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Inorganic and organic foliar fertilisation in olives

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Abstract: The application of nutrient solutions to the foliage of plants is an alternative means to fertilise crops. Foliar fertilisation is used to overcome the disadvantages of soil applications. Variable plant responses to these foliar fertilisation spray solutions have often been described in the literature. However, knowledge about the penetration mechanisms, the role of a leaf-applied inorganic or organic solution, and the results obtained by its application is still limited. The complex character of the factors determining the effects of sprays hinders the development of suitable foliar fertilisation strategies, applicable under variable local conditions and for various plant types. This review describes some basic factors involved in the penetration process of foliar sprays in olive (*Olea europaea* L.) trees. Chemistry, leaf penetration, and plant nutrition principles will be merged with the aim of clarifying the constraints, opportunities, and future perspectives of sprays to cure olive tree nutrient deficiencies and, hence, both increase the yield and improve the fruit quality.

Keywords: deficiency; fertilisation; nutrient; olive; penetration; sprays

The olive (*Olea europaea* L.) has constituted as being the most important tree crop since antiquity. The olive is generally a tree with few needs with excellent adaptation in the temperate Mediterranean climate. Despite the accumulated knowledge on cultivation practices, modern olive culturing management must place an emphasis on fertilisation in order to achieve satisfactory growth and fruit production as well as obtaining high quality olives and olive oil (Therios 2009). There is evidence that an adequate nutritional status for optimal olive growth is also optimal for olive tolerance to some biotic or abiotic stresses (Huber et al. 2012; Sanzani et al. 2012; Fernández-Escobar 2019). Olive trees grow and set fruits in a large variety of soil types, even those ones with low fertility. However, they are most productive in loamy soils of medium nutrient status that retain adequate humidity. Heavy soils with a low drainage capacity are inappropriate for olive cultivation, as their output is decreased and the qualitative characteristics of the produced olive oil are degraded. With regards to the chemical characteristics of soil, olive trees thrive in neutral or slightly alkaline (pH 7–8) and slightly acidic soils (pH 6–7). In pH val-

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ues lower than five and above 8.5, the growth and production of the olive are decreased. In general, olive trees easily adapt to dry thermal conditions, but they do not tolerate poorly drained and poorly ventilated soils. In addition to growing in a wide range of soil pHs, as already mentioned, the olive is characterised as a species moderately resistant to salinity (Therios 2009) (Table 1).

The olive tree has an abundant root system that efficiently utilises the soil moisture. Leaf transpiration is limited while the resistance to dry conditions is elevated due to the characteristics of the leaves which are leathery with a thick waxy layer, having an abaxial small, dense and sunk stomata. On the other hand, its needs in nutrients, which are largely determined by the quantities removed (Table 2), are proportional to the yield that is directly related to the age and the size of the canopy of the olive trees (El-Fouly et al. 2014; Fernández-Escobar et al. 2015). The critical stages for the adequacy of nutrients and water in olives are the following: (i) differentiation of the buds; (ii) flowering and fruiting; and (iii) hardening of the stone of the olive fruit and the rapid growth of the fruit (Therios, 2009).

Table 1. Optimum soil characteristics for establishing an olive orchard.

Soil characteristic	Value
Soil texture	medium
Drainage	good
Salinity	moderate
pH	6.5–8.0
Organic matter (% w/w)	> 1
Total N (% w/w)	0
$CaCO_3$ (% w/w)	2–20
Available P (mg/kg)	15–30
Exchangeable K (meq/100 g)	0.5–1.0
Exchangeable Ca (meq/100 g)	6–12
Exchangeable Mg (meq/100 g)	1–3
Available B (mg/kg)	> 0.3

Source: Therios (2009); Bienes et al. (2018)

Olive tree nutrition. To achieve the optimal nutrition in the olive (Table 3), the evaluation of the nutritional status of the tree is succeeded by determining the leaf nutrient concentrations (Beutel et al. 1983; Connell, Vossen 2007; Molina-Soria, Fernández-Escobar 2012).

Testing the soil and analysing the leaves should be used routinely to monitor the changes in the nutrient level and to conduct the annual fertilisation programme. The rational use of fertilisers is a key factor not only for increasing the yield, but for ameliorating the oil quality as well. According to several studies, manipulation of the nutrient levels in foliar fertilisers may optimise the olive oil composition and, as a result, the olive oils are enriched with beneficial phytochemicals, such as hydroxytyrosol, mannitol, and polyphenols (Tekaya et al. 2013; Tekaya et al. 2016; D'Amato et al. 2017). This is very important as phenolic compounds influence the sensory properties (flavour, bitterness, etc.) of olives and oil, and they protect them against oxidative rancidity by acting as antioxidants (Servili, Montedoro 2002).

The primary function of nitrogen (N) is to provide amino groups in an amino acid constituent of bases in the nucleotides of purine and pyrimidine. Besides these, N is an essential constituent of many non-protein compounds, such as coenzymes, photosynthetic pigments, secondary metabolites and polyamines and vitamins (Pandey 2015). N is the mineral nutrient mostly applied in olive orchards, since it is a ma-

Table 2. Average nutrient removal of fruits, pruned material and total nutrients per year per olive tree

Amount of nutrient element/tree	Fruits (65 kg/tree)	Pruned material (wood + leaves)	Total amount (nutrient/ year/ tree)
Nitrogen (kg)	0.176	0.090	0.266
Phosphorus (kg)	0.025	0.011	0.036
Potassium (kg)	0.244	0.045	0.289
Calcium (kg)	0.029	0.174	0.203
Manganese (g)	0.218	0.370	0.588
Zinc (g)	0.250	0.130	0.380
Copper (g)	0.184	0.217	0.401
Iron (g)	2.734	1.141	3.875
Boron (g)	0.481	0.120	0.601

Source: El-Fouly et al. (2014); Fernández-Escobar et al. (2015)

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Table 3. Concentrations of the optimal nutrition in the leaves that determine the nutritional status of the olive tree

Nutrient	Deficient	Optimum	Toxic
Nitrogen	< 1.4%	1.5–2.0%	> 2.55%
Phosphorus	< 0.05%	0.1–0.3%	> 0.34%
Potassium	< 0.4%	0.8–1.0%	> 1.65%
Calcium	< 0.6%	1.0–1.43%	> 3.15%
Magnesium	< 0.08%	0.10–0.16%	> 0.69%
Sulfur	< 0.02%	0.08–0.16%	> 0.32%
Iron	< 40 ppm	90–124 ppm	> 460 ppm
Zinc	< 8 ppm	10–24 ppm	> 84 ppm
Boron	< 14 ppm	19–150 ppm	>185 ppm
Manganese	< 5 ppm	20–36 ppm	> 164 ppm
Copper	< 1.5 ppm	4–9 ppm	> 78 ppm
Sodium			> 0.20%
Chloride		100 ppm	> 0.5 %

jor nutritional factor affecting plant growth. The olive yield and oil composition are influenced by nitrogen fertilisation (Fernández-Escobar et al. 2006; Dag et al. 2009). Depending on the soil fertility and moisture, a dosage of 500–1500 g N/tree is recommended.

Phosphorus, as a structural element, is a constituent of nucleic acids (DNA, RNA) and phospholipids of the biomembranes. Moreover, phosphorus (P) has a major role in the energy transfer reactions and the concentration of P_i (orthophosphate), which has a very important role in the process of photosynthesis (Pandey 2015). The absence of this nutrient is not common whereas phosphate fertilisation can be necessary in acidic soils or soils containing high amounts of $CaCO_3$. When phosphate fertilisation is necessary, it should not exceed the range of 1/3–1/5 of the amount of N added. Therefore, if one kg N/tree is added, the corresponding amount of phosphate should not exceed 200–333 g P_2O_5/tree.

In the olive, stomatal conductance under drought conditions is reportedly higher in K-deficient plants (loses water more easily) than in well-nourished ones displaying lower water-use efficiency and, therefore, has lower drought tolerance (Restrepo-Diaz et al. 2009). The explanation may be that K plays an important role in the stomatal opening and closure regulating the plant water status (Poffenroth et al. 1991). Other studies reported that under these conditions, the addition of Na^+ increases the stomatal conductance and have identified the olive as a species capable of partly replacing potassium (Na) by sodium (N) (Erel et al. 2014; Erel et al. 2015). Since K plays an important role in the regulation of the water status in olive trees, maintaining the leaf K concentrations above the sufficiency threshold is highly recommended. However, it has also been reported that the K uptake by olive trees is restricted by both the K deficiency of the tree and water stress (Restrepo-Díaz et al. 2008), indicating that a K fertiliser must be applied before the deficiency threshold is reached, and when trees present good water status, usually in spring if growing in drylands. The amount of K should be determined in combination with N, namely, the K dosage is adjusted to be equal to that of N (Rodrigues et al. 2012).

Calcium (Ca) stabilises membranes and influences their function. It also contributes to the resealing of the plasma membrane following damage (Schapire et al. 2009). A calcium deficiency can be corrected rather easily by adding 5–10 kg of CaO per tree. To avoid a Ca deficiency, the soil pH must be determined before planting a new orchard while the amount of Ca added must be determined after a soil analysis.

Magnesium is a component of chlorophyll and is required for photosynthesis and protein synthesis. To correct an Mg deficiency, 300–500 g of Mg can be applied, or alternatively, foliar sprays can be applied with 2–4% soluble $MgSO_4$ dilution (Sanzani et al. 2012).

The most important micronutrient for olive tree is boron (B) which is positively related with the yield, interacts with other elements, and influences the growth performance, nutrient status, and gas exchange parameters (Chatzissavvidis, Therios 2010; Hegazi et al. 2018). The role of B in the cell wall struc-

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ture has long been recognised and there is a particular positive role of B in pollen tube growth in different plants and in the olive too, enhancing the fruit set (Perica et al. 2001a). The boron availability to plants decreases with an increasing soil pH, particularly in calcareous soils or those with a high clay content. In olive trees, as in most other plants, B presents high phloem mobility, since it produces polyols (sorbitol, mannitol, dulcitol, etc.) translocated in the phloem to satisfy the demands for B (Brown, Shelp 1997; Perica et al. 2001b). Boron fertilisation in trees, with a boron deficiency, with borax (15% B) at 200 g or 400 g per tree 70 days before full flowering, showed and increased yield, except for the borax at 200 g/tree, but both fertilisations increased the B concentration in the leaves and inflorescences (Chatzissavvidis et al. 2011). In fully productive trees, 300–500 g sodium pyroborate or sodium tetraborate (borax) is added to the soil to control any B deficiency, while a smaller amount is used for younger trees (10 g for each year of the tree from the time of its planting) (Rodrigues et al. 2012; Sanzani et al. 2012). For a faster response, soluble sodium pyroborate can be applied by foliar fertilisation or through the irrigation system. Deficiencies of other nutrients, such as Fe, Zn, even Cu (although very rare) have also been reported in olive trees (Fernández-Escobar et al. 1993; Sanzani et al. 2012; Zipori et al. 2018).

Foliar fertilisation. The aim of using fertilisers is to maintain the nutrient status in plants by replenishing the amount of nutrients annually removed by them. Fertilisers can be applied to plants in three ways: (i) to the soil, which is the most common method to encourage root absorption; (ii) to the leaves, to encourage foliar penetration; and (iii) to the vascular system, through trunk or branch injections for the trees. The effect of nutrients on the plant growth is due to their role in plant metabolism and the proper management of plant nutrition may mitigate the negative effects of some biotic or abiotic stresses (Huber et al. 2012).

Foliar fertilisation (or foliar feeding) has been used as a means of supplying micro- and macronutrients, plant hormones, stimulants, and other beneficial substances to plants. It involves the application—through spraying of nutrients to the plant foliage and their absorption helps to overcome the adverse physical and chemical properties of the soil. Foliar applications have been proven to be economically successful, mainly for tree crops and grapevines, but it has also been used for cereals and vegetables (Voogt et al. 2013). Nutrients applied to the leaves can save a crop when soil-applied nutrients would be too slow to correct a deficiency. Foliar fertilisation is newer compared to the rest of the methods and its main advantages are: (i) very rapid effects and, hence, the instant correction of sudden deficiencies; (ii) possibility of carrying out targeted treatments in critical phases (pre-flowering, fruit setting and growth, etc.); (iii) reduction of the quantities of fertilisers needed by reducing nutrient losses; (iv) foliar fertilisation may be combined with pesticides. Foliar fertilisation may be necessary when the soil characteristics block the nutrient absorption from the soil. Used in both conventional and alternative production systems in combination with soil fertilisation, it is an auxiliary means for improving the crop nutrition. The effectiveness of a foliar fertiliser depends on the formulation of the active ingredient, the atomisation of the spray solution, the transfer of the spray to the target plant surface and the droplet impaction, the spreading and retention on the leaf surface, and the residue formation and penetration into the leaf (Brazee et al. 2004). The unperforated cuticle or breaks on it, openings in the epidermis, such as the stomata and hydathodes, are possible sites of entrance for foliar applied chemicals (Fernández et al. 2021). The process of foliar penetration of a leaf-applied solution is multifold and depends upon an array of environmental (notably, the moisture and temperature) and plant factors such as the leaf age and, specifically, in terms of the nutrient absorption, older leaves are less efficient than younger ones (Fernández et al. 2021). The environment has an essential influence (climate, soil conditions, nutrient status, stage of growth, conditions during application) on the species and formulation of the crop response indicated by the difference in the field crop response to foliar fertilisation. The comprehension of the conditions that lead to a positive crop response remains a major challenge. Plant research has shown that a foliar application with a small amount of nutrients (N, K, P, B etc.) increases the yield of crops (Asenjo et al. 2000). The efficacy of foliar nutrient fertilisation depends not only on the absorption of the nutrients, but also on the ability to be transported to other plant organs including the fruits, grains, young leaves, or flowers (Fernández et al. 2013). On the other hand, the main disadvantages of foliar fertilisation are: (i) the product may be leached if moderate rainfall takes place after the application and it possibly needs to be repeated,

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and (ii) phytotoxicity may occur at high concentrations (Fageria et al. 2009). Nevertheless, it is an effective technique of fertilising dry-farmed orchards.

Foliar fertilisation of olive trees. The foliar fertilisation of olives cannot completely replace nutrition through the roots. However, the results of many experiments with olive groves located in different environments, using one or a combination of several trade fertilisers, and special products for olives, confirmed the effectiveness of this practice for the nutrition of olives (Ferreira et al. 2019). Foliar applications at critical phenological stages, such as the pre-inflorescence, inflorescence, after the fruit-set and after the stone hardening, accelerate the vegetative growth and reproductive development, encouraging shoot growth and improving the fruit-set (Perica et al. 2001b; Chatzissavvidis et al. 2011). Foliar sprays during the summer boost the yield and improve the nutritional quality of the oil as the olive fruit is very efficient at removing nutrients from the leaves (Jordáo et al. 1990; Chatzissavvidis et al. 2004). The N provided through foliar fertilisation during the oil accumulation phase in olive trees under stress conditions, prompted significant effects on the tree vegetative and productive activity (Regni, Proietti 2019). It has been found that repeated foliar applications of N in the critical stages can maintain adequate leaf N levels throughout the growing season (Ferreira et al. 1978). Foliar N fertilisation with urea solutions (1–4%) can be particularly useful in rain-fed olive groves, especially with low water availability in the soil during the critical stone hardening period (Fernández-Escobar et al. 2011). This treatment can also be applied in other periods with temporary deficiencies. The leaves absorb more than half of the administered N in one day.

Phosphorus foliar fertilisation in the form of monopotassium phosphate (MKP; 1–3%) may be appropriate in some cases. Foliar applications with MKP (MKP 3% alone or plus urea or plus a surfactant) on olive trees, in general, improved the P concentration in the leaves mostly and the secondary K concentration, given that a P deficiency can affect the olive production, but also the quality of the olive oil produced (Dag et al. 2009; Barranco et al. 2010; Haberman et al. 2021).

The foliar K uptake can be conditioned by the nutritional status in the olive tree, being more effective when plants are low or deficient in K (Restrepo-Diaz et al. 2009; Fernández-Escobar et al. 2011). In soils with a low K content, or in olives with a K deficiency, foliar applications are recommended, such as KNO_3 (1–3%), which is extremely soluble. Olive plants sprayed with KCl solutions (0.2 and 4%) showed a positive linear response to increasing leaf K applications while the foliar K uptake was higher in the young olive leaves than in the mature ones (Southwick et al. 1996; Restrepo-Diaz et al. 2009). A foliar fertilisation with KNO_3 during the second and third phase of development of the fruit gave the best results in terms of the fruit size and flesh to pit ratio, whereas the oil quality was only marginally affected (Inglese et al. 2002). Foliar sprays with K_2SO_4 in the same stages also gave very satisfactory results (Inglese et al.2002). Potassium salts (KCl, K_2SO_4, KNO_3, K_2CO_3, and KH_2PO_4), as a foliar spray, seem to be effective in increasing the leaf K concentration. These foliar applications effectively increase the K content in K-deficient olive plants (and, therefore, the drought tolerance is improved) and proved, as already mentioned, to be more effective on the young leaves (Restrepo-Diaz et al. 2009; Saykhul et al. 2014). Moreover, the K spray application frequency affects the Fe and Zn concentrations in olive stems and leaves (Saykhul et al. 2014). A positive effect was observed with foliar KNO_3 applications on the salinity tolerance (Larbi et al. 2019) and, furthermore, the K_2SO_4 application improved the freezing tolerance and oil quality (Petridis et al. 2012; Atta, Mohamed 2017; Saadati et al. 2020).

As the Ca is concerned, the results suggest that foliar treatments with $CaCl_2$ plus salicylic acid may be useful in increasing the salt tolerance in olives, for use in arid and semi-arid environments by alleviating the toxic effects (Methenni et al. 2018). Furthermore, the beneficial effect of Ca on the salinity tolerance was achieved by foliar $CaCl_2$ applications (Larbi et al. 2019). Olive trees (cvs. Kalamata and Manzanillo) sprayed with $CaCl_2$ (21% Ca) and chelated Ca presented an improved number of inflorescences/shoot, the number of total flowers/inflorescence, the fruit set and yield and a decreasing fruit drop percentage (El-Hady et al. 2020). Thus, for this relatively salt-tolerant and economically important crop, K and Ca are recommended to be applied as a means to mitigate the harmful effects of salinity. Moreover, foliar applications of $CaCl_2$ at full bloom and after the fruit set improved the oil content and olive quality (Desouky et al. 2009; Morales-Sillero et al. 2020). More research is needed in the case of foliar spraying with CaO since the results show great variability among different olive cultivars in terms of its effect on the quality of the

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olive oil (Gouvinhas, Barros 2020). Foliar applications of $Ca(NO_3)_2$ 3% plus GA_3 at 10 and 20 ppm, applied in three stages, mid-April, mid-May and during the pit hardening stage, reduced the percentage of the fruit drop and increased the yield. The best results presented when $Ca(NO_3)_2$ at 3% plus GA_3 at 10 and 20 ppm was applied in mid-May followed by treatments during the pit hardening stage and mid-April, respectively, with significant impacts on the fruit, seed and flesh weight (Mikhail, Goargios 2014). Furthermore, spraying olive seedlings with $Ca(NO_3)_2$ had a positive effect on the plant height, lateral shoot number, stem diameter, root length and root number depending on the dose and application stage (Haggag et al. 2011).

Magnesium deficiencies can be overcome with $MgSO_4$ 0.5–3%, while MgO solutions were found to ameliorate the yield and oil quality (Gavalas, 1978; Zouari et al. 2014; Tekaya et al. 2016; Atta, Mohamed 2017). The results also indicated that foliar application with $MgSO_4$, especially at 1.5%, improved the vegetative growth, fruit set, yield, fruit and oil quality of 'Koroneiki' olives (Mahmoud et al. 2017). Foliar sprays with $Mg(NO_3)_2$ and $Ca(NO_3)_2$ are also recommended, especially in olive groves with acidic soils.

A foliar B application increases the percentage of perfect flowers, the fruit set and the yield without negative effects on the fruit size, while the beneficial effects of the foliar B application were greater when the fruit set was low. Foliar sprays of boron at 30 and 60 g B/tree in trees under boron deficiency with leafy product containing 17% B, at 567 mg B/L in the pre- and/or post-flowering stage, positively affected the yield, with the highest value was found in trees subjected to one spray before and one spray after the full bloom, showing a 98% increase compared to the control (Chatzissavvidis et al. 2011). In terms of the number of flowers per inflorescence, it increased in the trees treated with more than one B foliar application, increasing the B concentration in the leaves and inflorescences (Chatzissavvidis et al. 2011). Despite the encouraging effects of B foliar sprays, there are reports suggesting that B mobility seems to be cultivar-dependent (Ferreira et al. 2019). The results obtained depend on the stage that the foliar B applications took place, namely, prior to flowering, during the period of the floral bud initiation or after the fruit set (Perica et al. 2001b). Boron toxicity symptoms may occur after foliar spraying with a high B dosage including inhibition of the cell wall expansion and root growth, and a reduction in the leaf area, photosynthetic rate and plant growth (Nable et al. 1997; Reid et al. 2004; Chatzissavvidis, Therios 2010). Also, foliar applications with mixed boric acid (B 100 ppm) and $CaCl_2$ (Ca 2%) increased the fruit set, olive quality and oil content (Desouky et al. 2009).

The results showed that spraying 'Manzanillo' olive trees with Zn ($ZnSO_4$ 0.5%) had a positive effect on the olive fruit weight, total fruit yield per tree and oil content (Haggag et al. 2015). Experiments with foliar applications of $ZnSO_4$, boric acid and their combination resulted in the promotion of the soluble sugar, oil content, oleic acid and phenolic compounds of olive fruits (Saadati et al. 2013).

Foliar applications were carried out including foliar treatments using a combination of nutrients, for example a formulation of urea formaldehyde that includes N with B, Cu, Fe, Mn, Mo and Zn, applied at the start of vegetation, 10 and 20 days later, and another one rich in B, Mg, S and Mn, applied at the beginning of flowering and 10 days later, finally with a combination of the above treatments. These treatments were suggested to elevate the nutrient levels, but simultaneously caused a decrease in the total phenols and tocopherols in the olive fruits (Tekaya et al. 2013). Other reports revealed that boric acid alone or with a mixture of chelated Fe, Zn and Mn as foliar applications on olive trees improved their vegetative growth, increased the fruit set, yield and fruit quality (Sourour et al. 2011). The results proved that a foliar application of zinc sulfate 2 g/L alone, boric acid plus urea 5 g/L and zinc sulfate along with boric acid 2 g/L are highly effective in increasing the fruit set and yield and in diminishing the shot berries (Sayyad-Amin et al. 2015). Also, selenium (Se) contributes to controlling the water status of plants, prevents oxidative stress, delays senescence, and promotes growth (D'Amato et al. 2020). Studies have shown that a foliar Se-fertilisation before flowering enriched virgin olive oils in the phenolics (up to 401 mg/kg), such as oleasin, ligustroside, aglycone and oleocanthal, due to the increased PAL (L-Phenylalanine Ammonia-Lyase) activity, independently largely by climate (D'Amato et al. 2017).

The application of selenium (Se) on the olive foliage enhanced the production of the antioxidant compounds in the oil, such as chlorophylls, carotenoids, phenols, and selenomethionine (SeMet), elevating the olive oil stability against oxidation and, as a consequence, its shelf-life (D'Amato et al. 2018). Also,

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the important role of Se has been reported to alleviate the negative effect of water deficiency on the fruit production (D'Amato et al. 2018).

Other studies also present the effects of silicon (Si) foliar sprays. Although Si might be more effective when applied directly to the soil, or through irrigation water, its foliar application seems to alleviate stressed plants, including the olive, from abiotic and biotic factors (Savvas, Ntatsi 2015; Fernández-Escobar 2019).

Organic foliar fertilisation of olive trees. There is controversy surrounding the role of the humus on the plant nutrition. Initially, there was the hypothesis that humus is the only material which supplies nutrients to plants. However, in the last few years, there have been several reports which refer to the enhancement of plant growth promoted by the application of humic substances. This activity seems to be caused by the hormone-like materials present in the humic substances (De Sanfillippo et al. 1990). They are of particular interest in increasing the resistance of plants to salinity by foliar sprays with salicylic acid solutions (Naeem et al. 2020). The efficacy of leaf applications with organic substances on the olive has not been fully documented. Studies have shown that leaf applications with the antioxidants, ascorbic or citric acid, on olive trees grown in calcareous soil, improved the yield and fruit quality (Maksoud et al. 2009). In practice, the application of organic foliar fertilisers to olives aims at increasing the yield and producing a higher product quality, such as the elevated content of polyphenols, reduced acidity of olive oil, etc.

Foliar applications of amino acids, humic acids and antioxidants, such as ascorbic acid, on olive trees led to an increased yield, an increase in the total antioxidants, phenols and sugars, a higher oil content and an improved nutrient status (Fawy 2015). There are reports of the cultivation of edible and olive-bearing olives, which report that leaf biofertilisation causes an increase in the production due to the improved fruit set, an improvement in the quality characteristics, e.g., increase in the fruit size, especially under weather conditions unfavourable for the metabolic processes of fruiting. The results showed that the application of an organic liquid in olive leaves, which consists of beet molasses, great sources of N and K, or other organic materials rich in P, activated the metabolic activity of the olive and had positive effects on the number of flowers, as well as on the leaves, as well as their development and stomatal density (Dabbaghi et al. 2018a). Also, leaf biofertilisation has been reported to affect the characteristics of the leaves, flower buds and flowers in the flowering period, to change some biometric, biochemical parameters and enzymatic operation of the olive tree, which aimed to prepare the olive tree to the fruit set (Dabbaghi et al. 2018a). Foliar applications with biofertilisers rich in N, P, K, or Ca led to the improved physiological status of olive trees through the enhancement of some phytohormones and amino acids (Dabbaghi et al. 2018b). In addition, seaweed extracts (SWE) containing growth regulators (auxins, cytokinins, abscisic acid, salicylic and gibberellic acid), polyphenols and polysaccharides, when a foliar application was applied, increased the yield, oil content, improved the oil quality, and accelerated the maturation of the fruits (Chouliaras et al. 2008). Studies conducted with transplants of olive trees sprayed with ascorbic acid and humic acid showed a significant impact on most characteristics. Specifically, the leaf application of humic acid increased the plant height, leaf fresh and dry weight, leaf chlorophyll content, whereas the foliar application with ascorbic acid increased the plant height, leaf number and area, and lateral shoot number (Azad et al. 2014). Investigations with olive trees sprayed with humic acid at the beginning of the fruit set, led to a higher yield, fruit size and weight, and pulp/pit ratio (Haggag et al. 2013). An improvement in the set of physical characteristics of the olives after the application of amino acids and extra K has been also observed (Hernández-Hernandez et al. 2019). Other studies have shown the potential of an extract obtained from the aquatic duckweed (*Lemna minor* L.), with a high content of phenolic acids, phenols and flavonoids, to act as a biostimulant in olives, improving the leaf photosynthetic activity and chlorophyll content, plant growth and nutritional status (Regni et al. 2021).

It has been suggested that a foliar application of leonardite extract preparations to young olive plants stimulated the shoot growth when they were growing with no fertilisation. Moreover, under field conditions, the foliar application of the leonardite extracts stimulated the shoot growth and promoted the accumulation of K, B, Mg, Ca and Fe in the leaves. However, when the leaf N and K levels were below the threshold limit of the sufficiency range, the foliar application of humic substances was ineffective in promoting the accumulation of these nutrients in the leaves (Fernández-Escobar et al. 1996). Organic foliar applications of an organic product contain-

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ing 26% humic and fulvic acids as well as nutrients (N 0.1%, P2O5 0.01%, K2O 5%, CaO 0.03%, MgO 0.03%, trace elements, organic C 10.5%) and the soil type, positively affected the vigour and the fruit weight (Sotiropoulos et al. 2020).

The application of a foliar spray with a bio-organic fertiliser, formulated from a successful culture of cyanobacteria mixed strains in 1 : 1 tap water-diluted olive vegetation water was very effective in improving the growth, quality and productivity of 'Manzanillo' olive trees (Mostafa et al. 2016). Also, olive seedlings sprayed with amino acids at 0.5% plus microelements, presented with an increased plant height, more branches and leaves, a bigger stem diameter and leaf area (Yousef et al. 2011).

Conclusions and future perspectives. The use of organic foliar fertilisers, additionally with soil-applied ones, provides more environmentally friendly, target-oriented and effective nutrition to olive trees. When choosing a proper organic fertiliser with a suitable activator, there is a great possibility to succeed with the amelioration of the physical self-defence and resilience of olive trees. One of the goals of foliar fertilisation is to reduce the likelihood of a relative nutritional deficiency and to optimise the effectiveness of the foliar fertiliser applied. In conclusion, the response of olive trees to foliar fertilisation depends on the interaction among the environmental conditions, plant genotype and fertiliser formulation. The factors that define the effectiveness of inorganic and organic foliar fertilisation are complicated and encompass aspects of physics, chemistry and the environment.

The efficacy of an organic foliar application in the case of olives has not been fully documented, despite the excellent and encouraging results in many cases. Interestingly, while some basic principles of the usage of foliar fertilisers in olives are well known, there are many problems that remain to be solved and knowledge needs to be acquired. Therefore, conducting protocols for the effective foliar nutrition in olives remains a major challenge.

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