500 kg ha^{-1}, the nitrogenous fertilizer to be applied should not exceed 20 kg N ha^{-1} $year^{-1}$. This amount of N should be applied each year, to increase the efficiency in the use of N, given its characteristic of mobility in the soil and plant (Rodrigues *et al.*, 2012). Olive yield decreases significantly and progressively when nitrogen fertilization is eliminated for 4 consecutive years, compared to fertilization carried out annually (Rodrigues *et al.*, 2011). An increase in olive yield has been observed with applications of N to the soil, while those of phosphorus and potassium were made by foliar application; nevertheless, prior to the applications, the foliar analysis indicated adequate levels of nutrition in the plants (Centeno & Campo, 2011). In general, it is observed worldwide that olive growers overfertilize the crop, particularly with N. Annual applications of 80 to 200 kg N ha^{-1}, and even higher, are common in many areas of the Mediterranean zone (Fernández Escobar, 2011). The excessive use of N in agriculture translates into a decrease in its use efficiency and several negative effects from the environmental point of view (Raun & Schepers, 2008). Some studies have proposed that phosphorus fertilization is unnecessary because the extensive root system of the olive tree absorbs adequate amounts of such element. Olive fruits have a high K requirement, since large amounts of K are removed each year at harvest. That is why K deficiency has very negative effects on production (Fernández-Escobar *et al.*, 2008; Therios, 2009).

2.5. Fruit and olive oil quality parameters

Oil quality parameters were first associated with N concentration in leaves and fruits, which increased with nitrogen spraying. Potassium level had negligible effects. The phenolic content of the oil decreased linearly as a function of the increase of N in the leaves, indicating a competition between proteins and phenolic compounds in them. In general, the saturation level of fatty acids decreased with the N of the fruits, resulting in an increase in polyunsaturated fatty acids. Free fatty acids increased with increasing fruit N levels. The high load of fruits reduced their N content and consequently improved the quality of the oil (Erel *et al*., 2013). The high efficiency of foliar application reduces the need to apply fertilizers to the soil and thus decreases nutrient leaching/runoff as well as the impact of fertilizers on the environment (Dong *et al*., 2005; Rezk *et al*., 2008).

The process of development and ripening of the fruit is the result of a combination of biochemical and physiological changes that take place under strict genetic control, but with the influence of environmental factors, the age of the olive tree or the nutritional status of the tree (Connor & Fereres, 2005). The maturity of the fruits at the time of harvest influences the organoleptic quality and the properties of virgin olive oil. The highest quality oils are obtained if fruits with optimal maturity index are harvested (Jiménez Herrera *et al*., 2012). In addition, post-harvest and technological factors, such as transport, storage, washing, grinding, beating, etc., directly affect the organoleptic characteristics and chemical composition of the oils obtained (Jiménez & Carpio, 2008). The state of maturity of the olive is one of the most important factors associated with the sensory quality of virgin olive oil (Youssef *et al*., 2010). Apart from the well-known effects of olive ripening on fat yield, fruit deterioration, color, etc., the ripening factor must be a priority criterion to define the organoleptic quality of the oil. Depending on this state, the chemical composition (triglycerides and minority compounds) of the elaborated oil suffers alterations that, depending on the time of harvesting the fruit, exceed those produced by the variety factor (Sánchez Casas *et al*., 2006).

Numerous experimental evidence supports the existence of an inverse relationship between fruit ripening and content of polyphenols and volatile compounds (Bonoli *et al*., 2004; Rotondi *et al*., 2004; Gómez Rico *et al*., 2006; Youseff *et al*., 2010). During the ripening process, fruit weight, pulp-to-stone ratio, color, oil content, chemical composition, and enzymatic activity change dramatically. All these parameters influence the firmness of the fruits, the ease of extracting the oil and sensory characteristics (Bouaziz *et al*., 2004; Menz & Vriesekoop, 2010). Generally, as the fruit ripens, the oil becomes less stable due to the increase in polyunsaturated fatty acids and the decrease in polyphenol content (Ayton *et al*., 2007; Morello *et al*., 2004; Rotondi *et al*., 2004). These changes are of high commercial importance because they determine the sensory characteristics of the oil, as well as its storage time. Fruits harvested early produce oil with a high content of polyphenols that contribute to the level of bitterness and spiciness. The oil is relatively more stable due to the antioxidant effect of polyphenols (Dýraman & Dibekliog¢ lu, 2009). However, harvesting too early will yield oils that are organoleptically unacceptable due to an excessive concentration of polyphenols.

The oil yield is extremely important for the producer and must be considered together with the quality indices to define the harvest time. It is documented that the percentage of oil increases significantly from the beginning of fruit maturity (Lavee & Wodner, 2004). The oil content increased as the maturity index increased, reaching a maximum at a medium level of maturity and then decreasing (Baccouri *et al*., 2007). Free acidity increased as maturation progressed and an increase in enzymatic activity was found, especially by lipolytic enzymes (Baccouri *et al*., 2007). In addition, the low free acidity was due to healthy fruits and their rapid processing and it was evidenced that, with advanced stages of maturity, the peroxide values turned out to be lower in the oils obtained (Matos *et al*., 2007). In general, as the fruits mature, the oil becomes less stable due to the decrease in polyphenol content, increasing the polyunsaturated fatty acids (mainly linoleic acid) and decreasing the chlorophyll contents (Ayton *et al*., 2007). The latter contributes to the stability of the oil when it is found in fruits not yet harvested (Vincenzo *et al*., 2006); it is seen as a positive aesthetic characteristic of olive oil, giving it the green color, although the pro-oxidant effect is a negative attribute (Ayton *et al*., 2007).

Vitamin E is another important antioxidant that is formed by the tocopherols á, â and ã in virgin olive oils. Usually, the activity of vitamin E of the virgin olive oils is greater than that described for other edible oils. Pigments are responsible for the oil color which is considered as a quality parameter. In the olive virgin oil, carotenoids and chlorophyll pigments can be found. Carotenoids have antioxidant activity which protect oils from autooxidation, while chlorophylls act as a pro-oxidant in light (Fernández-Escobar *et al*., 2006). These authors reported that fertilization and pruning do not appear to affect olive oil quality parameters such as the acidity, the peroxide values and the absorption of UV-vis.

FINAL CONSIDERATIONS

The importance (1) of different fertilizations forms in the determination of different soil physicochemical and leaf chemical properties, olives yield, oil yield and quality, and (2) of different oil quality parameters were discussed in this review. Cover crops can be beneficial to soil properties. The plant and soil physical and biological properties, and the creation of favorable conditions for root development, longevity, and nutrient absorption can be improved by the incorporation of organic manures. In comparison to the non-organic treatments, oil yield and quality can be increased by organic cultivation. N, P and K can be very efficiently applied via foliar fertilization to olive trees, although several applications are required to meet the needs of the crop. When soil N fertilization is not made by different consecutive years, olive yield decreases significantly in comparison to annual N fertilization. Because of the extensive root system of the olive tree, some studies have proposed that soil P fertilization is unnecessary. Olive fruits have a high K requirement since large amounts of K are removed each year at harvest. However, fertilization with different levels of K had negligible effects on oil quality. In contrast, N concentrations in leaves and fruits were first associated with oil quality parameters. As a function of the increase of N in the leaves, there was a linear decrease in the phenolic content of the oil, indicating a competition between proteins and phenolic compounds in the leaves.

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