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EFFECT OF CITRUS ROOTSTOCKS ON LEAF MINERAL COMPOSITION OF 'OKITSU', 'CLAUSELLINA', AND 'SILVERHILL' MANDARIN CULTIVARS

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EFFECT OF CITRUS ROOTSTOCKS ON LEAF MINERAL COMPOSITION OF 'OKITSU', 'CLAUSELLINA', AND 'SILVERHILL' MANDARIN CULTIVARS

Celil Toplu,[1] Veli Uygur,[2] Mustafa Kaplankıran,[1] T. Hakan Demirkeser,[1] and Ercan Yıldız[1]

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□ *Citrus performance is strongly related with rootstock. This study was conducted to investigate leaf nutrient contents of 'Okitsu', 'Clausellina' and 'Silverhill' mandarin cultivars budded onto sour orange, 'Carrizo' and 'Troyer' citrange rootstocks in Dörtyol, Turkey in 2004 and 2005. The maximum nitrogen (N), potassium (K), and copper (Cu) contents were determined for 'Clausellina'; phosphorus (P) for 'Okitsu'; and sodium (Na) for 'Silverhill'. Calcium (Ca), magnesium (Mg), iron (Fe), manganese (Mn), and zinc (Zn) uptake were similar for the mandarin cultivars. 'Carrizo' citrange at N, K, Mg, Mn, and Cu uptake; 'Troyer' citrange at N, P, K, and Fe uptake; and common sour orange at Ca, Zn, and Na uptake was superior on the other rootstocks. It was observed that 'Carrizo' and 'Troyer' citrange rootstocks had advantages over sour orange in nutrient uptake. Thus, growth performance, yield, and quality parameters considered, 'Carrizo' and/or 'Troyer' citranges could be suggested as rootstocks for the studied mandarin cultivars under similar ecological conditions.*

Keywords: mandarin, citrus rootstocks, nutrient uptake

INTRODUCTION

There is an increasing demand for citrus fruits due to public awareness about the effects of citrus fruits on human health and nutrition. Thus, demand-driven citrus fruits production in the world have reached to 114,275,017 tons and Turkey has a share of 3,225,017 tons. Citrus fruits are mainly cultivated in the Aegean, Mediterranean, and Eastern Black Sea regions of Turkey. Mandarin production in Turkey has an economical importance with total of 791,225 tonnes production (FAO, 2006). Hatay in

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the eastern Mediterranean region has a share of 17.8% with 574,213 tonnes for citrus fruits production and 28.05% with 221,990 tonnes for mandarin production (Anonymous, 2006).

'Owari' used to be the common cultivar of Satsuma mandarins in production and exportation of Turkey, but 'Okitsu' and 'Clausellina' have been widely utilized in newly founded mandarin orchards since 1990 (Kaplankıran et al., 2001). The earliness of 'Okitsu' and 'Clausellina' over 'Owari' brought about popularity to these cultivars in many mandarin producing countries such as Spain, Argentina, Uruguay, and Turkey, especially in the eastern Mediterranean region (Saunt, 1990; Anonymous, 2000). This is a strategic approach to overcome or minimize the national and international commercial problems and to expand Satsuma production season by using 'Okitsu' and 'Clausellina' cultivars instead of 'Owari' in newly planted orchards (Kaşka et al., 2005).

Rootstock usage is necessary for overcoming limiting factors (i.e., soil, climate, disease, and pests), meeting producers and consumers demands (i.e., fertility, earliness, shorter juvenility, fruit quality) (Tuzcu, 1978; Davies and Albrigo, 1994). Common sour orange is the main rootstock but 'Trifoliate', 'Troyer' and 'Carrizo' citrange rootstocks are also used to a lesser extent. However, 'Carrizo' citrange has become more frequently used in the last couple of years. The trifoliate orange rootstock is common in the old mandarin orchards of Aegean region (Tuzcu et al., 1998; Kaplankıran et al., 2001). Despite many beneficial properties of common sour orange, which is widely used as rootstock, it is very susceptible to tristeza virus. Thus, researchers have concentrated on possible alternative rootstocks to overcome this deleterious problem of citrus (Tuzcu, 1978; Davies and Albrigo, 1994). The researchers have demonstrated that citrus rootstocks have differently influenced the performance, earliness, yield and yield quality of budded cultivars in relation to ecological conditions (Tuzcu et al., 1998; Bowman, 1998; Tsakelidou et al., 2002; Georgiou, 2002; Stenzel et al., 2003; Romero et al., 2006; Filho et al., 2007).

Since rootstock forms the root system of a tree, rootstocks primarily influence water and nutrient uptake and translocation among the plant organs. The uptake and transport of nutrient elements taking place critical role in physiological and biochemical processes, fertility, and yield quality are different for each rootstock-scion combination (Fallahiand Rodney,1992; Taylor and Dimsey, 1993; Kaplankıran et al., 1995, 1996; Georgiou, 2000, 2002; Moeen et al., 2001; Tsakelidouetal., 2002; Smith et al., 2004; Marathe et al., 2006). Rootstocks may behave differently depending on the climatic and soil conditions and reflect these effects to the scion. Thus, rootstock selection specific to a region is as important as cultivar selection (Davies and Albrigo, 1994). Rootstocks having better nutrient uptake and usage ability and enabling these effects to transfer to the budded cultivar will help to make more environmentally friendly and economically feasible fertilization program.

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Therefore, the aim of this study was to select best possible rootstocks for mandarin cultivars ('Okitsu', 'Clausellina', and 'Silverhill') by considering nutrient levels of leaves.

MATERIALS AND METHODS

The experiment was set up in the Mustafa Kemal University experimental farm in Dörtyol, Hatay, Turkey (36° 09′ E, 36° 51′ N; 9 m above the sea level) in randomized complete design (RCD) with five replicates. 'Okitsu', 'Clausellina', and 'Silverhill' mandarin cultivars were budded on the common sour orange (*Citrus aurantium* L. var. "common"), 'Troyer' and 'Carrizo' citranges (*Poncirus trifoliata* Raf. × *Citrus sinensis* Osb. var. 'Troyer' and 'Carrizo'). Seeds of rootstocks and buds of the mandarins were supplied from Cukurova University. One-year old budded trees were planted with 7 × 7 m spacing in 1998. Results of 2004 and 2005 were used in this study.

Some climatic parameters of Dörtyol for 2004 and 2005 were: averaged maximum temperature 30.3 and 24.6°C; averaged minimum temperature 8.6 and 14.2°C; average temperature 19.1 and 18.8°C, and aggregated precipitation 676.8 and 1030 mm, respectively.

The soil was coarse textured (sand 646–693, silt 245–270, and clay 64.6–69.4 g kg^{-1}) and slightly alkaline to alkaline in the soil profile (pH 7.8, 7.98 and 8.25 for 0–30, 30–60 and 60–90 cm depth, respectively, in 1:2.5 soil: water suspension), rich in carbonate content (61–63 g kg^{-1} for 0–60 cm and 113.5 g kg^{-1} for 60–90 cm depth). The trees were fertilized with 500 g nitrogen (N) $tree^{-1}$ (2/3 of it at the end of February/at the beginning of March and 1/3 at the end of May), 300 g phosphorus (P) $tree^{-1}$ (in December) and 300 g potassium (K) $tree^{-1}$ (by the end of January). Disease and pest control were made according to integrated pest management method.

Four- to seven-month old leaves were sampled from the fruitless shoots in autumn in 2004 and 2005 (Chapman, 1960). Leaf samples were decontaminated by washing with a detergent solution, tap water and rinsing with distilled water. Then, samples were dried at 70°C till constant weight and homogenized by particle size reduction to <0.5 mm. The powdered samples were then digested with nitric acid (HNO_3)- perchloric acid ($HClO_4$) mixture (3:1 v/v) (Kacar, 1972). In the extracts sodium (Na), K, magnesium (Mg), calcium (Ca), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) were determined by Inductively coupled plasma atomic emission spectrometer (ICP-AES, Varian Liberty Series II; Varian Inc., Palo Alto, CA, USA) and P by the Barton reagent at UV/VIS spectrometer (Shimadzu 1208, Shimadzu, Kyoto, Japan) (Barton, 1948). Total N was determined by a micro-Kjeldahl procedure (Lees, 1971). The elemental contents of leaves were evaluated according to threshold values given by Marchal (1987).

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The data were tested using the SAS program for analysis of variance (ANOVA) and the mean separation was made by Tukey test at $P = 0.05$ (SAS, Cary, NC, USA).

RESULTS

Cultivar, rootstock, and scion-rootstock interactions significantly affected the nutrient level of 10 elements. Leaf K and Cu levels were significantly affected by cultivars in both years with an observed maximum level for 'Clausellina'; N, P, and Na levels were only significantly affected in 2004; and the rest of the elements were not significantly influenced by the cultivars (Tables 1 and 2). The N, K, and Zn levels of 'Silverhill' leaves were just above the deficiency threshold while 'Clausellina' leaves were deficient in Mg content on average. The levels of other elements were in the optimum range.

The effects of rootstocks on leaf nutrients content were significant. The N, K, and Mg levels of mandarin leaves were deficient or just above deficiency threshold on common sour orange. Whereas nutrient levels of mandarin leaves budded on 'Troyer' and 'Carrizo' citranges were in the optimum range, but Zn was deficient on 'Troyer' citrange (Tables 1 and 2).

Cultivar/rootstock interactions were significantly affected leaf nutrient levels besides Zn content. Nitrogen content of cultivars budded on common sour orange was under or just above the deficiency threshold. 'Carrizo' citrange-scion interactions for all three cultivars allowed to uptake and accumulate more N in leaves (Table 1).

Phosphorus levels of the cultivars leaves were in the optimum range for all of the rootstocks but 'Silverhill'/common sour orange interaction was very close to the deficiency threshold.

Among the nine combinations 'Clausellina'/'Troyer' citrange combination had the maximum leaf K content ($1.35 \pm 0.015\%$) whereas 'Silverhill'/common sour orange combination yielded the minimum ($0.98 \pm 0.03\%$) level around the deficiency threshold. For leaf Ca content of cultivar/rootstock combinations, cultivars budded on common sour orange was superior than the other combinations; whereas the Ca uptake by 'Silverhill'/'Carrizo' citrange combination was minimum (Table 1). However, recorded Ca levels were well in the optimum range for all combinations. Magnesium levels of cultivar leaves budded on common sour orange was under the deficiency threshold whereas cultivar/'Carrizo' citrange interactions had better Mg uptake (Table 1). Sodium content of leaves was well within the optimum range and was likely to have no adverse effects related to toxicity (Table 2).

Iron, manganese, and copper levels of the cultivar/rootstock combinations were well within the optimum range despite weaker performances of cultivar/common sour orange combinations (Table 2). There were Zn

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TABLE 1 The effect of cultivar, rootstock and scion-rootstock combinations on mineral composition of mandarin leaf (N, P, K, Ca, Mg)

	N (%)		P (%)		K (%)		Ca (%)		Mg (%)	
Source	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Cultivars										
'Silverhill'	2.22 b	2.37	0.143 b	0.155	1.11 b	1.16 b	4.76	4.65	0.34	0.35
'Okitsu'	2.31 ab	2.41	0.161 a	0.169	1.14 b	1.20 ab	5.10	4.97	0.33	0.35
'Clausellina'	2.36 a	2.42	0.146 ab	0.161	1.27 a	1.30 a	4.87	4.80	0.30	0.31
$LSD_{0.05}$	0.13	N.S.	0.015	N.S.	0.11	0.12	N.S.	N.S.	N.S.	N.S.
Rootstocks										
Common sour orange	2.13 b	2.26 b	0.136 b	0.147 b	1.05 b	1.11 b	5.45 a	5.38 a	0.27 c	0.28 b
Troyer citrange	2.34 a	2.42 a	0.162 a	0.173 a	1.26 a	1.30 a	4.71 b	4.55 b	0.33 b	0.35 a
Carrizo citrange	2.42 a	2.51 a	0.152 ab	0.164 ab	1.21 a	1.25 a	4.57 b	4.50 b	0.36 a	0.37 a
$LSD_{0.05}$	0.11	0.10	0.017	0.018	0.09	0.10	0.21	0.18	0.02	0.03
Scion-rootstock comb.										
'Silverhill'/C. sour orange	1.99 c	2.17 c	0.124 b	0.132 b	0.95 c	1.01 c	5.34 a	5.27 a	0.28 cd	0.30 cd
'Silverhill'/Troyer citrange	2.30 a	2.41 ab	0.158 ab	0.170 a	1.23 ab	1.27 a	4.52 cd	4.37 c	0.34 ab	0.36 ab
'Silverhill'/Carrizo citrange	2.38 a	2.53 a	0.148 ab	0.162 ab	1.16 b	1.19 ab	4.40 d	4.32 c	0.36 a	0.38 a
'Okitsu'/C. sour orange	2.11 bc	2.27 bc	0.150 ab	0.160 ab	1.02 c	1.07 bc	5.60 a	5.49 a	0.29 c	0.29 cd
'Okitsu'/Troyer citrange	2.38 a	2.46 ab	0.168 a	0.178 a	1.22 ab	1.27 a	4.96 b	4.71 b	0.34 ab	0.36 ab
'Okitsu'/Carrizo citrange	2.45 a	2.51 a	0.164 a	0.170 a	1.19 b	1.25 a	4.76 bc	4.70 b	0.37 a	0.38 a
'Clausellina'/C. sour orange	2.29 ab	2.36 a-c	0.134 ab	0.150 ab	1.19 b	1.24 ab	5.42 a	5.38 a	0.24 d	0.26 d
'Clausellina'/Troyer citrange	2.35 a	2.39 ab	0.160 a	0.172 a	1.33 a	1.36 a	4.66 b-d	4.56 c	0.31 bc	0.33 bc
'Clausellina'/Carrizo citrange	2.44 a	2.50 a	0.144 ab	0.160 ab	1.27 ab	1.32 a	4.54 cd	4.46 c	0.34 ab	0.35 ab
$LSD_{0.05}$	0.18	0.20	0.035	0.037	0.12	0.16	0.30	0.25	0.04	0.04
Optimum range*	2.20–2.70		0.12–0.18		1.00–1.70		3.00–6.00		0.30–0.60	

*According to Marchal, 1987; N.S.: Not significant at $P = 0.05$.

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TABLE 2 The effect of cultivar, rootstock and scion-rootstock combinations on mineral composition of mandarin leaf (Na, Fe, Mn, Zn, Cu)

	Na (%)		Fe (mg kg^{-1})		Mn (mg kg^{-1})		Zn (mg kg^{-1})		Cu (mg kg^{-1})	
Source	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
Cultivars										
'Silverhill'	0.113 a	0.118	79.5	83.1	52.5	56.1	25.3	25.9	8.7 b	9.3 b
'Okitsu'	0.111 ab	0.115	82.1	88.0	56.7	60.5	26.7	28.0	10.7 a	10.6 b
'Clausellina'	0.100 b	0.110	83.0	89.3	55.4	58.8	26.9	26.4	11.9 a	13.1 a
$LSD_{0.05}$	0.012	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	1.76	1.83
Rootstocks										
Common sour orange	0.117 a	0.124 a	75.9 b	81.5 b	49.1 b	52.5 b	27.9 a	28.2	9.1 b	9.5 b
Troyer citrange	0.106 ab	0.108 b	86.7 a	91.5 a	56.5 ab	60.3 a	24.9 b	25.7	10.5 ab	11.2 ab
Carrizo citrange	0.101 b	0.111 ab	82.0 ab	87.4 ab	59.1 a	62.7 a	26.1 ab	26.4	11.7 a	12.3 a
$LSD_{0.05}$	0.012	0.015	7.03	7.49	8.32	6.75	2.42	N.S.	1.99	2.17
Scion-rootstock comb.										
'Silverhill'/C. sour orange	0.124 a	0.130 a	74.6 b	78.0 b	48.2	50.8 b	26.6	27.0	7.2 c	8.0 e
'Silverhill'/Troyer citrange	0.114 ab	0.114 ab	85.2 ab	86.6 ab	52.0	58.4 ab	23.8	24.6	8.8 bc	9.2 c-e
'Silverhill'/Carrizo citrange	0.102 ab	0.110 ab	78.6 ab	84.6 ab	57.2	59.2 ab	25.6	26.0	10.0 a-c	10.8 b-d
'Okitsu'/C. sour orange	0.116 ab	0.126 ab	76.4 ab	80.4 ab	50.2	54.8 ab	28.2	29.6	9.2 bc	8.8 de
'Okitsu'/Troyer citrange	0.108 ab	0.100 b	86.0 ab	93.8 a	57.2	58.8 ab	25.0	27.2	10.6 ab	11.4 b-d
'Okitsu'/Carrizo citrange	0.108 ab	0.118 ab	84.0 ab	89.8 ab	62.8	68.0 a	26.8	27.2	12.4 a	11.6 bc
'Clausellina'/C. sour orange	0.110 ab	0.116 ab	76.8 ab	86.2 ab	48.8	51.8 b	29.0	28.0	10.8 ab	11.6 bc
'Clausellina'/Troyer citrange	0.096 b	0.110 ab	88.8 a	94.0 a	60.2	63.6 ab	26.0	25.2	12.2 a	13.0 ab
'Clausellina'/Carrizo citrange	0.094 b	0.104 ab	83.4 ab	87.8 ab	57.2	61.0 ab	25.8	26.0	12.8 a	14.6 a
$LSD_{0.05}$	0.027	0.026	13.48	15.70	N.S.	14.18	N.S.	N.S.	2.84	2.78
Optimum range*	0.01–0.15		60–150		25–100		25–100		5.10–15.0	

*According to Marchal, 1987; N.S.: Not significant at $P = 0.05$.

deficiency problems for cultivars budded on 'Carrizo' and 'Troyer' citranges. Cultivar/common sour orange combinations performed better, but the statistical difference among different combination was not significant.

DISCUSSION

The leaf N levels of mandarin cultivars on 'Carrizo' citrange were higher than the other rootstocks. Nitrogen plays a critical role in the growth performance of citrus trees as all other plants. Many researchers have reported that the effect of rootstocks on N uptake by Satsuma (Kaplankıran et al., 1996) and Clementine (Georgiou, 2002) mandarins was not significant; whereas Fallahi and Rodney (1992) for Fairchild mandarin, Kaplankıran et al. (1995) for Clementine and Fremont, Georgiou (2002) for Nova, Tsakelidou et al. (2002) for Clementine mandarin have found that these mandarin cultivars on 'Carrizo' and 'Troyer' citranges uptake significantly higher N in comparison to sour orange as in this study. Wutscher (1989) listed the sour orange among the rootstocks with low nitrogen uptake ability. The N levels of different mandarin leaves were optimum (2.20–2.70%) on 'Carrizo' and 'Troyer' citranges but deficient for 'Silverhill' and 'Okitsu' cultivars on common sour orange. A survey study has revealed that majority of the citrus orchards in the eastern Mediterranean region were deficient in N (Tuzcu et al., 1981). Georgiou (2000, 2002) for Nova and Clementine, respectively, and Smith et al. (2004) for Ellendale mandarin have reported that the N levels were below or around the deficiency threshold. Similar low nitrogen levels found in this study could be related to coarse texture of the soil. In addition, nitrogen can easily undergo leaching, denitrification, fixation, and volatilization reactions depending on soil conditions and thus only 22–69% of fertilizer nitrogen may be used by citrus (Syvertsen and Smith, 1995). This rate is subjected to a drastic decrease with increasing precipitation and irrigation in coarse textured soils and thus, nutrient loss-induced deficiency of nitrogen are common (Davies and Albrigo, 1994; Alva et al., 2006).

The leaf P contents of all scion/rootstock combinations were in optimum limits (0.12–0.18%). However, P level of Silverhill/common sour orange combination was just about the deficiency threshold. There are conflicting reports about the effect of rootstocks on P level of leaves for example Kaplankıran et al. (1995), Georgiou (2002) reported no significant effect while Kaplankıran et al. (1996), Georgiou (2000), and Tsakelidou et al. (2002) reported that 'Troyer' and 'Carrizo' citranges were superior on the sour orange on P uptake as in this study. Indeed sour orange and 'Troyer' citrange were listed in rootstocks with low P uptake ability (Wutscher, 1989). However, 'Troyer' citrange performed better than common sour orange in this study. The density of surface root system (0–30 cm) is very critical for P uptake because P is an immobile element in the soil profile and usually has

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a tendency to accumulate in the surface horizon. Therefore low level of P for mandarins budded on the sour orange could be related to, some extent, smaller amount of nutritional root system in the surface horizon (Tuzcu et al., 1997).

Potassium levels of 'Silverhill' and 'Okitsu' mandarins on common sour orange were about the deficiency threshold whereas other combination showed a level well in the optimum range (1.00–1.70%). Results of Georgiou (2002) and Smith et al. (2004) for different scion/rootstock combinations the K content of leaves were in the optimum range but Kaplankıran et al. (1996), Georgiou (2000), and Tsakelidou et al. (2002) determined values under deficiency threshold for certain combinations. 'Troyer' citrange was superior on the other used rootstocks in K uptake and translocation to scion. 'Troyer' (Kaplankıran et al., 1996) and 'Carrizo' citranges (Fallahi and Rodney, 1992; Kaplankıran et al., 1995; Georgiou, 2000) were reported to be better rootstocks for different mandarin cultivars in K nutrition as in this study. On the other hand, Georgiou (2002) and Smith et al. (2004) did not find any considerable effect of rootstocks on K content of leaves. The reason for such differences could be scion/rootstock interaction and soil and climate related ecological factors (Davies and Albrigo, 1994).

Calcium content of leaves for all used scion/rootstocks combination was in optimum range (3.00–6.00%). The reason for this is high carbonate content of arid region soils. Similar to this study, there were no differences among rootstocks to supply the optimum range of Ca but sour orange was reported to have better ability in Ca uptake (Kaplankıran et al., 1995, 1996; Georgiou, 2000, 2002; Tsakelidou et al., 2002; Smith et al., 2004). In contrast to Ca uptake, common sour orange was not able to supply optimum range of Mg (0.30–0.60%) but it was well above the deficiency level for 'Troyer' and 'Carrizo' citranges. The effect of scion/rootstock combination was reported to be significant by the same researchers given above. Their findings are well in agreement with our results.

Sodium is common exchangeable cation of arid and semi arid regions' soils, thus Na content are in the optimum range for all cultivar/rootstocks combination which are in agreement with the results of Georgiou (2000, 2002). Sodium contents of leaves were comparatively higher than those reported by Kaplankıran et al. (1995, 1996). However Smith et al. (2004) determined Na content above the optimum limit depending on the irrigation water quality. Citrus orchards of eastern Mediterranean region have excessive Na (Tuzcu et al., 1981). In this study we did not determine excessive Na due to coarse texture and irrigation that both enable to leach away Na from the root zone. Maximum Na uptake was induced by common sour orange and the others showed similar effect. There are conflicting results in the literature on the effects of rootstocks on Na uptake that some reports no effect of rootstocks (Kaplankıran et al., 1996; Georgiou, 2000, 2002) and

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the other as in this study sour orange significantly increased Na uptake in comparison to other rootstocks (Kaplankıran et al., 1995).

Iron content of leaf was affected by cultivar/rootstock combinations, for example 'Clausellina'/'Troyer' citrange yielded the maximum whereas 'Siverhill'/common sour orange the minimum. Studies of Kaplankıran et al. (1996) and Georgiou (2000, 2002) showed that there were no effects of rootstocks on Fe uptake in contrast; Pestana et al. (2005) reported that 'Troyer' citrange was the most tolerant rootstock to Fe deficiency. Kaplankıran et al. (1995) determined in another study that 'Troyer' and 'Carrizo' citranges uptake more Fe. Iron levels in this study were in the optimum range; however, leaf analysis is not always useful for diagnosing Fe deficiency because the inconsistency of leaf Fe levels in separating chlorotic from non-chlorotic leaves (Marschner, 1995).

Manganese contents of cultivar/rootstock combinations were in the optimum range (25-100 mg kg^{-1}). 'Okitsu'/'Carrizo' interaction yielded maximum Mn uptake while 'Silverhill' and Clausellina/common sour orange combinations uptake the minimum Mn. In contrast to our results, 'Troyer' and 'Carrizo' citranges were reported to uptake smaller amounts of Mn (Tsakelidouetal., 2002; Smith et al., 2004) even under deficiency threshold (Tsakelidouetal., 2002); but Kaplankıran et al. (1995) and Georgiou (2002) determined a superiority of 'Carrizo' citrange over the others as in this study.

Besides 'Silverhill'/'Troyer' combination, Zn contents were just above the deficiency threshold (25 mg kg^{-1}). Zinc nutritional status of eastern Mediterranean region was reported "deficient" due to high carbonate content and pH of soils (Tuzcu et al., 1981). Sour orange enhanced the Zn nutrition of mandarins regarding to 'Carrizo' and 'Troyer' citranges. Our findings are in good agreement with those reported by Georgiou (2000, 2002) and Tsakelidou et al. (2002). In contrast, Kaplankıran et al. (1995, 1996) determined no significant effect of rootstocks on Zn uptake. These conflictions may be related to soil properties such as available Zn, soil pH, carbonate, Fe oxide, clay content, and other environmental factors.

As in this study, copper levels of leaves were generally in the optimum range (5.1–15 mg kg^{-1}) because Cu containing fungicides are frequently used in the citrus orchards (Kaplankıran et al., 1996; Georgiou, 2000, 2002; Smith et al., 2004). Despite coarse soil texture that can induce Cu deficiency; Cu contents of leaves were in the optimum range that can be attributed to usage of Cu-rich fungicides. Thus, the true effect of scion/rootstock interactions was shadowed; however, maximum Cu level was observed for 'Carrizo' citrange and the minimum for common sour orange. Similarly, Kaplankıran et al. (1996) and Georgiou (2000) suggested 'Carrizo' citrange whereas Georgiou (2002) 'Troyer' citrange for a better rootstock inducing Cu nutrition.

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A better yield and fruit quality of scion /rootstock combinations with the high ability to uptake essential nutrient elements is expected. Comparatively higher amounts of the essential nutrient elements of 'Okitsu', 'Clausellina' and 'Silverhill' budded on the 'Carrizo' citrange is an indication of the higher yield and yield quality which was in agreement with the results of Kaplankıran et al. (1999) who reported higher N, K, Fe, and Mn uptake ability of rootstocks enhanced fruits quality parameters. Kaplankıran et al. (2008) have reported that all of the three cultivars have resulted in maximum yield on 'Carrizo' citrange for the same experimental field and years, which is in good agreement with the presented results.

It can be concluded that there are considerable differences in nutrient uptake ability of rootstocks. For example 'Carrizo' citrange was performed better for N, Mg, Mn, and Cu uptake; 'Troyer' citrange for P, K, and Fe; and common sour orange for Ca, Zn, and Na. Therefore, by considering such differences in nutrient uptake, rootstock selection is as critical as cultivar selection and ecological conditions for a balanced, environmentally friendly and economically feasible fertilization program. The overall performance of 'Carrizo' and 'Troyer' citranges were better than the common sour orange in uptake of essential nutrient elements critical for yield and yield quality and other performance criteria such as vegetative growth, bud/rootstock interaction. Therefore, 'Carrizo' and, to a lesser extent, 'Troyer' citranges could be used as appropriate rootstocks for this region and regions with similar ecological conditions.

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