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Mycorrhizal treatments increase the compatibility between Pistachio (*Pistacia vera* L.) cultivars and seedling rootstock of *Pistacia terebinthus* L.

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ABSTRACT

The bud–rootstock compatibility is decisive in the success of grafting pistachios. Climate conditions and appropriate rootstock choice are the two key factors influencing grafting success. Despite producers' efforts, fluctuations in these factors result in frequent differences in annual yield. To minimize production losses by increasing the percentage of successful grafting would greatly benefit the introduction of this crop in new areas.

Here, we analyze the viability of *Pistacia terebinthus* L. differentially treated with mycorrhizae or phytohormones and used as rootstock for *Pistacia vera* buds. Our results, on an experimental plot of 12,905 plants, demonstrate that mycorrhiza-treated plants reached ~80% positive grafts, while the phytohormone-treated plants and controls had 32.3% and 38.4% success, respectively. The increase in grafting success could be explained by more efficient nutrient uptake in mycorrhiza-treated plants. An analysis of chemical element accumulation and assimilation in leaves reveals that mycorrhiza-treated plants selectively accumulated Ca, Fe, Mg, N, Al, S, Sr, Ti, V, Mn, and Tl, but lacked K with respect to the rest of the plants. Mycorrhiza-treated plants were shorter, but no significant differences were found in trunk diameter and circumference. We propose the use of mycorrhizae to increase bud–rootstock compatibility for this tandem of species.

1. Introduction

Pistacia vera L. is a much appreciated crop due to its edible fruit, the pistachio, which is consumed as finger food, and also used as the main ingredient of some beverages, oils, cold meats, cheeses, and sweets. Pistachio ranks fifth among global nut production, and is undergoing a surge worldwide. Although native to Mediterranean basin, it is currently cultivated on the five continents. The main producers are Iran and the United States, with over 70% of total production (Faostat, 2013). After a long history of domestication, there are over 50 cultivated varieties of pistachio with few morphological and physiological differences between them, related mainly to seed size, flowering time, and production rate (Spina, 1984). Like many other fruit trees, this crop is hard to root and requires a rootstock for vegetative propagation. While the rootstock does not influence the distinctive features of each variety, broad differences in production, vigor, and longevity have been reported depending on this selection (Tarango Rivero, 1993). Furthermore, the percentage of successful grafts is considered to be the key factor for the prosperity of pistachio breeding. Thus, the use of an appropriate bud–rootstock is a key issue that needs to be carefully considered for any given area (Ferguson et al., 2005a).

Temperature and humidity, and the type of grafting exert limiting effects on the growth of *de novo* tissue between the rootstock and bud (Couceiro, 1992; Ferguson et al., 2005b; Guerrero, 2011). Grafting takes place during the summer season. As a rule, during the first stages, temperatures should range between 15 °C and 32 °C, and humidity should remain below 50% (Couceiro et al., 2013). The most widely spread grafting is T-budding (Guerrero, 2011). Nevertheless, rootstock choice and its general condition are likely to the most influential factors in pistachio nurturing. Native plants are preferred because of the availability of specimens, and the lack of adaptation issues. Thus, in USA, *Pistacia atlantica* Desf. and *Pistacia integerrima* Stewartson are commonly used (Guerrero et al., 2005), as well as, some interspecific hybrids of *P. atlantica* × *P. integerrima* (UCB1 and PGII) (Ferguson et al., 2005a). *P. atlantica*

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Desf. is also prevalent in Morocco, Tunisia, Algeria, Iraq, and Iran (Guerrero, 2011), while *P. vera* L. is widely used in Iran, Turkey, Syria, and Tunisia, together with *P. khinjuk* stocks, a closely related species (Sheibani, 1996). *Pistacia terebinthus* L. is the main rootstock in Spain, Italy, and Australia (Hobman and Bass, 1986; Caruso et al., 1990).

Spain, where this research was conducted (Granada), has the potential climatic conditions to produce pistachios but the 5000 ha cultivated still represent a low percentage (Couceiro et al., 2013). The average of grafting success in Castilla La Mancha (Spain), using the same tandem of species studied here, is currently 60% after three rounds of grafting (Couceiro et al., 2013). This factor jeopardizes the establishment of new orchards. Thus, it is important to develop techniques to increase grafting success and thereby reduce the cost of nursery plants that in the long-term may facilitate the adoption of pistachio in Spain.

We hypothesized that any technique capable of promoting the uptake efficiency of a rootstock may increase the compatibility between the bud and the rootstock. In this context, we investigated the influence plant treatment with mycorrhizae and phytohormones on nutrient uptake and grafting success. Mycorrhizae, apart from providing some elements to the plant, encourage the formation of a larger root surface area (Dodd and Ruiz-Lozano, 2011). Phytohormones act as bio-stimulants that influence nutrient uptake (Miyashima and Nakajima, 2011). Thus, either treatment might indirectly affect the growth of *de novo* tissue required after grafting. To analyze these aspects, we laid out an experimental plot of *P. terebinthus* L. plants to be used as rootstocks. A third of the plants were treated with mycorrhizae (hereafter mycorrhizal plants), another third with phytohormones (hereafter phytohormonal plants), while the rest were left untreated as control.

2. Materials and methods

2.1. Plant material, treatments, and experimental design

The study was conducted in a plot at *Viveros Zuaime* SL, Caniles, Granada (Spain) from 06/12/2012 to 06/10/2013. A total of 12,905 one-year-old seedlings from a seedbed of *P. terebinthus* plants, homogenous in vigor and size, were selected and planted in the plot on a 2 × 1 m pattern. All plants were supplied with commercial irrigation during the experiment, and a standard nutrient solution. Three different groups of ~4000 individuals each were settled. A randomized complete-block design was used, and these were equally divided into three subgroups, according to the following treatments: (i) *control*, plants that underwent no further treatments, (ii) *phytohormonal*, plants treated with a mixture of auxins, gibberellins, and cytokinins at the time of transplanting to promote root growth and deep rooting (Stimulate, Stoller, USA); and (iii) *mycorrhizal*, plants inoculated with a mix of native *Glomus* spp. mycorrhizae by immersing the roots in a solution prior to planting (GLOMYGEL®, Mycovitro SL, Spain).

2.1.1. Grafting, plant growth, and percentage of grafting success

When the plants reached an optimal size, on 08/28/2012, T-bud grafting was performed using buds evenly split between *Kerman* and *Peter* varieties of pistachio (*P. vera*). Grafting was executed manually by the same team of technicians to minimize undesired interferences. Plant height and diameter and perimeter of plants at 5 cm of the graft union were measured on 10/17/2012. These parameters were measured in 307 control, 290 mycorrhizal, and 319 phytohormonal plants 7 weeks after the grafting. The percentage of successful grafts was visually checked the following season (06/10/2013) in all the experimental plants.

2.1.2. Mineral uptake by the rootstock

We determined mineral uptake capability by the rootstock, evaluating the concentration of 30 chemical elements in the leaves of the rootstock (Table 1). At random, 25 plants were sampled from the seedbed before the treatments on 06/12/2012 at the beginning of the experiment. Then, 25 plants taken at random from each group were sampled directly after the grafting on 09/27/2012, and on 11/13/2012. For each plant, 100 g of leaves were collected and dried out at 60 °C for 24 h, and then fine powdered. Analysis of total C and N was performed in a Flash EA 1112 Series-LECO TRUSPEC device. The analysis of the rest of elements was made by digestion with HNO_3/H_2O_2 in an UltraClave Microwave Milestone, and ICP-OES using an ICAP 6500 DUO device. These analyses were carried out at the Ionomic Laboratory of CEBAS-CSIC (Murcia, Spain).

2.2. Statistical analyses

Plant growth parameters and mineral concentration in leaves were subjected to a one-way analysis of variance (ANOVA) using the SPSS software package (SPSS 20 for Windows, 2007). The assumption of normality, homoscedasticity and the independence of the factors were previously set. To assure normality, a Saphiro–Wilk test was applied and the distribution was typified if it not previously.

Tukey's HSD (honest significant difference) was used as a *post hoc* test when Levene's test showed homoscedasticity ($\alpha > 0.05$); otherwise Dunnett T3 and Tamhane were used, as in the case of Cu, Mn, K, C, and Tl.

A randomized complete-block design with a significance level of 0.05, was used to guarantee the independence between the concentration of chemical elements and the plants growing in the plot (Table S1). For all the elements the result was favorable, supporting the null hypothesis and establishing that concentration did not depend on the plot.

Furthermore, a binomial *Z* test was used to corroborate the evidence of the grafting results (Table S2). Our data on the three treatments significantly differ from the binomial distribution ($p = 0.50$) taken as reference. It is remarkable the success of mycorrhizal plants (79%; $\alpha < 0.01$).

3. Results

3.1. Analysis of accumulation and assimilation of different chemical elements in P. terebinthus treated with mycorrhizae and phytohormones

At 77 days after the grafting, 25 random mycorrhizal, phytohormonal and control plants were sampled. Mycorrhizal plants were found to have increased B, Zn, Al, Ca, Fe, Mg, Mn, N, S, Sr, Ti, Tl, and V uptake with respect to the others (Table 1). However, K uptake showed the lowest values in mycrorrhizal plants. Mineral uptake between control and phytohormonal plants was similar in all cases except for B, Zn, and P; in comparison with controls, while phytohormonal and mycrorrhizal plants showed increased B uptake. Mycrorrhizal and phytohormonal plants showed the highest and lowest Zn mean values, respectively, while controls had intermediate mean value. Control values lacked significance with respect to either of the two other values. Finally, mycorrhizal and phytohormonal plants showed the lowest and highest P mean values, respectively. Controls showed an intermediate mean value. The three mean values lacked significance after the ANOVA and Bonferroni tests. Instead Tukey's HSD test demonstrated that the values of mycorrhizal and phytohormonal plants significantly differed, but lacked significance with respect to control (Table 1).

Table 1
Accumulation of chemical elements in mycrorrhizal, phytohormonal, and control *Pistacia terebinthus* plants 77 days after the grafting.

Element	Analysis 3							
	Mycorrhize	Phytohormone	Control	ANOVA		Tukey's HSD		
				Statistical F	Signification value	Mycorrhize–Control	Mycorrhize–Phytohormone	Control–Phytohormone
Al (mg/kg)	99.02	66.27	66.74	10.606	0.000	0.000	0.000	0.998
B (mg/kg)	68.19	55.83	45.10	3.161	0.048	0.001	0.138	0.221
C[a] (g/100 g)	49.43	49.08	49.69	2.194	0.119	0.644	0.456	0.099
Ca (g/100 mL)	1.83	1.25	1.12	12.961	0.000	0.000	0.001	0.694
Cr (mg/kg)	0.39	0.36	0.33	0.714	0.493	0.463	0.780	0.986
Cu[a] (mg/kg)	95.91	108.84	114.19	0.945	0.393	0.379	0.619	0.921
Fe (mg/kg)	86.98	65.51	68.00	7.963	0.001	0.005	0.002	0.907
K (g/100 g)	0.71	0.94	0.95	9.761	0.000	0.001	0.001	0.968
Li[a] (mg/kg)	0.83	0.72	0.96	1.160	0.319	0.691	0.760	0.287
Mg (g/100 g)	0.26	0.21	0.18	5.880	0.004	0.003	0.092	0.441
Mn (mg/kg)	67.12	40.45	39.87	12.500	0.000	0.000	0.000	0.995
N (g/100 g)	2.39	2.14	2.15	7.081	0.002	0.006	0.004	0.993
Na[a] (g/100 g)	0.025	0.024	0.017	2.667	0.076	0.092	0.962	0.165
Ni[a] (mg/kg)	0.32	0.74	0.55	0.342	0.711	0.794	0.724	0.991
P (mg/kg)	0.23	0.29	0.21	3.136	0.050	0.736	0.210	0.044
Pb[a] (mg/kg)	0.49	0.32	0.32	1.216	0.302	0.368	0.379	1.000
S (g/100 mg)	0.13	0.12	0.12	9.591	0.000	0.001	0.001	0.989
Sr (mg/kg)	66.05	47.76	42.04	7.963	0.001	0.001	0.014	0.641
Ti (mg/kg)	3.40	2.43	2.54	8.488	0.000	0.004	0.001	0.907
Tl (g/100 mg)	7.45	4.35	2.28	14.024	0.000	0.000	0.003	0.189
V (mg/kg)	1.79	1.36	1.18	7.373	0.001	0.001	0.030	0.515
Zn (mg/kg)	11.87	9.87	10.40	3.601	0.032	0.143	0.031	0.770

ANOVA and Tukey's significance value: $\alpha < 0.05$.
[a] C, Cr, Cu, Li, Na, Ni, and Pb showed no significant variations.

Table 2
Accumulation of some elements in *P. terebinthus* before the treatments, directly after the grafting, and 77 days after the grafting.

Element	Analysis 1	Analysis 2			Analysis 3		
		Mycorrhize	Phytohormone	Control	Mycorrhize	Phytohormone	Control
Al (mg/kg)		75.63	96.62	116.11	99.02	66.27	66.74
B (mg/kg)	30.00	39.37	44.15	53.91	68.19	55.83	45.10
C (g/100 g)					49.43	49.08	49.69
Ca (g/100 mL)	1.34	1.00	1.27	1.09	1.83	1.25	1.12
Cr (mg/kg)		0.27	0.33	0.51	0.39	0.36	0.33
Cu (mg/kg)	2.00	5.42	7.98	11.52	95.91	108.84	114.19
Fe (mg/kg)	15.00	56.67	91.99	74.11	86.98	65.51	68.00
K (g/100 g)	1.21	0.90	0.95	1.08	0.71	0.94	0.95
Li (mg/kg)		<0.5	<0.5	<0.5	0.83	0.72	0.96
Mg (g/100 g)	0.26	0.19	0.25	0.24	0.26	0.21	0.18
Mn (mg/kg)	71.00	56.41	58.08	67.60	67.12	40.45	39.87
N (g/100 g)					2.39	2.14	2.15
Na (g/100 g)		0.01	0.01	0.03	0.025	0.024	0.017
Ni (mg/kg)		0.21	0.36	0.51	0.32	0.74	0.55
P (mg/kg)	0.31	0.26	0.42	0.69	0.23	0.29	0.21
Pb (mg/kg)		0.48	0.50	0.50	0.49	0.32	0.32
S (g/100 mg)		0.12	0.13	0.14	0.13	0.12	0.12
Sr (mg/kg)		40.28	58.98	33.41	66.05	47.76	42.04
Ti (mg/kg)		2.82	3.19	4.06	3.40	2.43	2.54
Tl (g/100 mg)		<0.05	3.39	0.96	7.45	4.35	2.28
V (mg/kg)		1.37	1.95	1.83	1.79	1.36	1.18
Zn (mg/kg)	15.00	10.73	17.00	7.91	11.87	9.87	10.40

Table 3
Means of diameter, circumference, and height of plants. ANOVA and Tukey's significance value: $\alpha < 0.05$.

Analysis								
	Mycorrhize	Phytohormone	Control	ANOVA		Tukey's HSD		
				Statistical *F*	Signification value	Mycorrhize–control	Mycorrhize–phytohormone	Control–phytohormone
Diameter (mm)	10.5	10.2	10.1	0.698	0.498[a]	0.910	0.477	0.732
Perimeter (cm)	3.31	3.21	3.18	0.720	0.487[a]	0.913	0.468	0.717
Height (cm)	115.53	124.97	123.35	24.208	0.000	0.000	0.000	0.335

[a] Diameter and circumference showed no significant variations.

Table 4
Percentage of positive bud–rootstock unions in the three groups of plants studied.

Treatment	Plants analyzed	Percentage of positive matches (%)
Control	4675	38.4
Mycorrhized	4290	79.4
Phytohormoned	3940	32.3

In all the treatments, C, Cr, Cu, Li, Na, Ni, and Pb uptake was similar while As, Be, Bi, Cd, Co, Mo, Sb, and Se uptake fell below the detection range (<0.5 kg/m^3; Table 1).

3.2. Trends in accumulation of some elements in P. terebinthus during the treatments

For this analysis, we compared the three measures gathered at different times during the experiment. As described above, Ca, Fe, Mg, and Mn were significantly accumulated in mycrorrhizal plants, whereas K was significantly underrepresented. As the plants grew, a tendency of Ca, Mg, and Mn to slightly decrease over time was observable in all three groups. However, mycrorrhizal plants showed an upturn in coincidence with the grafting. The Fe concentration generally tended to increase up to the grafting time, after which values dropped in mycorrhizal and phytohormonal plants and in control. All plants exhibited the same trend for K assimilation, its concentration decreasing with time (see Fig. 1 and Table 2).

Our data suggest that B tended to accumulate over plant development in mycorrhizal and phytohormonal plants. Nevertheless, control plants showed a slight drop after grafting. Although at the last sampling, Zn and P values proved similar in all plants (Table 2), these elements had a different accumulation pattern in the three groups studied. On one hand, in mycrorrhizal and control plants Zn concentration decreased, but increased after grafting, while the dynamic in phytohormonal plants was the opposite (see Fig. 1 and Table 2). On the other hand, P tended to accumulate in phytohormonal and control plants until grafting, from which point there was a slight drop. Mycrorrhizal plants exhibited a steady decline in P concentration. Finally, all plants analyzed here showed a tendency to accumulate Cu (Fig. 1 and Table 2).

3.3. P. terebinthus growing pattern and percentage of bud–rootstock compatibility after the treatments

Mycrorrhizal plants showed the highest mean value of diameter and circumference of trunk, and the lowest height mean value (see Table 3). Diameter and circumference values were not significant according to the ANOVA. However, Tukey's test demonstrated that mycrorrhizal-plants mean height values were significantly lower than the other two mean values (see Table 3).

Mycrorrhizal plants increased the percentage of positive bud–rootstock union in comparison with phytohormonal and control plants (Table 4). Whereas 41 weeks after the grafting, 79.4% of mycorrhizal plants showed active buds with signs of tissue growth between them and the rootstock, their respective values for phytohormonal and control plants was only 32.3% and 38.4% (Table 4).

4. Discussion

Pistachio is a hard-to-root tree, and requires a rootstock for vegetative propagation. The percentage of successful grafting is decisive for the viability of this crop. The choice of the rootstock is made on the basis of bud–rootstock compatibility, which depends basically on the geographical region and the nutrient uptake efficiency (Ferguson et al., 2005a). As a whole, the fate of chemical elements relies largely on the efficiency of root genotypes, and varies depending on the choice of rootstock (Hokmabadi et al., 2005). Here, we hypothesize that changing the uptake efficiency of the rootstock might influence the final nutrient-uptake balance. For this, we have comparatively analyzed the influence of mycorrhizae and phytohormones in the nutrient uptake of the rootstock *P. terebinthus* L. in Spain, and ultimately its possible influence on *P. vera* L. bud-grafting success. *P. terebinthus* L. is a widely used rootstock in Spain, as it is native, cold resistant, highly tolerant to salinity, and of remarkable nutritional efficiency (Ferguson et al., 2005b).

It is well known that *Pistacia* species can easily establish symbiotic relations with mycorrhizae (Ferguson et al., 1998). In general, mycorrhizae provide the plant with a thicker root system, and represent an extra source of P and N. In *Pistacia*, mycrorrhizal plants showed better nutrient uptake efficiency under different water regimes and salt-stress conditions. In all cases K, Mn, P and Zn are found to be significantly accumulated in plants associated with mycorrhizae (Kafkas and Ortas, 2009; Bagheri et al., 2012). Bagheri et al. (2012) also found that Cu and Fe maintain their levels in mycrorrhizal plants.

Our dataset confirm a significant accumulation of Zn, Mn, P, and N in mycrorrhizal plants with respect to control and phytohormonal ones, in support of previous observations. This is remarkable, because the availability of P and N is probably the most limiting aspect in *Pistacia*, and affects a number of vital parameters such as water-usage efficiency, seed quality, and disease resistance. Also, Zn is important to reduce the percentage of empty fruits, and Mn is crucial for photosynthesis (Couceiro et al., 2013). Nevertheless, we found *K* to be underrepresented in plants inoculated with mycorrhizae. This discrepancy with data from Kafkas and Ortas (2009) and Bagheri et al., 2012 may be due to the low consumption of *K* during the vegetative growth, in which the samples were taken (Rosecrance et al., 1996). While confirming the observations in Cu, our data would suggest that Fe is preferentially accumulated in mycrorrhizal plants (see Table 1).

In the present study, we also analyzed the uptake of other elements, showing that Al, Ca, Mg, S, Sr, Ti, Tl, and V were preferentially accumulated in mycrorrhizal plants. On the contrary, C, Cr, Li, Na, Ni, and Pb showed no significant variations in the means values in any plants analyzed (Table 1). In all cases, mean values of phytohormonal plants were statistically similar to those of control plants, so that the mixture tested here seems not to have influenced the final accumulation of elements (Table 1 and Fig. 1).

Additionally, we studied the accumulation trends of some elements in the three groups of plants considered at different moments before and after the grafting. Mg, Mn, Ca, B, K, and Fe concentration decreased during the plant development (Fig. 1). We proved here that mycorrhizal treatment could avoid this natural loss of Ca, Fe, Mg, and Mn detected in phytohormonal and control plants. Together with N, Ca is probably one of the most consumed elements during pistachio development. In fact, there was a marked decrease in the Ca concentration during the vegetative period and around 70–80% of this Ca ultimately accumulates in the seed (Fig. 1). Fe, Mg, and Mn are essential elements for photosynthesis (Couceiro et al., 2013). Thus the influence of mycorrhizae on plant development could be considerable. Phytohormonal plants also showed a rise in B accumulation after grafting and, like mycorrhizae, would avoid the loss observed in control plants. For their part, phytohormones would prevent the loss of Zn registered in mycrorrhizal and control plants. It is thought that a growing shoot can stimulate differential accumulations or alterations in the transport of some elements (Zhou et al., 2007; Schwarz et al., 2010). With the control plants taken as reference, the B and Fe concentrations would reverse their trend to accumulate after grafting, and the concentration would decline. Nonetheless, Mg and Mn concentration dramatically plummeted after grafting, following the natural tendency of these elements to decrease. These data suggest

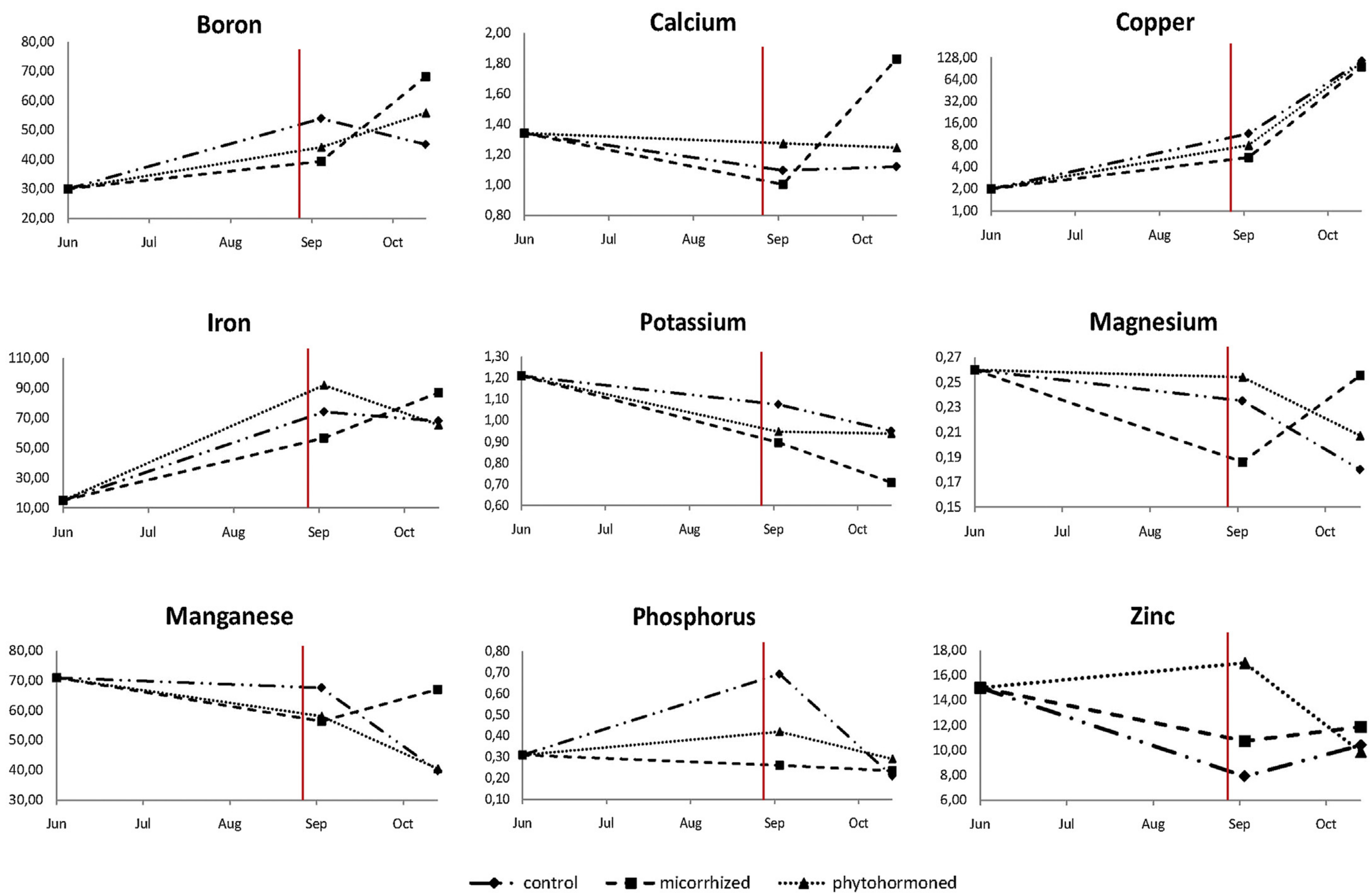

Fig. 1. Seasonal patterns of B, Ca, Cu, Fe, K, Mg, Mn, P, and Zn concentration on phytohormonal, mycrorrhizal, and control plants during the experiment. Red bar indicates moment of grafting. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

that grafting might alter nutrient uptake in pistachio, as suggested previously in different tree crops (Jensen et al., 2003; Martínez-Ballesta et al., 2010). However, the influence of other factors cannot be ruled out, and further research is needed to clarify this point.

Better nutrient uptake could result in a more vigorous rootstock. Previous studies correlating grafting and rootstock morphology have demonstrated the importance of rootstock vigor in bud development (Beede et al., 2005; Ferguson et al., 2005b; Holtz et al., 2005). Diameter is a key factor and positively correlates with grafting success. *P. terebinthus*–*P. vera* grafts for example are highly dependent on diameter (with coefficients of determination $R^2 > 0.75$), with respect to other rootstocks as *P. atlantica* Desf. ($R^2 = 0.35$). On the contrary, height is unlikely to affect the efficiency of the graft (Guerrero, 2011).

In our analyses, the mean diameter and circumference values did not significantly differ between treatments, so neither of these parameters appears to affect grafting success. However, a diameter among 12–15 mm has been suggested to favor grafts >50% in *P. terebinthus* L., and increasing this might positively affect the results presented here (Guerrero, 2011). On the other hand, mycorrhizal plants were significantly shorter than the others (Table 3). Nevertheless, this seems not to affect, at least negatively, the efficiency of the graft. It might be an indirect effect of nutrient allocation after grating.

Finally, we visually checked the success of grafting in all plants. Strikingly, 79.4% of mycrorrhizal plants gave successful results, *versus* 32.3% and 38.4% success in phytohormonal and control plants, respectively (Table 4). This would support the contention of Estaun et al. (1990) who proposed that mycorrhizal inoculation could benefit the pistachio crop in Spain. The average of positive grafting in Castilla La Mancha (Spain), using the same species is 60% after three rounds of grafting (Couceiro et al., 2013). Although our study is based exclusively on the first round, the dataset suggests that mycrorrhizal plants could boost grafting efficiency at least 40% with respect to control plants. In turn, phytohormone treatment does not positively affect the grafting effectiveness.

5. Conclusions

Pistachio requires a suitable rootstock, for which bud–rootstock compatibility is essential. The effect of mycorrhizae and phytohormones on nutrient uptake and their effect in grafting have been analyzed in this work using *P. terebinthus* as a rootstock for *P. vera* buds. Around 80% of mycrorrhizal plants gave rise to a successful graft, while 32.3% and 38.4% of phytohormonal and control plants had success, respectively.

After 77 days of the treatment, mycrorrhizal plants increased in Ca, Fe, Mg, N, Al, S, Sr, Ti, V, Mn, and Tl, but dropped in *K* with respect to phytohormonal and control plants. Mycorrhizal treatment hampered the loss of B, Ca, Fe, Mg, and Mn, and might influence the percentage of successful grafts. Except for B, mean values of elements were statistically similar to those of control in phytohormonal plants, so that the mixture tested here affects neither the final accumulation of elements nor the grafting success.

Although the circumference and the diameter of the trunk were similar in all cases, mycrorrhizal plants were significantly shorter.

Therefore, we propose the utilization of mycrorrhizal treatment of *P. terebinthus* plants as the rootstock, which could increase the efficiency of grafting at least 40% with respect to control pistachio plants.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.scienta.2014.06.039.

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