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Research Article
Influence of Foliar Application with Potassium and Magnesium on Growth, Yield and Oil Quality of ''Koroneiki'' Olive Trees

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Abstract
Background: The successful orchard management practices are directed toward obtaining a suitable yield with good fruit quality. One of the most important cultural practices is the mineral nutrition especially in the new reclaimed lands. Under sandy soil conditions the water and nutrient holding capacity is poor, so foliar application is a high efficiency to satisfy plant requirement with nutrient elements directly and quickly and economic than soil fertilizer. Although, the well known physiological roles of magnesium and potassium in plant metabolism, the number of studies addressing their significance effects on olive oil quality appears very limited. **Objective:** Therefore, the objective of this study was to evaluate the effects of foliar application with magnesium and potassium on growth, yield, fruit quality, physical and chemical oil properties. **Materials and Methods:** This study was conducted during two successive seasons 2014 and 2015 on 10 years old Koroneiki olive trees planted at 5×5 m grown in sandy soil at the experimental research station of National Research Center at El-Nobarya, El-Behera governorate Egypt. Trees were sprayed twice at final fruit set stage and 1 month later with magnesium sulphate at (0.5 and 1.5%) and potassium sulphate at (3 and 5%), besides control (spraying with water only). **Results:** Results indicated that the different concentrations of foliar application with magnesium and potassium sulphate especially 1.5 and 3% respectively improved the vegetative growth, fruit set, yield, fruit quality and oil content of Koroneiki olives. All samples of oils were classified as extra virgin olive oil. Free fatty acids, peroxide, iodine values, K_{232} and K_{268} significantly decreased. While, the oxidative stability significantly increased, furthermore it is higher in second season than the first season. Analysis of fatty acids composition by GC-capillary column of these oils indicated that the monounsaturated fatty acid (MUSFA) in particular oleic acid for samples which applied with magnesium and potassium sulphate was increased, whereas polyunsaturated fatty acids (PUSFA) in particular linoleic acid was decreased. The highest oleic acid content and the lowest K_{232} and K_{268} factors express the effectiveness of treatment on oil quality. **Conclusion:** The results of this study clearly demonstrate that spraying magnesium sulphate at 1.5% and potassium sulphate at 3% twice at final fruit set stage and one month later improving growth, yield, fruit quality and physical and chemical oil properties of Koroneiki olive. Thus, it may be recommended spray with this treatment under similar conditions.

Key words: Olive, Koroneiki, potassium, magnesium, spraying, growth, yield, oil, fatty acid, oxidative stability

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Olive (*Olea europea* L.) is a widely distributed tree grown healthy in many arid zone of the world, native to the Mediterranean region. The olive is an evergreen tree, belongs to the family Oleaceae and includes many cultivars which are used for oil extraction and pickling. Olive fruits are commercially valuable for their oil content or for their edible flesh. The oil is a source of energy but also a basic nutrient, supplying essential fatty acids, vitamins and antioxidants. Its flavors, color and aroma contribute to its quality. At the same time fruit size, pulp-stone ratio, oil content, flesh texture and chemical composition are important for table olives. Olive oil is very important because the beneficial effects on human health are attributed, in part, to the high content of monounsaturated fatty acids, particularly oleic acid. In addition, greater oleic acid content and lower linoleic acid content seems to improve oil oxidation stability[1,2].

The fruit components are defined during fruit growth and they are influenced by cultivar, climatic conditions and cultural practices such as nutrition[3]. In Egypt, low productivity in olive trees grown in sandy soil is a serious problem obviously noticed in the new introduced varieties i.e., Arbequina, Boutillan and Koroneiki related with planting density, the pruning and the harvesting, water requirement and fertilization especially the method of adding and doses[4].

Mineral nutrition is one of the major tools to optimize fruit yield and quality[5]. Potassium is regarded as an essential element in higher plants because potassium as a mineral osmosis plays as an important factor in osmotic and pressure regulator. As result this element plays an important role in cell enlargement, plant growth and finally opening and closing stomata of leaves[6]. This element also plays an outstanding role in activation of many photosynthetic enzymes, protein synthesis, oxidative metabolism and balancing the electricity charge of plant cell membranes[7]. Potassium, more than any other macroelement, is understood to have a positive effect on flowering[8] as it promotes the formation of amino acids that stimulate the formation of Indole Acetic Acid (IAA) oxidase which, in turn, stimulates flower induction[9]. Potassium might also promote the production of pyruvate kinase[10] and thereby influence the level of a number of amino acids involved in flowering induction. Consequently, potassium play vital role in olive yield, quality and oil yield[11]. Olive is a species with a high K requirement due to the high content of K present in the olive fruit[12]. Hegazi *et al.*[13] reported that foliar application of potassium nitrate at 4% improve vegetative growth, nutritional status, productivity, fruit quality and flesh oil content of picual olive fruit. Foliar application of potassium as potassium sulfate significantly increased seed yield of Egyptian cotton cultivar (*Gossypium barbadense* Giza 86) and the content of seed protein and oil, seed oil refractive index, un-saponifiable matter and total unsaturated fatty acids (oleic and linoleic). In contrast, oil acid and saponification value as well as total saturated fatty acids were decreased by foliar application of potassium[14].

Magnesium is the main component of chlorophyll and is responsible for a number of functions in plants as an activator of the enzymatic systems that regulate processes of photosynthesis, energy transformations and synthesis of carbohydrates, proteins and fats. Magnesium deficiency during plant growth causes a decrease in the yield and its quality[15].

On Manzanillo olive trees, El Khawaga[16] sprayed magnesium sulphate four times in April, May, June and July and found that magnesium sulphate significantly increased growth of shoot and leaves. Olive trees treated with magnesium sulfate fertilizer (12-24 g tree^{-1} year^{-1}) in January increased the level of magnesium and showed significantly increase in the vegetative growth and enhanced flowering density, fruit set and yield[17]. Hegazi *et al.*[18] found that magnesium sulphate at the rate of 100 g tree^{-1} in each of January, April, June and August increased significantly vegetative growth, photosynthetic pigments, leaf mineral contents (N, P, K and Mg), carbohydrates content in leaves, flowering, fruit quality and caused to increase fruit oil content (18-20%) in comparison with (12%) in untreated trees. Moreover, yield of treated trees with magnesium sulphate was doubled (43 kg tree^{-1}) in comparison with 20 kg tree^{-1} in untreated trees.

Nutrient uptake depends on nutrient supply to the root system i.e., nutrient availability and the nutrient requirement level and the uptake period[19]. Such as, Kene *et al.*[20] discovered that high concentration of magnesium in the soil reduced the calcium absorption by plants and plants grown under such conditions may soon deal with calcium deficiency. Vafaie *et al.*[21] mentioned to antagonistic relationship between magnesium and calcium and also among potassium and magnesium. In this respect, Jakobsen[22] reported that the application of high levels of potassium could have adverse or antagonistic effects on absorption of calcium and magnesium because of accumulation of potassium in the soil that the density of this effect on plants depends on plant variety and soil type. The negative interaction among consumption of potassium and magnesium it may be their effects on sodium content of leaves[23]. Soil properties have a strong influence on nutrient availability. For instance, clay soils typically have a high K-fixing capacity and thus, often show little response to soil applied K fertilizers because much of the available K is quickly fixed to the clay particles[24]. Under sandy soil conditions application is almost without effect if leached with excess irrigation and/or rainfall[25]. Moreover, fertigation relative to broadcast application has been shown to increase K mobility in the soil[26]. Foliar application of nutrients is in general helpful to satisfy plant requirement and provides a fast method to correct nutrient deficiencies in plants which is fast. Moreover, it is a convenient procedure of applying highly soluble fertilizers, especially in very small amounts[27,28].

Thus, the aim of this study was to investigate the effect of foliar application with potassium and magnesium sulphate on vegetative growth, yield, fruit quality, oil physicochemical properties, fatty acids composition and oxidative stability of ''Koroneiki'' olives.

MATERIALS AND METHODS

This study was carried out through two successive seasons 2014 and 2015 on 10 years-old Koroneiki olive trees planted at 5×5 m and grown in sandy soil at the experimental research station of National Research Center at El Nobarya, El Behera governorate Egypt. The soil was characterized by: pH = 8.82, EC = 1.11 dS m^{-1}, organic matter = 0.31%, $CaCO_3$ = 12.8%, sand = 63%, silt = 13% and clay = 3%. Drip irrigation system was applied using river Nile water. Trees were of normal growth, uniformed in vigour and received the same horticultural practices. The experiment followed complete randomized block design on 15 trees as 5 treatments were applied. Each tree was considered a replicate, three replicates trees per each treatment. Selected trees were sprayed twice at final fruit set stage (after 60 day full bloom) and 1 month later with magnesium as magnesium sulphate at (0.5 and 1.5%) and potassium as potassium sulphate at (3 and 5%), besides control (spraying with water only). The response to investigated treatments was evaluated through determining the following parameters.

Vegetative growth:

- **The averages of extension:** Diameter (mm) of three current shoots on the selected branch from each replicate tree was measured and the average numbers of leaves on them were counted
- **Leaf area:** At mid July of each season, leaf area (cm^2) was determined as average of three leaves from the middle portion of the tagged shoots on each replicate tree according to Ahmed and Morsy[29] using the following equilibration:

$$\text{Leaf area} = 0.53\,(\text{length}\times\text{width})+1.66$$

Fruiting:

- **Fruit set (%):** The total number of perfect flowers on each selected shoot was counted at full bloom. The number of set fruits was counted on the same shoots after 60 days full bloom. Fruit set percentage was calculated as follows:

$$\text{Fruit set (\%)} = \frac{\text{No. of developing fruitlets}}{\text{Total No. of flowers}}\times 100$$

- **Fruit retention (%):** The numbers of fruits retained until harvest were counted and fruit retention percent estimated as follows:

$$\text{Fruit retention (\%)} = \frac{\text{No. of retained fruits}}{\text{Total No. of fruits}}\times 100$$

- **Yield:** At maturity stage (November), fruits of each replicate tree were separately harvested, then weighted and yield as kg $tree^{-1}$ was estimated
- **Fruit characteristics:** Samples of 20 fruits from each replicate tree i.e., 60 fruits from each of the applied treatments were picked randomly at harvest to determine: Average fruit weight (g), diameter (cm), length (cm), size (cm^3), pulp per seed ratio, fruit moisture percentage and fruit oil content as a dry weight according to AOAC[30]

Chemical analysis:

- **Extraction of virgin olive oil:** After harvest olive fruits washed by tap water and crushed in a cracker, packed in a cheese cloth and pressed using a hydraulic laboratory (carver) press. The obtained juice was collected and left for 5 h in a separatory funnel until complete separation. The oil layer (upper layer) was separated, dried over anhydrous sodium sulfate, then filtered through a filter paper No. 1 and kept in brown glass bottles at -5°C till analysis
- **Fruit total proteins (%):** The total nitrogen was determined by the usual Kjeldahel method[30]. The crude proteins were then calculated by multiplying the total nitrogen by a factor of 6.25
- **Fruit total carbohydrates (%):** Fruit total carbohydrates percentage was extracted and determined according to the method described by DuBois *et al*.[31]
- **Fruit mineral content:** Nitrogen, phosphorus, potassium and magnesium in fruits were determined by using the method of AOAC[30]

Chemical and physical properties of oil:

- **Free Fatty Acids (FFA) and Peroxide Value (PV):** The FFA and PV were determined according to the methods[30]
- **Iodine (IV) and Saponification Values (SV):** The IV and SV were calculated from fatty acids percentage by equation according to O'Keefe and Pike[32]
- **Refractive Index (RI):** The RI of olive oils was determined at 25°C according to AOAC[30] by using refractometer (NXRL-3 poland)
- **Absorbency in ultraviolet (K_{232} and K_{268}):** Ultraviolet and visible spectra were conducted using a pye unicum double beam recording spectrophotometer Model SP 1600 as described by Kates[33]. The oil samples were dissolved in freshly distilled cyclohexane and the absorption were measured at 232 and 268 nm
- **Oxidative Stability (OS):** It was evaluated by the Rancimat method[34]. Stability was expressed as the oxidation induction time (hour), measured with the Rancimat 679 apparatus (Metrohm Co., Switzerland), using an oil sample of 5 g heated to 100°C with air flow of 20 L h^{-1}
- **Fatty acids composition:** The fatty acids methyl esters were prepared using trans-esterification with cold methanolic solution of potassium hydroxide. The fatty acids methyl esters were identified by GC-capillary column according to the methods[35]

Statistical analysis: All obtained data during both 2014 and 2015 experimental seasons were subjected to analysis of variances according to using (CO/STAT). Least Significant Difference (LSD) was used to compare between means of treatments according to Snedecor and Cochran[36] at probability of 5%.

RESULTS AND DISCUSSION

Vegetative growth: Data in Table 1 indicated the effect of spraying magnesium and potassium sulphate on shoot length, diameter, number of new shoots, number of leaves per shoot and leaf area of Koroneiki olive trees during the two seasons of study. Shoot length increased significantly by different treatments in both seasons. Magnesium sulphate at 0.5% and potassium sulphate at 3% gave the highest shoot length (83.66 and 90 cm in the first season and 88.33 and 78.66 cm in the second season, respectively). Concerning shoot diameter magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest values (1.03 and 0.97 mm in the first season and 0.88 and 0.75 mm in the second season, respectively). Number of new shoots, the results took the same trend of shoot diameter. Magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest number of new shoots (15 and 16.67 in the first season and 18.33 and 13.67 in the second season, respectively), while the lowest number of new shoots was recorded by control (10.67 and 11) in the first and second season. Regarding number of leaves per shoot, results indicated that there are no significant differences between all treatments in both seasons. Leaf area, results showed that no significant differences between treatments in the first season, while magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest values (4.97 and 4.63 cm^2) in the second season.

The improvement in vegetative growth of Koroneiki olive trees might be attributed to the important role of magnesium in chlorophyll building which leads to higher photosynthetic activity. Additionally of magnesium acts as an enzyme activator which facilities a wide diversity of reactions, especially in the transfer of energy; these all metabolites are needed for plant growth and development[18]. Moreover, the physiological role of potassium in carbohydrate formation is translocation and accumulation within plant organs[37]. Also, potassium is involved in plant meristematic growth and cell enlargement[38]. In addition to synergistic effect between K and indole acetic acid and the enhancement of K on gibberellic acid and cytokinins effects on plant growth[39].

Fruit set, fruit retention and yield: Data presented in Table 2 illustrated the effect of spraying magnesium and

Table 1: Effect of spraying magnesium and potassium sulphate on vegetative growth of Koroneiki olive trees

	Shoot length (cm)		Shoot diameter (mm)		No. of new shoots		No. of leaves per shoot		Leaf area (cm^2)	
Treatments	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Control	72.33^b	63.33^b	0.65^b	0.70^a	10.67^b	11.00^b	25.67^a	29.33^a	4.67^a	3.86^b
$MgSO_4$ (0.5%)	83.66^{ab}	88.33^a	0.82^{ab}	0.83^a	11.33^b	11.33^b	26.33^a	29.33^a	5.07^a	4.63^{ab}
$MgSO_4$ (1.5%)	80.66^{ab}	83.33^a	1.03^a	0.88^a	15.00^a	18.33^a	29.33^a	31.33^a	5.50^a	4.97^a
K_2SO_4 (3%)	90.00^a	78.66^{ab}	0.97^{ab}	0.75^a	16.67^a	13.67^b	28.33^a	29.33^a	5.43^a	4.63^{ab}
K_2SO_4 (5%)	76.33^{ab}	76.66^{ab}	0.68^b	0.72^a	13.33^{ab}	13.00^b	31.67^a	36.67^a	4.83^a	4.31^{ab}

Means followed by the same letters within the column are not significantly different at p = 0.05

Table 2: Effect of spraying magnesium and potassium sulphate on fruit set, fruit retention and yield of Koroneiki olive trees

	Fruit set (%)		Fruit retention (%)		Yield (kg tree^{-1})	
Treatments	2014	2015	2014	2015	2014	2015
Control	27.67^{c}	21.00^{c}	3.96^{a}	4.86^{a}	30.00^{aa}	31.00^{b}
$MgSO_4$ (0.5%)	39.33^{b}	33.33^{b}	4.18^{a}	4.95^{a}	30.00^{ab}	32.33^{b}
$MgSO_4$ (1.5%	66.67^{a}	58.33^{a}	4.63^{a}	5.10^{a}	35.00^{b}	35.00^{a}
K_2SO_4 (3%)	62.67^{a}	55.00^{a}	4.11^{a}	4.90^{a}	40.00^{a}	41.67^{a}
K_2SO_4 (5%)	45.33^{b}	40.00^{b}	3.99^{a}	4.90^{a}	36.67^{b}	37.33^{b}

Means followed by the same letters within the column are not significantly different at p = 0.05

Table 3: Effect of spraying magnesium and potassium sulphate on fruit length, diameter and fruit shape ratio of Koroneiki olive trees

	Fruit length (cm)		Fruit diameter (cm)		Fruit shape ratio (L/D)	
Treatments	2014	2015	2014	2015	2014	2015
Control	1.40^{c}	1.63^{c}	0.87^{b}	1.13^{b}	1.61^{a}	1.44^{a}
$MgSO_4$ (0.5%)	1.53^{bc}	1.97^{b}	0.90^{b}	1.30^{a}	1.70^{a}	1.52^{a}
$MgSO_4$ (1.5%)	1.77^{ab}	2.00^{b}	1.10^{b}	1.37^{a}	1.61^{a}	1.46^{a}
K_2SO_4 (3%)	1.87^{a}	2.20^{a}	1.37^{a}	1.40^{a}	1.57^{a}	1.52^{a}
K_2SO_4 (5%)	1.60^{a-c}	2.13^{ab}	1.00^{b}	1.37^{a}	1.60^{a}	1.63^{a}

Means followed by the same letters within the column are not significantly different at p = 0.05

Table 4: Effect of spraying magnesium and potassium sulphate on fruit weight, pulp weight, seed weight and pulp per seed ratio of Koroneiki olive trees

	Fruit weight (g)		Pulp weight (g)		Seed weight (g)		Pulp/seed ratio	
Treatments	2014	2015	2014	2015	2014	2015	2014	2015
Control	1.13^{bc}	0.92^{e}	1.00^{d}	0.79^{d}	0.13^{a}	0.13^{a}	7.69^{d}	6.08^{e}
$MgSO_4$ (0.5%)	1.40^{a-c}	1.64^{d}	1.25^{c}	1.46^{c}	0.15^{a}	0.18^{a}	8.33^{c}	8.11^{d}
$MgSO_4$ (1.5%)	1.50^{ab}	1.71^{c}	1.34^{b}	1.53^{c}	0.16^{a}	0.18^{a}	8.38^{c}	8.50^{c}
K_2SO_4 (3%)	1.57^{a}	2.28^{a}	1.43^{a}	2.12^{a}	0.14^{a}	0.16^{a}	10.21^{a}	13.25^{a}
K_2SO_4 (5%)	1.51^{ab}	2.01^{b}	1.37^{b}	1.83^{b}	0.14^{a}	0.18^{a}	9.79^{b}	10.17^{b}

Means followed by the same letters within the column are not significantly different at p = 0.05

potassium sulphate on fruit set, fruit retention and yield of Koroneiki olive trees during the two seasons of study. Fruit set percentage was significantly increased by applications in both seasons. Magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest fruit set percentage (66.67 and 62.67% in the first season and 58.33 and 55% in the second season), whereas the lowest fruit set percentage was obtained by the control (27.67 and 21%) during 2014 and 2015 seasons. Concerning fruit retention percentage results showed that no significant differences between treatments in the first and second seasons. Regarding yield as (kg tree^{-1}), it could be noticed from Table 2 that all treatments significantly increased yield (kg tree^{-1}) than the control in both seasons. Spraying trees with magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest yield weight (35, 40, 35 and 41.67 kg tree^{-1}) in the first and second seasons, respectively. On the other hand, the control trees exhibited the lowest yield weight (30 and 31 kg tree^{-1}) in the first and second seasons, respectively.

The increment in yield may be due to the effect of magnesium and potassium treatments on improve the nutritional status of trees and increase availability of assimilates which may leading to stimulate the flower induction and increased both inflorescence formation, fruit set and fruit retention[40]. These results are in agreement with those obtained by Ramezani and Shekafandeh[41] who found that foliar applications of potassium improve olive yield and quality. El Khawaga[16] reported that spraying magnesium sulphate increase yield of Manzanillo olive.

Fruit characteristics: Data presented in Table 3 and 4 show the effect of spraying magnesium and potassium sulphate on fruit physical characteristics of Koroneiki olive trees. It was observed that fruit length and diameter were significantly affected by different treatments in both seasons. Magnesium and potassium sulphate at 1.5 and 3% gave the highest fruit length and diameter in both seasons; meanwhile control treatment gave the lowest values of fruit length and diameter. Concerning fruit shape ratio results showed that no significant differences between treatments in the first and second seasons (Table 3). From Table 4 it can be noticed that, fruit and pulp weight were significantly increased as affected by different treatments in both seasons. Magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest fruit and pulp weight in both seasons (1.50, 1.57, 1.34 and 1.43 g in the first season, respectively) and (1.71, 2.28, 1.53 and 2.12 g in the second season, respectively).

Table 5: Effect of spraying magnesium and potassium sulphate on fruit moisture, oil, protein and carbohydrate content of Koroneiki olive trees

Treatments	Fruit moisture content (%)		Fruit oil content (%)		Fruit total proteins (%)		Fruit total carbohydrates (%)	
	2014	2015	2014	2015	2014	2015	2014	2015
Control	62.74^{b}	63.04^{a}	30.65^{b}	32.34^{b}	5.12^{b}	5.31^{b}	19.37^{b}	19.77^{a}
$MgSO_4$ (0.5%)	64.85^{a}	60.53^{b}	32.19^{b}	34.13^{ab}	5.38^{a}	5.44^{ab}	20.41^{ab}	19.97^{a}
$MgSO_4$ (1.5%)	60.35^{c}	61.21^{ab}	33.18^{b}	35.27^{ab}	5.38^{a}	5.44^{ab}	20.64^{ab}	20.26^{a}
K_2SO_4 (3%)	60.05^{c}	56.03^{c}	35.01^{ab}	38.43^{a}	5.50^{a}	5.48^{a}	21.66^{a}	20.78^{a}
K_2SO_4 (5%)	61.97^{b}	61.20^{ab}	33.16^{b}	36.05^{ab}	5.48^{a}	5.48^{a}	20.61^{ab}	20.65^{a}

Means followed by the same letters within the column are not significantly different at $p = 0.05$

Concerning seed weight, it was observed that there were no significant differences between different treatments in both seasons of the study. Data also in Table 4 showed that pulp per seed ratio of Koroneiki olive fruits significantly increased by spraying magnesium and potassium sulphate. Magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest pulp per seed ratio (8.38 and 10.21 in the first season and 8.50 and 13.25 in the second season), while control treatment gave the lowest pulp per seed ratio (7.69 and 6.08) in both seasons. Data presented in Table 5 show that fruit moisture percentages were affected significantly by the levels of spraying magnesium and potassium sulphate. The fruit moisture ranged between 60.05-64.85% in the first season and 56.03-63.04% in the second season, respectively.

The enhancement of fruit characteristics such as weight, dimensions (length and diameter), pulp weight and pulp/seed ratio are due to different roles of magnesium and potassium in plant physiological processes. Applying potassium to the trees improved fruit quality by enhancing the formation and translocation of carbohydrates from the shoot to storage organs (fruits) and carbohydrate enzymes[41]. These results confirm those obtained by Elloumi *et al.*[11] and Inglese *et al.*[27] that foliar application of K during the second and the third phase of olive growth improved the fresh weight and the flesh to pit ratio. The role of magnesium in an increasing fruit quality can be attributed to its complex roles in chlorophyll, protein biosynthesis and carbohydrate formation in plants which enhance the leaf photosynthetic capacity[15], inducing a higher assimilates availability for fruit growth.

Fruit oil content: It is clear from Table 5 that all treatments significantly increased oil content on dry basis than the control in both seasons. Spraying trees with magnesium and potassium sulphate at 1.5 and 3% gave the highest oil content (33.18 and 35.01% in the first season and 35.27 and 38.43% in the second season, respectively). On the other hand, the control trees exhibited the lowest oil content (30.65 and 32.34%) in both seasons, respectively. In literature[4], oil content in Koroneiki olive trees is within the range of 38-44% on dry basis. This progress in oil content for the 2 years of study is could be attributed to the increase of total photo-assimilates (e.g., lipids) and the translocated assimilates to the sink as a result of applying magnesium and potassium which may control on the biosynthesis of oil by enzymes[42] during the main metabolic pathway. This is noticed further to fertilizing brought at just moment and during the critical stages of development of olive tree. Indeed, the accumulation of the oil in the olive is a process which depends on the quantity of the carbohydrates resulting from fruits and old leaves[43].

Fruit total proteins (%): In the first season, results showed that no significant differences between treatments in protein content. In the second season, it was observed that significant differences exhibited between magnesium and potassium sulphate treatments. But, there were no significance within concentrations. Magnesium sulphate at 0.5 and 1.5 gave 5.44% and potassium sulphate at 3 and 5 gave 5.48% (Table 5).

The improvement of fruit protein content might be to the role of magnesium in protein synthesis[15] and the favorable effects of potassium on the metabolism of nucleic acids and proteins[44]. These are manifested in metabolites formed in plant tissues and directly influence the growth and development processes, thereby producing changes in olive oil yield and quality.

Fruit total carbohydrates (%): In the first season, magnesium and potassium sulphate sprays significantly increased carbohydrates percentage of Koroneiki fruits. Magnesium sulphate at 1.5% and potassium sulphate at 3% gave the highest values (20.64 and 21.66%). In the second season, results showed that no significant differences between treatments (Table 5).

Fruit mineral content: From the data in Table 6, it can be noticed that the nitrogen content in Koroneiki olives was increased compared with the control as a result of spraying magnesium and potassium sulphate, it ranged from 0.83-0.88% (2014) and 0.85-0.88% (2015). The phosphorus content of olives which sprayed by magnesium sulphate at 0.5% and potassium sulphate at 3% gave the highest values (0.19 and 0.16% in the first season and at 0.5 and 5% was 0.14

Table 6: Effect of spraying magnesium and potassium sulphate on fruit mineral content of Koroneiki olive trees

	Nitrogen (%)		Phosphorus (%)		Potassium (%)		Magnesium (ppm)	
Treatments	2014	2015	2014	2015	2014	2015	2014	2015
Control	0.83^{b}	0.85^{b}	0.12^{c}	0.12^{d}	1.03^{d}	1.03^{d}	13.01^{d}	10.34^{d}
$MgSO_4$ (0.5%)	0.86^{a}	0.87^{ab}	0.19^{a}	0.14^{c}	1.04^{c}	1.05^{c}	20.21^{b}	20.91^{b}
$MgSO_4$ (1.5%)	0.86^{a}	0.87^{ab}	0.13^{c}	0.12^{d}	1.03^{d}	1.03^{d}	26.09^{a}	26.16^{a}
K_2SO_4 (3%)	0.88^{a}	0.88^{a}	0.16^{b}	0.16^{b}	1.07^{a}	1.07^{a}	19.00^{c}	13.28^{c}
K_2SO_4 (5%)	0.88^{a}	0.88^{a}	0.13^{c}	0.19^{a}	1.05^{b}	1.06^{b}	20.04^{b}	19.37^{b}

Means followed by the same letters within the column are not significantly different at p = 0.05

Table 7: Effect of spraying magnesium and potassium sulphate on chemical and physical properties of Koroneiki olive oil during 2014 season

	Treatments				
Samples items	Control	$MgSO_4$ (0.5%)	$MgSO_4$ (1.5%)	K_2SO_4 (3%)	K_2SO_4 (5%)
FFA (%) (as oleic acid)	0.3100^{a}	0. 1700^{c}	0.1200^{d}	0.1300^{d}	0.2300^{b}
PV (meq O_2 kg^{-1} oil)	8.0270^{a}	7.7700^{b}	6.5770^{c}	6.0730^{e}	6.4700^{d}
IV (I2/100 g oil)	87.2100^{a}	84.1600^{c}	84.7600^{b}	80.3500^{e}	82.5300^{d}
SV (mg KOH g^{-1} oil)	200.5700^{a}	199.6800^{d}	200.5200^{b}	199.6300^{e}	200.1400^{c}
$K_{232\ nm}$	1.7430^{a}	1.7010^{b}	1.5660^{d}	1.4680^{e}	1.5970^{c}
$K_{268\ nm}$	0.2210^{a}	0.1030^{c}	0.0580^{e}	0.0750^{d}	0.1240^{b}
RI at 25°C	1.4685^{c}	1.4685^{c}	1.4762^{a}	1.4737^{b}	1.4674^{c}
OS at 100°C	15.3700^{c}	15.5300^{c}	19.4300^{b}	22.2000^{a}	18.4300^{b}

Means followed by the same letters within the column are not significantly different at p = 0.05, FFA: Free fatty acids, PV: Peroxide value, IV: Iodine, SV: Saponification values, RI: Refractive index, OS: Oxidative stability

Table 8: Effect of spraying magnesium and potassium sulphate on on chemical and physical properties of Koroneiki olive oil during 2015 season

	Treatments				
Samples items	Control	$MgSO_4$ (0.5%)	$MgSO_4$ (1.5%)	K_2SO_4 (3%)	K_2SO_4 (5%)
FFA (%) (as oleic acid)	0.1700^{a}	0.1600^{a}	0.0800^{c}	0.1200^{b}	0.1600^{a}
PV (meq O_2 kg^{-1} oil)	1.3230^{a}	1.1630^{b}	0.8400^{c}	0.7670^{d}	0.7630^{d}
IV (I2/100 g oil)	82.4300^{a}	81.0800^{d}	81.0300^{e}	81.4600^{c}	81.7100^{b}
SV (mg KOH g^{-1} oil)	200.1400^{e}	200.6400^{b}	200.5600^{c}	200.7200^{a}	200.3900^{d}
$K_{232\ nm}$	1.9460^{a}	1.9390^{b}	1.8720^{c}	1.7830^{d}	1.6410^{e}
$K_{268\ nm}$	0.2030^{a}	0.1320^{c}	0.1360^{b}	0.0980^{e}	0.1160^{d}
RI at 25°C	1.4675^{c}	1.4677^{bc}	1.4677^{bc}	1.4681^{ab}	1.4681^{a}
OS at 100°C	36.1600^{d}	35.1600^{e}	39.5000^{c}	45.9200^{a}	41.2700^{b}

Means followed by the same letters within the column are not significantly different at p = 0.05, FFA: Free fatty acids, PV: Peroxide value, IV: Iodine, SV: Saponification values, RI: Refractive index, OS: Oxidative stability

and 0.16% in the second season). The variation in potassium content in fruits of Koroneiki olive that sprayed with magnesium and potassium sulphate and the control was significant during the two seasons. Indeed, there is an increasing in levels of potassium with spraying magnesium sulphate at 0.5% and potassium sulphate at 3% was 1.04 and 1.07% (2014) and 1.05 and 1.07% (2015) compared to the control 1.03% in both seasons (Table 6). Concerning magnesium fruit content, spraying magnesium sulphate at 1.5% and potassium sulphate at 5% gave the highest values (26.09 and 20.04 ppm in the first season and 26.16 and 19.37 ppm in the second season). On the other hand, the control trees exhibited the magnesium fruit content (13 and 10 ppm) in both seasons, respectively.

The improvement of carbohydrate and mineral content of Koroneiki fruits may be due to the assimilation of potassium in fruits which influencing on the assimilation of other elements hence moving from production site (roots and/or leaves) to fruits. These results suit to those of Abou Rayya *et al.*[45] and Malek and Mustapha[46] noticed that the improvement of nutritional status of Arbequina olive fruits especially K and P, probably because the better assimilation of potassium in the pulp.

Chemical and physical properties of olive oil: Data in Table 7 and 8 show the effect of different concentrations of foliar application magnesium and potassium sulphate on chemical and physical properties of Koroneiki oil in 2014 and 2015 seasons.

Concerning acidity as oleic acid, it ranged 0.12-0.31% and 0.08-0.17% during 2014 and 2015 seasons, respectively. The highest value of acidity is 0.31% lower than the 0.8% reference value for this quality according to International olive council[47]. Consequently, oil obtained was classified as virgin olive oils of extra category. In this manner, these results are in agreement with that mentioned by El Antari *et al.*[48].

Regarding peroxide value, it ranged 6.07-8.02 meq O_2 kg^{-1} oil in season 2014 but in season 2015 ranged 0.763-1.323 meq O_2 kg^{-1} oil. Foliar application of magnesium and potassium sulphate led to Koroneiki oils classified as extra virgin under international olive oil council standards. The limit set for "Extra" oils is $\leq$20 meq O_2 kg^{-1} oil.

The difference in acidity and peroxide value which obvious between two seasons of the study may be due to oxidative degradation in oil, additionally free fatty acids affected by various factors related to both hydrolsis and oxidation of the oil.

Iodine value was significantly decreased by magnesium and potassium sulphate treatments in both seasons of the study compared to untreated trees (Table 7, 8). It could be observed that potassium sulphate at 3 and 5% gave the lowest value (80.35 and 82.53) in the first season. Meanwhile magnesium sulphate at 0.5 and 1.5% gave the lowest value (81.08 and 81.03) in the second season (Table 8). On the contrary, the control gave the highest value (87.21 and 82.43) during 2014 and 2015 seasons.

The decrease in iodine value may be due to low content of polyunsaturated fatty acid (C18:2, 8.98 and 9.32%) in the first season (Table 9) and (C18:2, 8.21 and 7.49%) in the second season (Table 10) compared with control (10.76 and 8.44%) in both seasons, respectively.

Table 9: Effect of spraying magnesium sulphate and potassium sulphate on fatty acid composition of Koroneiki olive oil season 2014

		Treatments				
Fatty acids	Carbon chain	Control	$MgSO_4$ (0.5%)	$MgSO_4$ (1.5%)	K_2SO_4 (3%)	K_2SO_4 (5%)
Palmitic acid	C16:0	14.46^a	12.58^d	14.33^b	13.24^c	14.35^b
Palmitoleic acid	C16:1	1.32^a	1.06^c	1.28^b	1.05^c	1.26^b
Margaric acid	C17:0	0.03^b	0.05^b	0.03^b	0.04^b	0.09^a
Heptadecenoic acid	C17:1	0.07^c	0.08^c	0.24^a	0.07^c	0.10^b
Stearic acid	C18:0	2.22^e	2.51^b	2.54^a	2.36^c	2.33^d
Oleic acid	C18:1	69.71^c	69.44^d	68.29^e	72.56^a	70.94^b
Linoleic acid	C18:2	10.76^c	12.62^a	11.85^b	8.98^e	9.32^d
α-linolenic acid	C18:3	0.76^a	0.75^a	0.73^b	0.72^b	0.72^b
Arachidic acid	C20:0	0.40^c	0.47^a	0.45^b	0.49^a	0.44^b
Gadoleic acid (Eicosenoic)	C20:1	0.28^c	0.33^{ab}	0.26^d	0.33^{ab}	0.31^b
behenic acid	C22:0	0.00^d	0.11^c	0.00^d	0.16^a	0.14^b
T. SFA		17.11^b	15.72^d	17.35^a	16.29^c	17.35^a
T. USFa		82.90^c	84.28^a	82.65^d	83.71^b	82.65^d
MUSFA		71.38^c	70.91^d	70.07^e	74.01^a	72.61^b
PUSFA		11.52^c	13.37^a	12.58^b	9.70^e	10.04^d
USFA/SFA		4.84^b	5.36^a	4.76^b	5.14^a	4.76^b
MUSFA/PUSFA		6.20^c	5.30^e	5.57^d	7.63^a	7.23^b

Means followed by the same letters within the column are not significantly different at p = 0.05

Table 10: Effect of spraying magnesium and potassium sulphate on fatty acid composition of Koroneiki olive oil season 2015

		Treatments				
Fatty acids	Carbon chain	Control	$MgSO_4$ (0.5%)	$MgSO_4$ (1.5%)	K_2SO_4 (3%)	K_2SO_4 (5%)
Palmitic acid	C16:0	14.76^e	15.60^b	15.08^c	16.09^a	15.05^d
Palmitoleic acid	C16:1	1.18^d	1.32^c	1.35^b	1.32^c	1.40^a
Margaric acid	C17:0	0.04^a	0.05^a	0.05^a	0.05^a	0.04^a
Heptadecenoic acid	C17:1	0.08^a	0.08^a	0.08^a	0.07^a	0.07^a
Stearic acid	C18:0	2.28^a	2.25^b	2.15^c	2.04^d	1.95^e
Oleic acid	C18:1	72.38^a	70.76^c	71.20^b	69.66^e	70.55^d
Llinoleic acid	C18:2	8.44^c	8.21^d	7.49^e	9.15^b	9.26^a
α-linolenic acid	C18:3	0.89^b	0.97^a	0.90^b	0.85^c	0.83^d
Arachidic acid	C20:0	0.46^b	0.48^a	0.43^c	0.39^d	0.42^c
Gadoleic acid (Eicosenoic)	C20:1	0.32^a	0.14^c	0.32^a	0.29^b	0.31^a
Behenic acid	C22:0	0.12^b	0.14^a	0.00^d	0.09^c	0.12^b
T. SFA		17.66^a	18.04^a	17.71^a	18.66^a	17.58^a
T. USFA		83.29^b	81.49^c	81.34^b	81.34^d	82.42^a
MUSFA		73.96^a	72.31^c	72.95^b	71.34^d	72.33^c
PUSFA		9.33^e	9.18^d	8.39^c	10.00^b	10.09^a
USFA/SFA		4.41^b	4.52^c	4.59^b	4.36^d	4.69^a
MUSFA/PUSFA		7.92^a	7.87^b	8.69^c	7.13^e	7.17^d

Means followed by the same letters within the column are not significantly different at p = 0.05

As for saponification values of oils extracted, results clearly that different treatments significantly influences on saponification values in the two seasons (Table 7, 8). It can be observed that the foliar fertilization with magnesium sulphate at 0.5 and 1.5% , potassium sulphate at 3 and 5% and control (without treatment) were 199.68, 200.52, 199.63, 200.14 and 200.57 in the first season respectively, while season 2015 was 200.64, 200.56, 200.72, 200.39 and 200.14 respectively.

The foliar application of magnesium and potassium sulphate decreased the absorbance of olive oil at 232 and 268 nm compared with control (Table 7, 8). The values of K_{232} and K_{268} extinction coefficients for all oils complied with the limits for "Extra" olive oil K_{232} of $\leq$2.50, K_{268} of $\leq$0.22 as reported by IOC[47]. Thus low absorbance at 232 and 268 nm that limit mentioned correspond to good olive oil quality. These results are in harmony with those obtained by Solinas *et al.*[49].

Concerning refractive index (Table 7, 8) cleared that a little variation in the two seasons. The values ranged from 1.4674-1.4762 and 1.4675-1.4681 at 25°C in the two seasons, respectively. In all varieties index may be due to the relation between the refractive index and iodine value which depends on the degree of unsaturated fatty acids. These results are in agreement with those reported by Ibrahim *et al.*[50] and Khalil *et al.*[51].

On the other hand oxidative stability (Table 7, 8), although not considered a standard parameter of quality, is useful for providing information on the oil's hypothetical shelf-life. Oxidative stability of the oil samples was determined by the Rancimat test, an accelerated method that shortens analysis time and the influence of the different foliar treatments on this parameter was investigated in the two seasons. The values of the oxidative stability ranged between 15.37-22.20 and 35.16-45.92 during 2014 and 2015 seasons, respectively. Meriem *et al.*[52] reported that the stability of oils is higher when the content of monounsaturated oleic acid is high and the content of linoleic acid is low and suggested that oleic on linolic acids ratio is then closely associated with stability.

Fatty acids composition: The oil chromatographic analysis permitted identification of many fatty acids, varying from C16 to C22 as known for olive oil. Fatty acids play a very important role in the determination of the olive oil quality. Results revealed that fatty acids composition was also modified by spraying magnesium and potassium sulphate at different treatments (Table 9, 10). All fatty acids composition was in the range of international olive council standard[47]. The predominant Saturated Fatty Acids (SFA) found palmitic acid C16:0 followed by stearic acid C18:0. Palmitic acid percentage was decreased in samples which spraying with magnesium and potassium sulphate at different treatments compared with control sample (untreated). While stearic acid slight increased in sample oils extracted from olive trees foliar application with magnesium and potassium sulphate at different treatments compared with control sample in the first season and vice versa in the second season in both palmitic and stearic acids. Generally, there is no significant difference in palmitic acid percentage for samples which spraying magnesium and potassium sulphate at 1.5 and 5% compared with control sample in both seasons. Data in Table 9 and 10 showed that the effect of spraying magnesium and potassium sulphate at different treatments on oleic acid C18:1 major unsaturated fatty acid (USFA), it could be observed that spraying potassium sulphate at 3 and 5% caused increase in oleic acid of olive oil compared with control sample (without treatment), it was 72.56, 70.94 and 69.71, respectively. While spraying magnesium sulphate at 0.5% no significant (69.44) in first season. In the second season, all treatments significantly decreased than the control in oleic acid (Table 10). Polyunsaturated fatty acids (PUSFA) are very important for human nutrition as they are considered to be essential acids. Linoleic acid C18:2 was the dominant polyunsaturated fatty acid in Koroneiki olive oil which applied with magnesium sulphate at 0.5 and 1.5% more than control sample in the first season; it was 12.62, 11.85 and 10.76%, respectively. In the second season potassium sulphate at 3 and 5% gave higher than control sample 9.15, 9.26 and 8.44%, respectively. Concerning Total Saturated Fatty Acid (TSFA) percentage results showed that no significant differences between foliar application treatments with magnesium at 1.5%, potassium at 5% and control sample in both seasons. Monounsaturated fatty acids (MUSFA) significantly increased as to spray potassium sulphate at 3 and 5% (74.04 and 72.62) compared to control sample (without treatment) 71.38, vice versa in spraying magnesium sulphate at 0.5 and 1.5% in the first season. It could be noticed that all treatments significantly decreased than the control in second season. From Table 9 it can be noticed that, monounsaturated/polyunsaturated fatty acid ratio were significantly increased as affect by different treatments for the potassium sulphate compared with the control, vice versa of magnesium sulphate at different treatments. While Table 10 illustrated that the monounsaturated/polyunsaturated fatty acid ratio were significantly decreased as affect by different treatments for the magnesium and potassium sulphate than the control. This difference in fatty acids composition from season to other season may be related to change in environmental condition. Moreover, the influence of the magnesium and potassium applications on these parameters was dependent of the management practices and climate conditions throughout the experimental period, justifying the significant mean effect ($p \leq 0.05$) in both seasons.

The enhancement of Koroneiki oil quality is due to the different roles of magnesium and potassium in plant physiological processes. Magnesium and potassium plays a significant role in many cellular activities for instance enzymes, metabolism of nucleic acids, photosynthesis of leaves, CO_2 absorption and improve photosynthetic transportation, glucose transportation, vitamins, proteins and starch synthesis and other underlying growth materials[44] which are considered as important during development accumulation oil processes in olive fruits. Utilization of potassium is found out to be effective in oilseed crops[53,54]. This attributed to the role of K in biochemical pathways in plants, where K acts as an activator for several enzymes involved in carbohydrate metabolism[55]. These may be reflected in distinct changes in oil quality. Mekki *et al.*[56] stated that, foliar application with K decreased oil acid value and increased the oleic acid on sunflower seed oil. Froment *et al.*[57] found that, the favored fatty acid composition (high oleic acid content), linoleic acid content in linseed oil and iodine value, which indicates the degree of un-saturation of the final oil, was highest in treatments receiving high K concentration. The beneficial effect of applied K on TU and TU/TS ratio suggests that it might be due to the regulated effect of K which acts as an activator on many enzymic processes, where some of these enzymes may affect the oil content from these organic matters. Seo *et al.*[58] found that the height rates of K increased oleic acid content, whereas the intermediate rates increased linoleic acid content.

CONCLUSION

It could be concluded that spraying Koroneiki olive trees grown in sandy soil conditions with magnesium sulphate at 1.5% and potassium sulphate at 3% twice at final fruit set stage and 1 month later, since it improved shoot length, diameter, number of new shoots, number of leaves per shoot and leaf area, fruit set, fruit retention and yield (kg $tree^{-1}$). Also, it increased fruit weight, oil, protein carbohydrate and mineral content. Moreover, it decreased free fatty acids, peroxide, iodine values, K_{232} and K_{268} and polyunsaturated fatty acids in particular linoleic acid and finally, it enhanced oxidative stability and monounsaturated fatty acid content in particular oleic acid which express the effectiveness of treatments on oil quality.

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