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Potential of Mineral Uptake Efficiency by Some Apple Rootstocks

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Introduction

High density apple orchards need appropriate nutritional management. Use of high nutrient efficiency rootstocks minimize the need for chemical fertilizers and can affect fruit yield and quality (Fallahi et al., 1985). One of the theories on rootstock mechanisms is that the rootstock brings about its effect on the scion by influencing the amount of minerals taken up and translocated through the tree (Olien and Lakso, 1984; Higgs and Jones, 1991). Different rootstocks have different mineral uptake efficiencies throughout the season (Poling and Oberly, 1979; Sharma and Chauhan, 1991; Tagliavini et al., 1992, Aguirre et al., 2001). For example, some rootstocks have been rated as tolerant to salinity due to their ability to prevent Na^+ and/or Cl^- uptake or Ca-uptake and translocation to aerial parts of the plant (fruits). Fallahi et al., (2001) reported on significant differences in mineral uptake in apple orchards with the same scion on rootstocks of different degrees of vigor.

Amiri et al., (2008) reported visual symptoms of K, Fe, and Mg deficiencies during the growing season of apple trees. One of possible cause of mineral deficiencies is the low rate of mineral uptake by some dwarfing rootstocks (Aguirre et al., 2001). Several researchers have shown that scion leaves of trees on more vigorous rootstocks have higher mineral (K, Mg) content than those on size-controlling rootstocks. Marini et al., (2002) found inconsistent effects of rootstock on plant tissue mineral concentration across different production areas. Abdalla et al., (1982) reported that 'Golden Delicious' apple trees on dwarfing rootstocks had more yield efficiency and higher leaf Mn but lower leaf K than trees on vigorous rootstocks. Ferree and Barden, (1971) declared trees grafted on local seedling are less likely to show Ca or K deficiency than MM106 rootstock. Aguirre1 et al., (2001) reported trees grafted on M.9 rootstock were more efficient at N uptake regardless of the season of N application, whereas, seedling rootstocks were more efficient at K uptake. It has been found that M.7 EMLA rootstock decreased leaf K content (Fallahi et al., 1984).

Hierit and Flower, (2000) found no effect of rootstock on scion growth rate or final fruit size of Gala apples. However, the effect of most rootstock studies was not consistence from site to site and varied over time (Autio et al., 1991; Autio et al., 2003). To evaluate the full commercial potential of a particular apple rootstock it is important to take into account other source of variability and to evaluate rootstock effect on scion growth for specific regions or cultivars (Autio and Southwick, 1993). Many rootstocks are used for adaptability to different environmental conditions. How rootstocks bring about their effects on mineral use efficiency is still not understood. This research describes and discusses the potential of mineral uptake by 'Red Gala' and 'Golden Delicious' grafted on four different rootstocks (M.9, MM.106, MM.111, and seedling), and thus the effects on fruit and leaf mineral composition.

Materials and Methods

The project was conducted in Zanjan province, Zanjan, Iran and data were collected over three years (2006–2008). 'Golden Delicious' and 'Red Gala' scion cultivars grafted on four rootstocks: Malling M.9 (M9-EMLA), Malling Merton MM106, (the semi-invigorating), MM111 (Northern Spy _ Merton 793), and seedling (*Malus domestica* Borkh cv. local) were planted in a randomized complete block/split plot design, with scion cultivar as the whole plot and rootstock as the split plot. Five replications were used for each treatment. Rootstock was analyzed as the main effect, and cultivar as the sub-factor. The orchard was established in a sandy loam. The physical and chemical characteristics of the soil were clay 12%, silt 15% and sand 73%, with low level of organic matter (0.6%), pH 7.3 (in 1M KCl), and optimum concentrations of available P (80 mg kg^{-1}), K (160 mg kg^{-1}), and Mg (50 mg kg^{-1}) in the top soil layer (0–30 cm). Irrigation of the orchard was carried out using a drip irrigation system. Irrigation frequency was two times per week (irrigation amounts for M9 were reduced by 20%). All treated trees were similarly fertigated with essential minerals in accordance with traditional local standards (soil mineral nutrient analyses). Trees were trained to a modified-center system and planting distances for the different rootstocks reflected the anticipated vigor of the trees, so that orchard area per tree was least for the dwarfing rootstock (M9) and increased for MM106, and MM111, and seedling.

In each year of the study, four trees of each cultivar per rootstock were identified. Samples of 10 leaflets from the mid-section of current year shoots and 40 fruits at harvest time (2nd to 5th October) were collected. Leaves were washed with a mild detergent, then rinsed with distilled water and dried in a forced air drying oven at 70°C to constant weight. Leaves were ground to pass a 40 mesh screen. One g of dried ground leaf sample dry ashed at 550°C for 5 h. The ash was then dissolved in 5 ml of 20% HCl. These samples were analyzed for P, K, Mg Ca, Fe, Zn and Zn by atomic absorption spectrophotometer (Perkin-Elmer 1100 B, Norwalk, CT). Nitrogen (N) concentration of each sample was measured by leaf tissue combustion, using LECO (FP-528, LECO Corp., St. Joseph, MI). In this process, about 0.185 g of dried leaf tissue of each sample was combusted, and total N (expressed as percentage of dry weight) was measured. Fruit mineral content was measured based on fresh weight.

Yield efficiency (kg tree^{-1} m^{-3}) was calculated annually on each treatment. Although yield efficiency can be expressed as yield (by fruit weight) per trunk cross-sectional area (CSA), for this experiment it was calculated as: yield (kg tree^{-1}) per crown volume (m^{3}). This is often of more interest to physiologists (Robinson and Lakso, 1991). Parameters were recorded annually and are presented as the mean of three years. All data of three years were analyzed using SAS statistical software using least significant differences (LSD, $p = 0.05$).

Results

There were significant differences in foliar and fruit concentrations (%DW) of N, K, Mg, Ca, Fe, Mn and Zn of both cultivars ‘Golden Delicious’ and ‘Red Gala’. Cultivars grafted on M.9 had higher leaf N, Mg, Fe, Mn concentrations than other rootstocks (Table 1). Cultivars grafted on MM.106 rootstock accumulated the highest P concentration in their leaves (Table 1). Cultivars grafted on seedling rootstock had significantly higher K concentrations in leaves and fruits, compared to other rootstocks. Golden fruits had more K than Gala fruits (Tables 1&2).

The least concentrations of microelements (Fe and Zn) in leaves were recorded in the seedling rootstock (Table 1). Rootstock also significantly affected the N/Ca ratio of fruits, which was highest in the dwarfing rootstock (M.9), and lowest in the seedling rootstock (Table 2). There was no significant difference among treatments for N concentrations in apple fruits (Table 2). Ratios of N/Ca, K/Ca and (Mg+K)/Ca in fruits were influenced by rootstock. The ratio N/Ca, K/Ca, and (Mg+K/Ca) were within optimum ranges for storage (Table 2).

The concentration of individual nutrients is primarily affected by the rate of uptake by specific rootstocks. The highest yield efficiency (6.5 kg m^{-3}) was recorded on Golden Delicious/M9 trees, whereas, the lowest (4.8 kg m^{-3}) on Red Gala/seedling trees (Table 2).

Discussion

This study found significant differences in the mineral concentrations of leaves and fruits of ‘Red Gala’ and ‘Golden Delicious’ apple trees grafted on M9, MM106, MM111, and seedling rootstocks (Tables 1&2). Other workers in different conditions have also reported significant rootstock effects on mineral uptake and fruit quality (Ferree and Barden, 1971; Abdalla et al., 1982; Sharma and Chauhan, 1991; Tagliavini et al., 1992; Aguirre et al., 2001; Fallahi et al., 2001). Dong et al. (1998) also observed higher N uptake in M.9 EMLA rootstocks. Tolerant rootstock (i.e. M.9) to some mineral deficiencies (N, Fe, and Mn) suggests that leaf mineral concentrations of grafted plants was higher than other rootstocks (Dong et al., 1998). The higher mineral concentration in leaf blades may have resulted from greater uptake by roots and rapid transport from root system (xylem) to leaves (Fallahi et al., 1984). It can be inferred that M.9 rootstock differs greatly in it's mineral uptake and it's ability to transport mineral nutrients. On the other hand, it can be said the lower mineral consumption due to a lower rate of growth and yield suggest that M.9 rootstock may be able to accumulate and to maintain high concentration of minerals in leaves.

Among the rootstocks, significant differences in Ca, and K concentrations were found in leaves and fruits, independent of the cultivar. Other scientists reported that rootstock significantly affected Ca and K concentrations of apple (Abdalla et al., 1982), also reported that some dwarf (M.9) rootstock is rated as sensitive to Ca and K deficiencies, which is in agreement with our result (Dong et al., 1998), while seedling and MM. 111, were less sensitive to them (Aguirre et al., 2001). The opposite behavior was recorded for Mg absorption by these rootstocks probably due to an antagonistic effect between K and Mg (Table 1). The effect of rootstock on leaf P concentration was independent of cultivar. Although, soil in which apple trees are grown is characterized by high pH (7.3), carbonate content and low organic matter (0.6%), the levels of Ca, and K in the leaves in both cultivars were not higher than the threshold level. The threshold K (%1.30 to 1.60) and Ca (%1.20 to 1.50) levels for deficiency or toxicity appear to be in mid summer (Amiri and Fallahi, 2008).

Rootstock selection can be a useful management tool in poor soils (Kennedy et al., 1980). The importance of the rootstock in regulating plant water relation and transport was discussed by Sinclair (1984), who noted that trees on rough lemon and *P. trifoliate* had higher transpiration rates than those on 'Cleopatra' mandarin and sour orange rootstock. Therefore, water relations and mineral nutrients uptake and transport could also be altered in rootstock × scion combinations, in both normal and saline condition (Syvertsen and Graham, 1985). Specific mechanism may exist for mineral uptake similar to those reported by (Zhang et al., 1991).

Many of the rootstocks are used for adaptability to different environmental conditions (Carlson, 1967; Atkinson, 1999). How rootstocks bring about their effects on mineral use efficiency is still not understood. Differences in mineral leaf concentrations among different rootstocks (M.9, MM.106, MM.111, and seedling) may be attributable to the differences in mineral uptake and growth rate, mainly in the pathway from soil to stem. This suggests that the hydraulic conductivities of the xylem rootstocks may not be similar. Early work on xylem anatomy of apple (*Malus domestica* Borkh.) rootstocks led to the conclusion that xylem anatomy influences the rate of mineral uptake (Hussein and McFarland, 1994). The ability of the hydraulic conductance to supply mineral solution (raw saps) through roots, stems to the leaves (Atkinson et al., 1999) is related to anatomical characteristics of rootstock. Lower rates of mineral uptake will lead to decreased plant tissue mineral concentrations and may lead to mineral deficiency. In many cases, reduced hydraulic conductance will also reduce the rate of mineral uptake and growth (and perhaps yield) potential, and this has been suggested as a possible mechanism for dwarfing (M.9) of apple trees by rootstocks (Higgs and Jones, 1991).

Rootstock effects on nutritional status may be explained as differences in root distribution and root functions may affect mineral uptake efficiencies and possible differences in root and stem anatomy that affect the rate of mineral uptake and movement into the xylem and leaves (Jones, 1986). The observed differences in the rates of translocation of nutrients between roots and scions in trees, may be attributable to the ability of the rootstock's root system to take up minerals (Higgs and Jones, 1991).

References

Abdalla, O.A., H. Khatamian, and N.W. Miles. 1982. Effect of Rootstocks and Interstems on Composition of 'Delicious' Apple Leaves. *J. Am. Soc. Hort. Sci.* 107:730-733.

Aguirre, P.B., Y.K. Al-Hinai, T.R. Roper, and A.R. Krueger. 2001. Apple tree rootstock and fertilizer application timing affect nitrogen uptake. *HortScience* 36(7):1202–1205.

Amiri M.E. and E. Fallahi. 2009. Impact of Animal Manure on Soil Chemistry, Mineral Nutrients, Yield, and Fruit Quality in 'Golden Delicious' Apple. *Journal of Plant Nutrition* 32: 610 – 617.

Amiri M.E., E. Fallahi and A. Golchin. 2008. Influence of Foliar and Ground Fertilization on Yield, Fruit Quality, and Soil, Leaf, and Fruit Mineral Nutrients in Apple. *Journal of Plant Nutrition* 31:365-370.

Atkinson, A. J., M. Policarpo, A. D. Webster, and A. M. Kuden. 1999. Drought tolerance of apple rootstocks: Production and partitioning of dry Matter. *Plant and Soil* 206: 223–235.

Autio, W. R. and F. W. Southwick. 1993. Evaluation of a spur and standard strain of 'McIntosh' on three rootstocks and one dwarfing interstem over ten years. *Fruit Var. J.* 47:95-102.

Autio, W. R., J. A. Barden, and G. R. Brown. 1991. Rootstock affects ripening, size, mineral composition, and storability of 'Starkspur Supreme Delicious' in the 1980-81 NC-140 Cooperative Planting. *Fruit Var. J.* 45:247-251.

Autio, W.R., J.R., Schupp, C.G. Embree, and R.E. Moran. 2003. Early performance of 'Cortland', 'Macoun', 'McIntoch', and 'Pioneer Mac' apple tree on various rootstocks in Maine, Massachusetts, and Nova Scotia. *J. Amer. Pomol. Soc.* 57:7-14.

Carlson R. F. 1967 Growth response of several rootstocks to soil water. *HortScience* 2:109-110.

Dong, S., L. Cheng, and L.H. Fuchigami. 1998. Nutrient uptake by new roots of six clonal apple rootstocks. *HortScience* 34:492-493.

Fallahi, E., I. Jo. Chun, G. H. Neilsen, and W.C. Michael. 2001. Effects of three rootstocks on photosynthesis, leaf mineral nutrition, and vegetative growth of "Bc-2 Fuji" apple trees. *Journal of Plant Nutrition* 24(6): 827-834.

Fallahi, E., D. G. Richardson, and M. N. Westwood. 1985. Quality of apple fruit from a high-density orchard as influenced by rootstocks, fertilizers, maturity, and storage. *J. Am. Soc. Hort. Sci.* 110(1):71–74.

Fallahi, E., M. N. Westwood, M. H. Chaplin, and D. G. Richardson. 1984. Influence of apple rootstocks, K and N fertilizers on apple leaf mineral composition and yield. *Journal of Plant Nutrition* 7(8):1161–1177.

Ferree, M. E. and J. A. Barden. 1971. The Influence of Strains and Rootstocks on Photosynthesis, Respiration, and Morphology of 'Delicious' Apple Trees. *J. Am. Soc. Hort. Sci.* 96(4):453-457.

Higgs, K. H. and H. G. Jones. 1991. Water relations and cropping of apple cultivars on a dwarfing rootstock in response to imposed drought. *Journal of Horticultural Science* 66:367-379.

Hierit, P.M. and R.R. Flowers. 2000. Rootstock effects on growth and cell size of 'Gala' apple fruit. *Acta Horiculture* 517: 189-194.

Hussein, I. A. and M.J. McFarland. 1994. Rootstock-induced differences in sap flow of ‘Granny Smith’ apple. *HortScience* 29: 1120-1123.

Jones, O. P. 1986. Endogenous growth regulators and rootstock/scion interactions in apple and cherry trees. *Acta Horticulture 179:* 177-183.

Kennedy, A. J., R. W. Rowe, and T. J. Samuelson. 1980. The Effects of Apple Rootstock Genotypes on Mineral Content of Scion Leaves. *Euphytica* 29:477-482.

Marini, R.P., J.A., Barden, J.A. Cline, R.L. Perry, and T. Robinson. 2002. Effect of apple rootstocks on average 'Gala' fruit weight at four locations after adjusting for crop load. *J. Am. Soc. Hort. Sci.* 127:749-753.

Olien W.C. and A.N. Lakso. 1984. A. comparison of the dwarfing character and water relations of five apple rootstocks. *Acta Horticulture* 146:151-158.

Poling, E. B. and G. H. Oberly. 1979. Effect of Rootstocks on Mineral Composition of Apple Leaves. *J. Am. Soc. Hort. Sci.* 104:799-801.

Robinson, T. L. and A. N. Lakso. 1991. Bases of yield and production efficiency in apple orchard systems. *J. Am. Soc. Hort. Sci. 116:* 188-194.

Sinclair, W.B., 1984. The biochemistry and physiology of the lemon and other citrus fruits. University of California, Division of Agriculture and Natural Resources. USA, pp: 51-56.

Sharma, D. D. and J. S. Chauhan. 1991. Effects of Different Rootstocks and Training Systems on the Mineral Composition of 'Delicious' Apple Leaves. *Journal of Horticultural Science* 66:703-707.

Syvertsen, J.P. and J.H. Graham, 1985. Hydraulic conductivity of roots, mineral nutrition and leaf gas exchange of citrus rootstocks. *J. Am. Soc. Hortic. Sci.*, 110: 865-869.

Tagliavini, M., D.Scudellari, B. Marangoni, A. Bastianel, F. Franzin and M. Zamborlini. 1992. Leaf mineral compostion of apple tree: Sampling date and effects of cultivar and rootstock. *Journal of Plant Nutrition* 15:605-619.

Zhang, F., V. Rohmheld and N. Marschner, 1991. Release of Zink mobilizing root exudates in different plant species as affected by zinc nutritional status. *J. Plant Nutrition* 14: 675-686.

Table 1

Effect of rootstock on leaf mineral concentration (% DW) of apple scions 'Golden Delicious' and 'Red Gala' grown on M9, MM106, MM111, and seedling rootstocks in the region of Zanjan, Iran*.

Treatments	**N %**	**P %**	**K %**	**Ca %**	**Mg %**	**Zn ppm**	**Fe ppm**	**Mn ppm**	**Cu ppm**
Gala/M9	1.87	0.37	1.30	1.30	0.64	48	125	75	28
Gala/MM106	1.69	0.46	1.31	1.38	0.48	43	110	74	27
Gala/MM111	1.54	0.39	1.42	1.42	0.43	40	113	49	28
Gala/Seedling	1.52	0.40	1.48	1.45	0.40	42	108	70	27
Golden/M9	1.95	0.40	1.43	1.25	0.59	52	142	72	28
Golden /MM106	1.89	0.44	1.46	1.22	0.53	48	134	71	30
Golden /MM111	1.67	0.38	1.40	1.39	0.45	52	115	72	30
Golden /Seedling	1.45	0.41	1.55	1.46	0.38	49	104	74	32
LSD$_{0.5}$	0.30	0.06	0.17	0.28	0.15	6.2	8.5	3.4	1.8

Data presented are the mean of three years; LSD at $p \leq 0.05$.

Table 2

Effect of rootstock on mineral concentration of apple fruit (%DW) of ‘Golden Delicious’ and ‘Red Gala’ cultivars grown on M9, MM106, MM111, and seedling rootstocks in the region of Zanjan, Iran*.

Treatments	N	Ca	Mg	K	P	N/Ca	K/Ca	(Mg+K) /Ca	Yield ef[a].
	(mg kg^{-1} fresh weight)								kg tree^{-1} m^{-3}
Gala/M9	560	50	45	1280	105	11.20	25.60	26.50	6.1
Gala/MM106	538	48	52	1375	118	11.17	28.65	29.73	5.8
Gala/MM111	497	55	56	1453	104	9.30	23.06	23.95	5.2
Gala/Seedling	475	67	67	1560	98	7.10	26.55	27.57	4.8
Golden/M9	580	51	52	1354	116	11.37	26.55	27.57	6.5
Golden /MM106	545	55	58	1480	120	9.91	26.91	27.96	5.9
Golden /MM111	488	61	62	1524	110	8.00	25.08	26.00	5.5
Golden /Seedling	470	66	69	1618	102	7.12	24.52	25.56	5.4
LSD$_{0.1}$	86.5	10.2	9.5	72.5	15.1	2.8	2.40	4.50	1.08

Data presented are the mean of three years.

[a] Yield efficiency was calculated as: yield (kg tree^{-1}) per crown volume (m^3).