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RESEARCH ARTICLE

Growth and nutrient status of olive plants as influenced by foliar potassium applications

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Abstract

Olive (*Olea europaea* L.) plants were sprayed (one, two or three times) with nutrient solutions containing KCl, KNO_3 and K_2SO_4 with the same amount of K (0, 1, 2 and 3% w/v). The weight of the plants was unaffected by salt type, number of sprays or K concentration of salts, whereas the dry matter percentage was significantly increased in the plants treated with K_2SO_4. Furthermore, the application of K_2SO_4 led to a significantly higher N concentration in leaves than that of KCl. K-salts increased K concentration in plants in the following order: KCl> KNO_3> K_2SO_4 and three foliar applications were significantly more efficient than one. Moreover, irrespective of plant part, K spray application frequency significantly affected Fe and Zn concentrations in the plants studied. Finally, although KCl increased Cl concentrations more than KNO_3 and K_2SO_4, the former fertilizer was the most efficient to improve the K status of the olive cv. Chondrolia Chalkidikis.

Keywords: Chondrolia Chalkidikis, fertilizers, *Olea europaea* L., perlite, pot experiment, sprays

1. Introduction

Research on foliar fertilization most probably started in the early 1950s. In the early 1980s studies were conducted on foliar application of fertilizers for selected crops, but the research was limited only to micronutrients in high-value horticultural crops (Girma *et al*., 2007). Nutrients applied to the foliage are generally absorbed more rapidly than when applied to the soil. 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 (Brady and Weil, 2002). Therefore, K foliar fertilizer applications are considered as a valid alternative in order to provide nutrients to plants when soil conditions may limit root uptake or during periods of fast growth when nutrient needs may exceed root supply (Swietlik and Faust, 1984; Toscano *et al*., 2002). In addition, as a rule, fruit trees have a deep rooting system, which limits the efficiency of fertilizers applied to the soil surface (Mengel and Kirkby, 2001). From a practical point of view, K foliar application is recommended for orchards located in dry lands because of (i) the lower cost of application, and (ii) the lack of moisture in the soil during the growing period that could limit K uptake. Foliar application 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.

Potassium is known to play important role in olive and oil yield (Elloumi *et al*., 2009). Olive is a species with a high K requirement due to the high content of K present in the olive fruit (Fernandez-Escobar, 2004). Potassium deficiencies are common in olive trees, especially those cultivated under dry land conditions on calcareous soils and represent the main nutritional problem in non-irrigated orchards (Restrepo-Diaz *et al*., 2009).

Several authors have studied the response of different fruit trees to foliar K fertilization, e.g. Dikmelik *et al.* (2000) evaluated its effectiveness in olive. In the latter species, there is great variability in leaf K concentration between 'on' and 'off' years due to crop load. In this case, foliar application in the spring of the 'on' year is an effective way to apply K. Soon after the leaves have been sprayed with K, it is rapidly translocated to the reproductive structures of olive (Fernandez-Escobar *et al*., 1999), improving vegetative growth and fruit yield. Some studies, however, have reported irregular responses of fruit trees to foliar fertilizer applications (e.g. in apple, Khemira *et al*., 1999). Factors such as leaf age, salt type and concentrations, number of foliar applications, water stress and nutritional status of the tree may influence foliar K uptake in fruit trees (Swietlik and Faust, 1984).

For these purposes, the objective of this study was to evaluate the effect and efficiency of foliarly applied K forms on the growth and nutrient status of the olive cultivar Chondrolia Chalkidikis.

2. Materials and Methods

2.1. Plant material and growth conditions

One-year-old, uniform, own-rooted olive plants of the significant Greek table olive cultivar 'Chondrolia Chalkidikis' were planted in three-liter polyethylene bags containing inert perlite medium. The experiment was carried out in a lathhouse situated on the farm of the Aristotle University of Thessaloniki, Greece (latitude 40^{o}53'N, longitude 22^{o}99'E) and lasted from 15 March to 30 June (108 days) with an average temperature of 30^{o}C.

2.2. Treatments

Olive plants were irrigated every 15 days with 500 ml of 50% Hoagland solution (minus K), and every two days the plants were irrigated with good quality tap water. Before planning this experiment, the previous year (2009) we run a similar preliminary experiment in order to choose the appropriate chemicals and concentrations for the main experiment. The preliminary results agree with the results reported in our experiment. The experiment was planned by using three K-salts with the same amount of K (0, 1, 2 and 3%). The experiment included ten treatments containing the control and three concentrations of KCl, KNO_3 and K_2SO_4 salts equivalent to 0, 1, 2 and 3% K, with twelve plants per salt treatment. The experiment comprised 120 plants in total. The salt treatments are presented in Table 1. About 300 ml of foliar salt solution per twelve plants (4 plants X 3 per time) were used. In order to improve adhesiveness, glycerin (2 ml/l) was added to the spray solution. Control plants were sprayed with the same amount of deionised water (-salt). Three foliar sprays were applied as follows:

1st application: 13 days after the initiation of the experiment (27/3/2010). All twelve plants per salt treatment were sprayed.

2nd application: 38 days after the initiation of the experiment (21/4/2010). Eight of the twelve plants per salt concentration were sprayed.

3rd application: 63 days after the initiation of the experiment (16/5/2010). Four of the twelve plants per salt concentration were sprayed.

Table 1. Treatments used in the experiment.

Treatment code	Number of sprays	K-salt	Salt concentration (% w/v)
C-1	1	no K-salt	-
KC1-1	1	KCl	2.00
KC2-1	1	KCl	4.00
KC3-1	1	KCl	6.00
KN1-1	1	KNO_3	2.70
KN2-1	1	KNO_3	5.40
KN3-1	1	KNO_3	8.10
KS1-1	1	K_2SO_4	2.33
KS2-1	1	K_2SO_4	4.66
KS3-1	1	K_2SO_4	6.99
C-2	2	no K-salt	-
KC1-2	2	KCl	2.00
KC2-2	2	KCl	4.00
KC3-2	2	KCl	6.00
KN1-2	2	KNO_3	2.70
KN2-2	2	KNO_3	5.40
KN3-2	2	KNO_3	8.10
KS1-2	2	K_2SO_4	2.33
KS2-2	2	K_2SO_4	4.66
KS3-2	2	K_2SO_4	6.99
C-3	3	no K-salt	-
KC1-3	3	KCl	2.00
KC2-3	3	KCl	4.00
KC3-3	3	KCl	6.00
KN1-3	3	KNO_3	2.70
KN2-3	3	KNO_3	5.40
KN3-3	3	KNO_3	8.10
KS1-3	3	K_2SO_4	2.33
KS2-3	3	K_2SO_4	4.66
KS3-3	3	K_2SO_4	6.99

2.3. Plant growth traits and chemical status

At the termination of the experiment (108th day), plants were harvested and leaves (new and old), stems and roots were separated. The leaves that developed after the treatments started, were considered as new leaves. Plant height and fresh weight (FW) of all plant parts were recorded. Following, all samples were washed twice with deionized water, dried at 75^{o}C for 48 h, weighed for dry matter weight (DW) and then ground to a fine powder to pass through a 30-mesh sieve. The dry matter content was calculated using the following equation: DW (%) = (DW/ FW) X 100.

The Kjeldahl method was used to determine N concentration (Jones, 1991). Tissue boron (B) concentration was determined by dry ashing 0.5 g of dry plant material in a muffle furnace at 500^{o}C for 6 h. The ash was dissolved in 0.1N HCl and B was determined colorimetrically (420 nm) with the Azomethine-H method (Bingham, 1982). Analyses for P, K, Ca, Mg, Fe, Mn and Zn were conducted by dry ashing of plant material as above. Following, the ash was dissolved in 3 ml 6N HCl and each solution was diluted (16-fold) with deionised water. Phosphorus concentration was determined using the vanado-molybdo-phosphate yellow colour method (Page *et al*., 1982) and K, Ca, Mg, Fe, Mn and Zn concentrations were determined using atomic absorption spectroscopy (Perkin-Elmer 2380, Waltham, MA, USA), using standard methods. Chloride (Cl) was determined by titration with 0.0141 N $AgNO_3$.

2.4. Data analysis

The experimental layout was a randomized complete block design with one cultivar, ten treatments, four replicates per treatment and three foliar sprays. The data were subjected to analysis of variance (ANOVA) using the SPSS (17.0 for Windows) statistical package (SPSS, Inc., Chicago, Illinois). For mean comparison, the Duncan's multiple range test at $p \leq 0.05$ was used.

3. Results

3.1. Plant growth parameters

The analysis of variance for the FW and DW of whole plants showed that they were unaffected by salt type, number of sprays or K concentration (Tables 2 and 3). The maximum and minimum FW of new leaves were found in the KC1-1 (35.09 g) and KN3-3 (10.75 g) treatments, respectively, whereas the respective values for old leaves were found in the KN2-2 (29.51 g) and C-3 (12.19 g) treatments. Also, the maximum and minimum DW of new leaves were found in the

(78.92 g) and KN3-3 (33.37 g) treatment, respectively, while the respective values for DW were found in the KS3-1 (29.43 g) and C-3 (16.29 g) treatments. On the other hand, dry matter percentage was significantly increased in the plants treated with one, two or three foliar applications with K_2SO_4. In detail, the maximum and minimum dry matter percentages were found in the KS2-1 (56.99%) and KC2-3 (43.29%) treatments, respectively.

3.2. Concentration of macroelements in tissues

All macro elements at the initiation of the experiment were at sufficient level, as shown by the analysis performed and according to Therios (2009). Overall, analysis of variance (ANOVA) showed that the factor 'salt type' significantly affected leaf N concentration (Table 3). That is, the application of K_2SO_4 led to a significantly higher N concentration in leaves than that of KCl (Figure 1). In contrast, spray application frequency and K concentration of salts did not affect leaf N concentration. The highest and lowest N concentration in new leaves were found in the KC1-1 (2.74%) and C-1 (1.91%) treatments, respectively, whereas the respective values in old leaves were found in the KN3-3 (2.07%) and KS1-2 (1.59%) treatments.

In the treatment with one foliar spray, new leaf P concentration increased significantly in all plants treated with K-salts; however in the treatments with two sprays, P concentration decreased compared to control (data not shown). Minimum and maximum P concentrations of new leaves were observed in the C-1 (0.11%) and KS1-1/ C-2 (0.26%) treatments. A similar trend was observed for the P concentration of old leaves in the treatments with K_2SO_4. The maximum and minimum P concentrations of old leaves were observed in the KS2-1 (0.19%) and KC3-3/ KS3-3 (0.07%) treatments, respectively. In the stems of plants treated with one foliar spray, P concentration differed significantly with K-salt type and concentration. In contrast, the P concentration of plants sprayed twice was not affected by salt concentration, while in the treatments with three sprays there were no significant differences regarding salt-type or concentration. The maximum and minimum P concentrations in stems were observed in the KS2-2 (0.117%) and C-1 (0.045%) treatments, respectively. In roots, P concentration was not affected by salt concentration but varied with salt types in the one spray treatments. The maximum and minimum root P concentrations were observed in the KN2-3 (0.102%) and C-1 (0.032%) treatments, respectively. Concerning whole plants, salt type, number of sprays and K concentration of salts did not significantly affect the P content of plants (data not shown).

New leaf K content of plants treated with one foliar spray was significantly increased in most salt treatments compared to the control (Figure 1, Table 3). The maximum and minimum K concentrations were observed in the KC3-3 (2.10%) and C-1 (0.97%) treatments, respectively. On the other hand, the K concentration of old leaves was significantly increased by KCl applications, mainly by two or three foliar sprays. The maximum and minimum K concentrations were observed in KC3-3 (1.39%) and C-1 (0.37%) treatments, respectively. In the stems of 'Chondrolia Chalkidikis', K concentration was significantly affected by one or three spray applications with K-salts. The maximum and minimum K concentrations were observed in KC3-3 (1.22%) and C-1 (0.43%) treatments, respectively. In roots, there was no consistent trend in the effect of applications with K-salts on K concentration. The maximum and minimum K concentrations were observed in KS3-3 (0.65%) and C-1 (0.38%) treatments, respectively. According to ANOVA, K concentration of the plants in the study was significantly affected by salt type, number of sprays and K concentration of salts (Table 3). Namely, K-salts increased the K concentration in plants in the following order: KCl>KNO_3>K_2SO_4 and three foliar applications were significantly more efficient than one application. In general, Ca concentration in leaves, stems and roots of plants was not affected by the K-salt treatments. This was supported by the ANOVA results which showed that there was no significant effect of salt type, number of sprays or K concentration of salts on whole plant Ca content (Table 3).

The maximum and minimum Ca concentrations of new leaves were observed in the KS2-3 (1.06%) and KN2-2 (0.63%) treatments, respectively, whereas the respective values in old leaves were found in the KS2-1 (3.04%) and KS2-3 (2.08%) treatments. On the other hand, the maximum and minimum Ca concentrations in stems were observed in the KC3-1 (1.32%) and KC2-1 (0.98%) treatments, respectively, whereas the respective values in roots were recorded in KC1-3 (0.92%) and C-3 (0.66%) treatments. At the end of the experiment, neither the K-salts or the number of spray applications affected Mg concentration in leaves, stems and roots, as was also indicated by ANOVA for whole plants (Table 3). The maximum Mg concentration of new and old leaves, stems and roots was observed in the KN3-3 (0.22%), C-3 (0.42%), KN3-2 (0.27%) and KN1-1/ KN2-1 (0.52%) treatments, respectively. On the other hand, the respective minimum values were found in the treatments KC2-1/ KS2-1/ KC2-2/ KS3-3 (0.17%), KC1-2 (0.30%), C1-1/ KC2-1 (0.16%) and KS2-3 (0.38%) (data not shown).

Table 2. Fresh and dry weight of new leaves, old leaves and roots and dry matter (%) of olive (*Olea europaea* L.) cv. Chondrolia Chalkidikis at the end of the experiment (108 days).

	Treatments	**Fresh weight (g)**			**Dry weight (g)**			**Dry matter (%)**
		New leaves	**Old leaves**	**Roots**	**New leaves**	**Old leaves**	**Roots**	
1 foliar application	C-1	28.72cde	19.59ab	54.50a-d	12.80bcd	10.21ab	19.79a	46.68a-d
	KC1-1	35.09e	18.98ab	61.36a-d	14.14d	8.88ab	22.91a	44.27ab
	KC2-1	33.43de	23.60ab	58.32a-d	13.68cd	11.40ab	22.94a	46.82a-d
	KC3-1	25.95b-e	20.78ab	53.45a-d	9.94a-d	9.65ab	19.90a	45.79a-d
	KN1-1	21.50a-e	24.69ab	54.18a-d	8.77a-d	12.06ab	19.46a	45.18abc
	KN2-1	20.56a-d	22.33ab	56.23a-d	7.97a-d	10.81ab	21.48a	45.32abc
	KN3-1	15.82abc	20.49ab	42.08ab	6.25ab	9.93ab	17.25a	48.95b-e
	KS1-1	14.90abc	26.48ab	44.77ab	5.71a	12.88ab	18.92a	51.59e
	KS2-1	12.40ab	27.41ab	48.75abc	5.36a	14.59b	24.61a	56.99f
	KS3-1	19.66a-d	27.34ab	61.60a-d	7.57a-d	13.53ab	29.43a	50.12cde
2 foliar applications	C-2	15.61abc	22.02ab	58.02a-d	6.39ab	10.95ab	21.89a	46.50a-d
	KC1-2	21.92a-e	19.99ab	61.81a-d	8.76a-d	9.16ab	23.20a	44.70ab
	KC2-2	23.41a-e	14.70ab	47.85abc	8.56a-d	6.60ab	19.51a	46.37a-d
	KC3-2	22.78a-e	16.76ab	60.12a-d	8.34a-d	7.49ab	22.96a	45.21abc
	KN1-2	15.14abc	18.10ab	47.68abc	5.93a	8.76ab	16.60a	43.99ab
	KN2-2	17.60abc	16.90ab	48.64abc	6.21ab	8.13ab	19.89a	46.26a-d
	KN3-2	20.37a-d	16.78ab	40.58ab	7.91a-d	8.30ab	19.70a	50.67de
	KS1-2	19.94a-d	24.74ab	46.38abc	7.99a-d	12.12ab	21.17a	48.98b-e
	KS2-2	24.77a-e	29.51b	56.01a-d	10.45a-d	14.52b	26.25a	50.65de
	KS3-2	21.54a-e	29.24b	52.39a-d	8.92a-d	13.86b	27.64a	51.64e
3 foliar applications	C-3	19.03a-d	22.59ab	49.01abc	7.76a-d	10.88ab	16.29a	44.28ab
	KC1-3	25.89b-e	19.63ab	55.95a-d	9.91a-d	9.07ab	19.13a	43.43a
	KC2-3	23.52a-e	15.20ab	62.11a-d	8.86a-d	7.06ab	21.57a	43.29a
	KC3-3	19.65a-d	12.19ab	57.94a-d	7.10abc	5.50a	24.07a	45.44abc
	KN1-3	21.92a-e	19.19ab	65.67bcd	9.13a-d	9.61ab	22.80a	44.29ab
	KN2-3	25.09a-e	17.28ab	75.94cd	9.94a-d	8.68ab	28.74a	46.51a-d
	KN3-3	18.93a-d	19.50ab	60.45a-d	7.31abc	9.46ab	22.94a	45.80a-d
	KS1-3	20.97a-e	20.10ab	78.92d	8.32a-d	10.00ab	28.79a	45.49abc
	KS2-3	17.63abc	17.63ab	42.82ab	7.58a-d	8.77ab	21.64a	51.96e
	KS3-3	10.75a	17.73ab	33.37a	4.53a	8.77ab	16.46a	52.96ef

Means with different letters in the same column are significantly different for $p \leq 0.05$ (n=30). Control=C-1, C-2 and C-3. KCl 2%=KC1-1, KC1-2, KC1-3; KCl 4%=KC2-1, KC2-2, KC2-3; KCl 6%=KC3-1, KC3-2, KC3-3. KNO_3 2.7%=KN1-1, KN1-2, KN1-3; KNO_3 5.4%=KN2-1, KN2-2, KN2-3; KNO_3 8.1%=KN3-1, KN3-2, KN3-3. K_2SO_4 2.3% = KS1-1, KS1-2, KS1-3; K_2SO_4 4.6% = KS2-1, KS2-2, KS2-3; K_2SO_4 6.9% = KS3-1, KS3-2, KS3-3

Table 3. P-values of the two-way ANOVA for the variables salt type, number of sprays and K concentration of salts. Weight and nutrient concentrations (except N) concern whole plants.

	Salt type	**Number of sprays**	**K concentration**
Fresh weight	0.627ns[1]	0.519ns	0.737ns
Dry weight	0.362ns	0.416ns	0.697ns
Leaf N	0.009**	0.412ns	0.474ns
P	0.123ns	0.069ns	0.694ns
K	<0.001***	0.005**	<0.001***
Ca	0.975ns	0.267ns	0.950ns
Mg	0.885ns	0.670ns	0.962ns
Mn	0.727ns	0.290ns	0.805ns
Zn	0.115ns	<0.001***	0.247ns
B	0.143ns	0.148ns	0.606ns
Fe	0.643ns	0.034*	0.812ns
Cl	<0.001***	<0.001***	<0.001***

[1]Non significant. *Significance for $p<0.05$. **Significance for $p<0.01$. ***Significance for $p<0.001$.

3.3. Concentration of microelements in tissues

At the initiation of the experiment, there was a relatively deficient range level in leaf Mn concentration (Therios, 2009). At the end of this study, although Mn increased slightly, it was still below sufficiency level. In general, Mn concentration in leaves, stems and roots was unaffected by salt treatments or spray application frequency and this is also shown by the results of ANOVA (Table 3). The maximum Mn concentration in new and old leaves, stems and roots were observed in the treatments KS2-3 (36 μg/g), KC2-1 (52 μg/g), KS3-3 (14 μg/g) and KS3-3 (101 μg/g), respectively, whereas the respective minimum values were found in the treatments KS2-1 (18 μg/g), KS3-1 (30 μg/g), KN2-3 (7 μg/g) and KN3-2 (49 μg/g) (data not shown).

Before the application of K foliar sprays, there was a sufficient range level of Zn concentrations in leaves (Therios, 2009). In new leaves, Zn concentration did not present any significant difference as a result of salt treatments (Table 3). The maximum and minimum Zn concentrations were observed in the KC2-2 (29 μg/g) and KS2-3 (16 μg/g) treatments, respectively (Figure 2). On the other hand, Zn concentration of old leaves was reduced in all salt treatments and spray application frequencies compared to the control (C-1). The maximum and minimum Zn concentrations were observed in the C-1 (34 μg/g) and KS2-3 (13 μg/g) treatments, respectively. Similarly, the highest Zn concentration in stems was that of the control (C-1), but did not significantly differ than most treatments. The maximum and minimum Zn concentrations of stems were observed in the C-1 (15 μg/g) and C-3 (6 μg/g) treatments, which were the controls of one and three foliar application treatments, respectively. Zinc concentration in roots did not present significant differences to the control or among salt treatments.

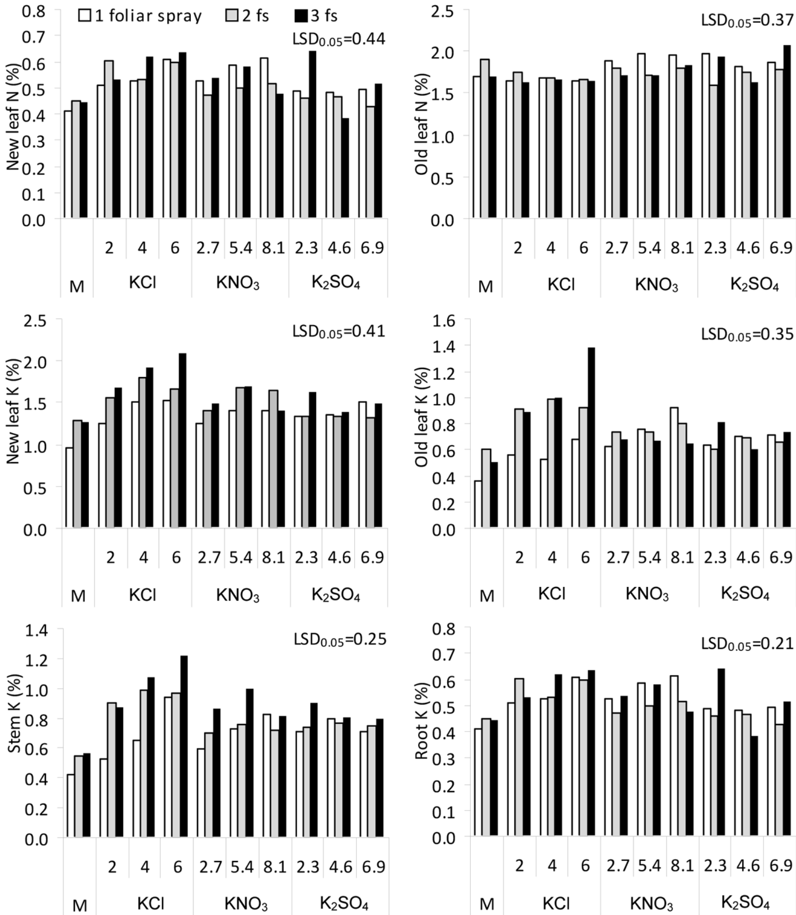

Figure 1. Nitrogen concentrations in new and old leaves, and potassium concentrations in new leaves, old leaves, stems and roots of olive (*Olea europaea* L.) cv. Chondrolia Chalkidikis at the end of the experiment (108 days). Control is indicated with 'M' and salt concentrations in treatments are expressed as percent (%) w/v.

The maximum and minimum Zn concentrations were observed in the KS3-2 (18 μg/g) and KN3-2 (10 μg/g) treatments, respectively. Finally, irrespective of plant parts, spray application frequency significantly affected Zn concentration in the plants of the study (Table 3). More specifically, one foliar spray with K-salts had more favourable results on the Zn concentration of whole plants than two or three sprays. Analysis of leaves at the beginning of the treatments showed that there was a sufficient range level in B concentration (Therios, 2009). Boron concentration in the leaves of the control plants did not differ significantly from that of the salt-treated plants (Table 3). The maximum and minimum B concentrations of new leaves were observed in the KN3-1 (24 μg/g) and KN3-2 (12 μg/g) treatments, respectively, whereas the respective values for old leaves were observed in the KS1-2 (27 μg/g) and C-1 (17 μg/g) treatments (data not shown).

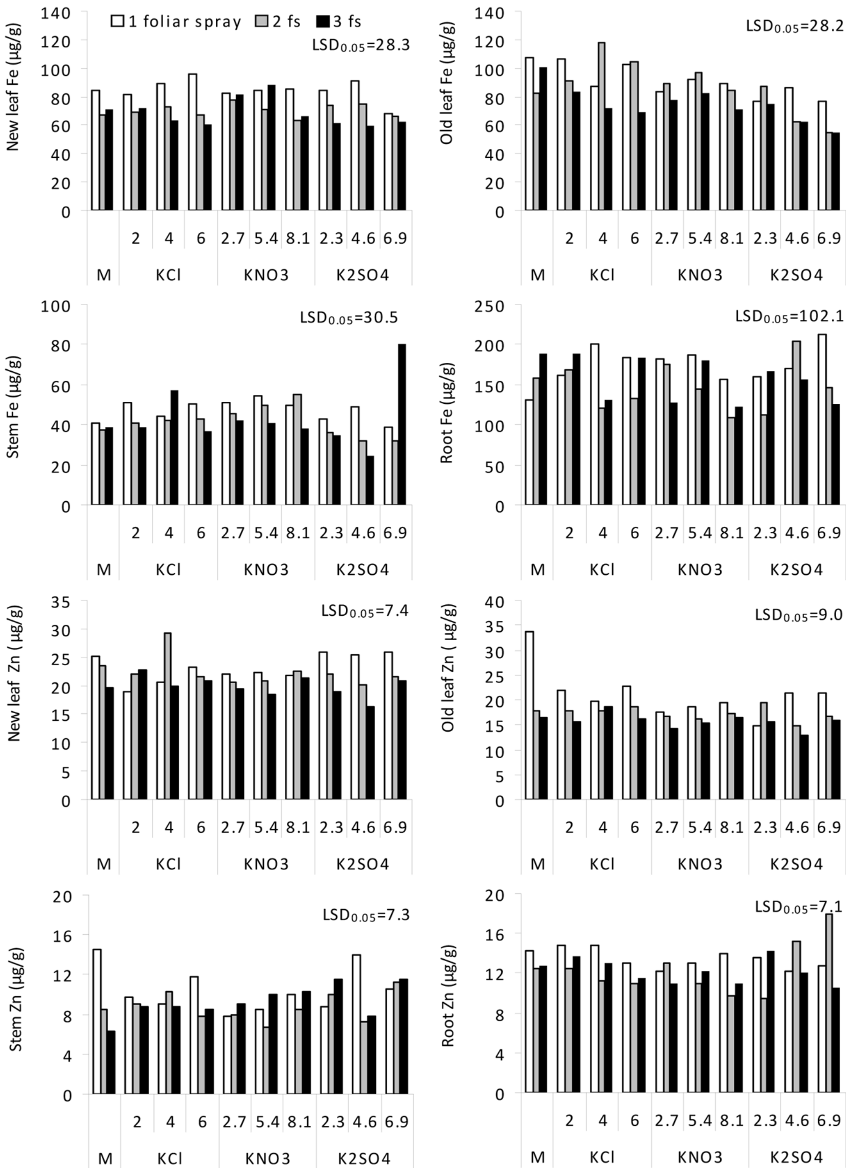

Figure 2. Iron and zinc concentrations in new leaves, old leaves, stems and roots of olive (*Olea europaea* L.) cv. Chondrolia Chalkidikis at the end of the experiment (108 days). Control is indicated with 'M' and salt concentrations in treatments are expressed as percent (%) w/v.

Boron concentration of stems was found to be slightly, but not significantly, increased after the 3rd foliar application of salts. The maximum and minimum B concentrations in stems were observed in the KC1-3 (21 μg/g) and KN3-1 (12 μg/g) treatments, respectively. Similarly, regarding B concentration in roots, no significant variation was observed with different salts and their application frequency. The maximum and minimum B concentrations in roots were observed in the KN1-2/ KS3-2 (25 μg/g) and KN3-2 (19 μg/g) treatments, respectively. Overall, ANOVA showed that salt type, number of foliar applications and K concentration of salts did not significantly affect B concentration (Table 3).

At the initiation of this study, olive plants were found to be Fe-sufficient (Therios, 2009). At the end of the experiment, Fe concentration of all plant parts did not vary significantly compared to the control (Figure 2). Only in old leaves did the application of K-salts lead to a significant decrease in Fe concentration compared to the control. ANOVA revealed that spray application frequency had a significant effect on Fe content of olive plants (Table 3). More specifically, one-spray treatment gave significantly better results than two or three sprays. The maximum and minimum Fe concentrations in new leaves were observed in the KC3-1 (96 μg/g) and KS2-3 (60 μg/g) treatments, respectively, whereas the respective values for old leaves were found in the KC2-2 (118 μg/g) and KS3-3 (55 μg/g) treatments. Moreover, the maximum and minimum Fe concentrations in stems were observed in the KS3-3 (80 μg/g) and KS2-3 (24 μg/g) treatments, respectively. Finally, in roots, the maximum and minimum Fe concentrations were observed in the KS3-1 (213 μg/g) and KN3-2 (108 μg/g) treatments, respectively.

Most of plants treated with KCl presented significantly higher leaf Cl concentration than the control (Figure 3). The maximum and minimum Cl concentrations of new leaves were observed in the KC3-3 (0.967%) and C-1 (0.026%) treatments, respectively. On the other hand, the maximum and minimum Cl concentrations in old leaves were observed in the KC3-3 (1.17%) and KN2-1 (0.015%) treatments, respectively. In stems, Cl concentration was not significantly affected by the K-salt treatments compared to the control in the one-spray application. However, after the 2nd and 3rd spray application, there was a significant increase in the Cl concentration in stems in comparison to the other treatments. The maximum and minimum Cl concentrations were observed in the KC3-3 (0.470%) and KS1-3 (0.005%) treatments, respectively. Regarding the Cl concentration in roots, it was not affected by any of the treatments and by none of the foliar application frequencies. The maximum and minimum Cl concentrations of roots were observed in the KC2-2 (0.672%) and KS3-3 (0.030%) treatments, respectively. Generally, Cl concentration in olive plants was significantly affected by salt type, number of foliar applications and K content of salts (Table 3). As expected, KCl treatments led to the highest Cl concentrations, about four times higher than in the KNO_3 and K_2SO_4 treatments. Also, three sprays with K-salts led to higher Cl concentrations than the two-spray treatments and the latter gave better results than the one-spray treatments. Moreover, the efficiency of the K content (in % w/v) of salts on the Cl concentration of plants followed the order 3> 2> 1> control.

4. Discussion

It is clear that the foliar application of the K-salts studied at different concentrations and frequencies had no significant effect on the FW and DW of the different plant parts of the olive cultivar 'Chondrolia Chalkidikis'. This is in line with the results of Restrepo-Diaz *et al*. (2009) experimenting on olive, although they applied KCl at concentrations higher than 4%. In agreement with our findings, Ben Mimoun *et al*. (2004) suggested that no effect of the KNO_3 treatments was observed on the vegetative growth of olive. The lack of significant effects on the biomass of soybeans treated with high rates of foliar K fertilizer has been also reported (Mallarino and Ul-Haq, 1998).

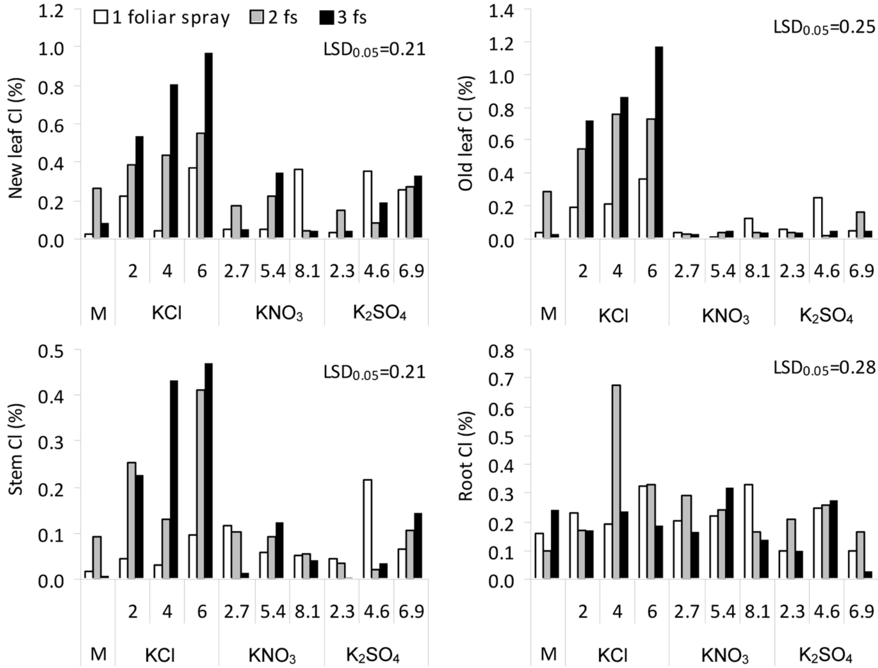

Figure 3. Chloride concentrations (%) in new leaves, old leaves, stems and roots of olive (*Olea europaea* L.) cv. Chondrolia Chalkidikis at the end of the experiment (108 days). Control is indicated with 'M' and salt concentrations in treatments are expressed as percent (%) w/v.

Potassium as a highly phloem mobile element (Marschner, 2002) can move from organs of relative abundance to growing tissues so that plants do not immediately exhibit K deficiency or depressed plant growth when the demand for the particular nutrient is higher than its uptake rate (Fernandez *et al*., 2013). On the other hand, in the present study, it appears that in comparison to the control, the dry matter percentage was significantly increased only in the treatments with K_2SO_4. Similar results were found in foliar treatments with K_2SO_4 which improved the shoot FW of sunflower (Saeed Akram *et al*., 2009). This may be due to the beneficial effect of sulphate in enhancing dry matter percentage. Our findings showed that there was an increase in N concentration in both new and old leaves with one application of different concentrations of KNO_3 compared to the control. However, N concentration was not affected after two and three applications of K-salts. Similar conclusions for olive (i.e. that N was not significantly influenced by K concentration) have been also reported by other researchers (Saykhul *et al*., 2013). In our case, however, leaf N concentration increased significantly by about 30% with KNO_3 compared to the other K salts.

Regarding P, our results suggested that its concentration was affected by some K-salt treatments with one or two spray applications, but the trend was not consistent. In agreement to these findings, Veberic *et al.* (2005) experimenting with apple cv. Golden Delicious reported that foliar application of K fertilizers led to minor changes of leaf P concentration.

As regards K concentration of the new leaves of the control plants it never reached deficiency level (<0.50%; Therios, 2009) throughout the study. On the other hand, there was a significant increase in the K concentration of different parts of the olive plant with all K salts and spray frequency in the present study compared to the control. Restrepo-Diaz *et al*. (2009) have also reported a significant interaction between the number of foliar applications and leaf K concentration of olive plants. Namely, they suggested that foliar applications with KCl, KNO_3, K_2SO_4, KH_2PO_4 and K_2CO_3 are effective in increasing leaf K concentration in olive leaves and that two foliar applications of KCl (0.05 or 2.50 mM) were enough to increase leaf K concentrations. In our study, although KCl applications were effective in increasing K content in olive plants when grown in a K-deficient medium, they were not effective when plants were adequately fertilized. These findings are supported by a number of different studies. Zeng *et al*. (2001) had similar results in pistachio. Sotiropoulos *et al*. (2010) also reported that foliar application of agriphos, chelan-K, silene-K, and KNO_3 resulted in an increase in leaf K concentration of the peach (*Prunus persica* (L.) Batsch), for three consecutive years of experimentation. Shafer and Reed (1986) who evaluated the K absorption of several K sources of soybean (*Glycine max* L.) excised leaves found that KNO_3, K_2CO_3 and a few phosphate forms were very promising. It has also been reported that KCl was very effective in enhancing K concentration of groundnut (*Arachis hypogaea* L.) leaves when applied foliarly (Umar *et al*., 1999). Furthermore, similar findings were observed in cotton, where a greater increase in leaf K concentration resulted from the foliar application of KC1 than K_2SO_4 (Chang and Oosterhuis, 1995). The greater effectiveness of KCl compared to the two other K-salts may be attributed to its lower point of deliquescence (POD; Schönherr, 2002). The latter is defined as the relative humidity (RH) value at which the salt becomes a solute. Thereby, the lower the POD of a salt, the sooner it will dissolve upon exposure to ambient RH and penetrate cuticle (Fernandez *et al*., 2013). Accordingly, in our study, the lower the POD value of a salt, the higher its efficiency to supply plants with K.

Furthermore, in the present study it was found that there was no significant variation in Ca and Mg concentrations in different plant parts among the control and K treatments. Similarly, Saykhul *et al*. (2013) experimenting with three olive cultivars under hydroponic culture, reported that leaf Ca and Mg concentrations were not – in most cases – influenced by K treatments.

In addition, we found that the micronutrient concentrations in different parts of the plants were, likewise, not significantly affected by K treatments. This is in agreement with the findings of Sotiropoulos *et al*. (2010) who reported that in the peach cv. Andross Fe, Mn, and Zn concentrations of leaves were not affected by the foliar sprays with different K-containing fertilizers. The observation that two or three sprays with K led to lower Fe concentration compared to one spray may be attributed to the 'dilution effect' due to close relation between cell extension and K content. In detail, cell extension is the consequence of the accumulation in the cells of K+, which is required for both stabilizing the pH in the cytoplasm and increasing the osmotic potential in the vacuoles (Marschner, 2002). Moreover, in accordance to our results, B concentration in cotton was not affected by preplant application of 112 kg K ha^{-1} (Pettigrew and Meredith, 1997).

On the other hand, our results showed that, compared to the control, Cl concentration significantly increased with the KCl foliar sprays. This may be due to the higher solubility of KCl resulting in greater availability of free Cl- and better penetration through leaf cuticles. However, it was found that in all cases the leaf Cl- concentration did not exceed the toxicity threshold level of 0.5% DW. This indicates that the use of KCl on young olive plants does not cause toxicity problems as a result of high concentrations of Cl- (Restrepo-Diaz *et al*., 2009). Similar findings were reported in pistachio (Zeng *et al*., 2001), whereas the opposite was observed in citrus which are very sensitive to Cl- toxicity (Maas, 1993).

Finally, comparing different K salts, Schönherr and Luber (2001) reported that KCl and K_2CO_3 were the most appropriate K-salts for foliar fertilization because of their high solubility and good penetration through leaf cuticles. The application of high concentrations of K may, however, cause leaf injuries or leaf burning (not observed in our case) with a subsequent reduction in leaf K accumulation (Marschner, 2002). The reduction in nutrient absorption through the leaves that we observed in some cases may have been due to destruction of ectodesmata structures. This is further supported by Weinbaum (1988), who reported that leaf burning, which is a common problem of foliar spraying at high concentrations can be avoided with the use of low salt index fertilizers (i.e. those that are free of Na and Cl), containing low K and a proper adjuvant. Moreover, phytotoxicity problems were not observed by any of the foliar K sources or concentrations when the pH levels of the spray solutions ranged from 6.5 to 7.7 (Jifon and Lester, 2009).

5. Conclusions

Our results suggest that foliar K uptake can be regulated by selecting an appropriate K-salt which will be sprayed at an adequate number of times. With the exception of K and Cl, spray applications of KCl, KNO_3 or K_2SO_4 do not seem to alter significantly the nutritional status of olive plants. Obviously, the K status of the olive cultivar 'Chondrolia Chalkidikis' could be better improved by applying foliarly KCl than KNO_3 or K_2SO_4, but Cl concentration in leaves should be kept below toxic levels. The results of our short-term study suggest that foliar fertilization with K should merely be used as a supplemental fertilization method, taking into consideration some limitations. Further studies with olive trees in the field are proposed, in order to reach sound conclusions, since there are numerous outdoor factors that influence fertilizer efficiency.

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