Performance of the apple (*Malus domestica* Borkh) cultivar Imperial Double Red Delicious grafted on five rootstocks

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ABSTRACT: The performance of the apple (*Malus domestica* Borkh) cultivar Imperial Double Red Delicious (Imperial D.R.D.) grafted on the following 5 rootstocks: (*i*) seedling, (*ii*) M 7, (*iii*) MM 104, (*iv*) MM 106, and (*v*) MM 109 was investigated. The highest yield per tree was recorded for trees on seedling rootstock, while the lowest for the cultivar grafted on M 7. Production efficiency of Imperial D.R.D. was higher when grafted on MM 106 and M 7, intermediate on seedling and MM 104, and the lowest on MM 109. The highest leaf photosynthetic rate (Pn) was measured for scions grafted on seedling although it was not significantly different from MM 109. Nitrogen concentrations of leaves of the cv. Imperial D.R.D. grafted on M 7 and MM 106 were significantly lower in comparison to the seedling variant. Flesh firmness at harvest, pH of juice at harvest, soluble solids content and titratable acidity at harvest and after four months of storage were not significantly different among the rootstocks.

Keywords: apple; fruit quality; mineral uptake; photosynthetic rate; production efficiency; rootstocks

Apple rootstocks vary in their adaptation to soil and climatic conditions (Anderson et al. 1984; Czynczyk, Holubowicz 1984), and resistance to diseases (Ferree et al. 1983). Furthermore, apple rootstocks affect tree size and vigor (Ferree, Carlson 1987), tree nutrition (Stylianidis et al. 2002), productivity and yield efficiency (Ferree 1980), photosynthetic rate (Schechter et al. 1991), and fruit size and quality (Daugaard, Callesen 2002). Rootstock usage and practices vary by country (Ferree, Carlson 1987). The use of seedlings as apple rootstocks has been abandoned in many countries of the world due to variability in tree size and performance. The rootstocks belonging to the Malling and Malling-Merton series are extensively used in many countries of Western Europe, and in other countries to a lesser extent as well. M 9, M 26, and MM 106 rootstocks were often used in Greece during the last twenty years for establishment of high-density apple orchards. However, other selections of the Malling and Malling-Merton series were also used but not widespread.

The aim of the present research was to study the performance of the cultivar Imperial Double Red Delicious grafted on five rootstocks in terms of yield, fruit weight, production efficiency, net photosynthetic rate, trunk growth, fruit quality parameters, and leaf mineral status of the trees.

MATERIALS AND METHODS

The scions of the apple (*Malus domestica* Borkh) cultivar (cv.) Imperial D.R.D. were grafted on the following rootstocks: (*i*) seedling, (*ii*) M 7, (*iii*) MM 104, (*iv*) MM 106, and (*v*) MM 109. The experimental trees were planted in 1985 and trained as a typical vase shape at distances 5 × 5 m apart. Trees were irrigated by means of microsprinklers. Annual fertilization per hectare consisted of 105 kg N, 32 kg P, and 85 kg K. Three composite soil samples, consisting of 5 subsamples, were collected around the trees from a depth of 50 cm. The soil samples were air dried, crushed to pass a 2-mm screen and analyzed for pH in a 1:1 soil to water ratio, electrical conductivity in a 1:5 soil to water extract, texture (hydrometer method), $CaCO_3$ with a volumetric calcimeter and organic matter content after wet oxidation (Page et al. 1982). The soil was silty clay loam in texture and had an average pH of 6.8, and electrical conductivity of 0.68 mmhos/cm. The free $CaCO_3$ and organic matter contents were 1.1% and 0.98%, respectively. Soil chemical analysis of the experimental orchard was (mg/kg of air dried soil):

12, P; 120, K; 372, Ca; 138, Mg; 24, Mn; 0.98, Zn; 9.59, Fe; and 0.25 mg B/L of saturation extract of the soil. Phosphorus was determined by the Olsen procedure, K after extraction with ammonium acetate, Ca and Mg volumetrically with 0.1N EDTA, while Fe, Mn and Zn with atomic absorption spectrometry after extraction with DTPA (Page et al. 1982). Boron was determined by the azomethine-H method in the saturation extract of the soils (Wolf 1971). Leaf samples were collected on July 15 (mid-summer) for two consecutive years (17th and 18th year of the tree age) and consisted of 50 leaves per sample. Leaves were collected from the middle of moderately vigorous shoots from each tree around the periphery, at shoulder height. Leaf samples were initially washed once with tap water and twice with distilled water. Then, they were dried in a forced draft oven at 68°C for 72 h and ground in a mill to pass a 30 mesh screen. Nitrogen was determined by the Kjeldahl's procedure, B by the azomethine-H method (Wolf 1971), P by the ammonium phosphovanadomolybdate method (Jackson 1969) and K, Ca, Mg, Fe, Mn and Zn by atomic absorption spectrophotometry. Trunk circumference was measured at a point 30 cm above soil level every year, but the presented data are values from the end of the 19th year of the tree age. Mean fruit weight and mean yield (kg/tree) are mean values of 3 years (from the 16th till the 18th year of the tree age). Production efficiency [kg/tree/trunk cross section (cm^2)] was also calculated by the end of the 18th year. Flesh firmness was measured by an Effegi penetrometer (11 mm tip) at harvest (141, 143 and 140 days after full bloom for 3 years). Soluble solids, titratable acidity and pH were determined using freshly prepared juice. Soluble solids content was measured using a digital, temperature-compensated refractometer (model PR-101, Atago Co) at harvest and after 4 months of storage under control atmosphere conditions. Titratable acidity was determined by titrating 10 ml juice with 1M KOH to pH 8.2 (Mitcham, Kader 1996) at harvest and after 4 months of storage. Pn was measured on 30 July for 2 years (17th and 18th year of the tree age), at full sunshine (1,590–1,840 μmol/m^2/s) from 11:00 to 13:00 h by using a portable infrared gas analyzer apparatus (LI-6200, LI-COR).

The experimental design was a randomized block with 4 replications of 5 treatments (rootstocks) and 4 trees per plot. Differences between means were evaluated by Duncan's multiple range test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Trunk circumference was highest when scions of the cv. Imperial D.R.D. were grafted on MM 109 rootstock and followed by seedling, while the lowest values were recorded on M 7 (Table 1). In comparison with the rootstock MM 106, Imperial D.R.D. grafted on M 7 had smaller trunk circumference. The results are in agreement with those of Barritt et al. (1996) who studied the performance of Delicious cv. grafted on several rootstocks. The ranking of rootstocks for trunk circumference in the present study was generally similar to earlier reports with a range of cultivars (Larsen, Fritts 1982; Granger et al. 1993). Apple rootstocks produce trees ranging from trees larger than those on seedling rootstocks (e.g., M 25), to 15 to 20% of the size of trees on seedling (e.g., M 27) (Ferree, Carlson 1987).

Rootstocks had a significant effect on yield, causing major differences with the scion cultivar Imperial D.R.D. (Table 1). The highest yield per tree was recorded for trees on seedling rootstock, while the lowest when the cultivar was grafted on M 7. Cumulative yield per tree generally increases as tree size increases when rootstocks vary in tree size from

Table 1. Trunk circumference, fruit weight, yield, production efficiency, and net photosynthetic rate of the apple cultivar Imperial Double Red Delicious grafted on five rootstocks

Rootstock	Trunk circumference (cm)	Fruit weight (g)	Mean yield (kg/tree)	Production efficiency (kg/tree/ trunk cross section cm^2)	Net photosynthetic rate (μmol CO_2/m^2/s)
Seedling	59.5 b*	186 c	177 a	1.3 b	20.9 a
M 7	41.5 e	207 a	75 e	2.0 a	18.1 c
MM 104	50.7 c	197 b	154 c	1.2 b	19.4 b
MM 106	45.2 d	208 a	87 d	2.1 a	18.5 bc
MM 109	62.7 a	192 bc	162 b	0.8 c	20.4 ab

*Means followed by the same letter in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

dwarfing, such as M 9, to semi-dwarfing, such as M 7 (Ferree et al. 1995). Production efficiency of Imperial D.R.D. was highest when grafted on MM 106 and M 7, intermediate on seedling and MM 104, and lowest on MM 109 (Table 1). The results are in agreement with those reported by Ferree et al. (1995) who concluded that higher yield efficiencies of the cvs. Redchief and Macspur were obtained by smaller trees. Other studies also found dwarfing trees to be more efficient than vigorous ones (Hirst, Ferree 1995; Ferree et al. 1998).

Rootstocks significantly affected mean fruit weight (Table 1). The highest mean fruit weight was measured when scions were grafted on less vigorous rootstocks such as M 7 and MM 106 and the lowest on seedling. Fruit weight of the cv. Smoothee (Ebel et al. 1999) grafted on M 7A, and MM 106 EMLA were not significantly different. Similar results were obtained for the cv. Delicious grafted on M 7, and MM 106 rootstocks (Barden, Marini 1999). Schupp and Koller (1998) reported that fruit weight of the cv. Liberty grafted on M 26 EMLA and Mark rootstocks was significantly lower than that on M 27 EMLA.

The highest Pn was measured for scions grafted on seedling although it was not significantly different than MM 109 (Table 1). The lowest Pn was recorded for scions on M 7 and MM 106 rootstocks. Our results are in agreement with those of Schechter et al. (1991) who reported that net Pn rates of apple trees on dwarfing rootstocks such as M 27 EMLA were lower than Pn rates of trees on more vigorous ones such as M 7 EMLA and MAC 24. Rootstocks differ in their influence on partitioning of photosynthetically produced dry matter between fruit and wood, even for genetically distinct rootstocks producing trees of similar size (Švihra et al. 1974). Rootstock effects on Pn may represent a mechanism by which the rootstock exerts its effect on scion growth and productivity (Schechter et al. 1991). However, Barden and Ferree (1979) reported that rootstocks do not affect apple scion Pn. Hunter and Proctor (1986) indicated that yield was directly proportional to the light intercepted in the canopy of apple trees. In the present study, the higher Pn of scions on seedling and MM 109 rootstocks were associated with higher yields, in comparison to the other rootstocks.

Nitrogen concentration of leaves of the cv. Imperial D.R.D. grafted on M 7 and MM 106 was significantly lower in comparison to the seedling (Table 2). The results are in agreement with those of Jones (1971) who reported that exudates from dwarfing rootstocks contained lower N concentrations in comparison to more vigorous ones. Leaf N concentration of the cv. Starkspur Supreme Delicious was significantly different when grafted on the rootstocks M 7 EMLA, M 9, M 26 EMLA, and M 27 EMLA (Rom et al. 1991). Kennedy et al. (1980) reported that leaf N concentration was more influenced by environmental factors than by rootstock genotype. Leaf P concentration of scions on M 7 were lower than on MM 106, whereas leaf K concentration of scions on MM 109 and seedling were higher than those on MM 106 and M 7 (Table 2). Jones (1971) also reported that exudates from dwarfing rootstocks contained lower K concentrations in comparison to more vigorius ones. Calcium concentration of leaves of scions grafted on seedling were higher than on the other rootstocks. Previous report indicated that trees on M 9 had significantly higher foliar Ca, and M 9 EMLA had 14 to 17% greater leaf Ca than M 7 EMLA (Rom et al. 1991). Rootstocks with the apple Northern Spy as a parent (Malling-Merton rootstock series) had low Ca levels as was reported by Ferree and Carlson (1987). Our results confirm this observation, too. Boron concentration of leaves of scions grafted on seedling and MM 109 were higher than on the other rootstocks. The rootstocks tested in our study did not significantly affect Mg, Fe, Mn, and Zn concentrations of leaves of the cv. Imperial

Table 2. Mineral concentration of leaves of the Imperial Double Red Delicious apple cultivar grafted on five rootstocks over a period of two years

Rootstock	N	P	K	Ca	Mg	Fe	Mn	Zn	B
	(% d.m.)					(μg/g d.m.)			
Seedling	2.46 a*	0.21 ab	1.91 a	1.57 a	0.30 a	117 a	90 a	25 a	38 a
M 7	2.31 c	0.18 b	1.81 b	1.39 b	0.32 a	121 a	87 a	27 a	26 c
MM 104	2.40 ab	0.22 ab	1.88 ab	1.31 bc	0.34 a	125 a	85 a	26 a	32 b
MM 106	2.38 b	0.24 a	1.83 b	1.23 c	0.32 a	113 a	89 a	24 a	29 bc
MM 109	2.43 ab	0.22 ab	1.92 a	1.26 c	0.31 a	120 a	86 a	27 a	37 a

*Means followed by the same letter in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

Table 3. Flesh firmness, soluble solids content, titratable acidity, and pH of juice of the apple cultivar Imperial Double Red Delicious grafted on five rootstocks

Rootstock	Flesh firmness at harvest (kg/cm^2)	Soluble solids content (g/l juice) at harvest	Soluble solids content (g/l juice) after 4 months of storage	Titratable acidity (g malic acid per l juice) at harvest	Titratable acidity (g malic acid per l juice) after 4 months of storage	pH of juice at harvest
Seedling	9.3 a*	11.8 a	15.2 a	0.39 a	0.36 a	3.68 a
M 7	9.1 a	12.4 a	15.7 a	0.39 a	0.35 a	3.75 a
MM 104	9.4 a	12.1 a	15.0 a	0.39 a	0.37 a	3.71 a
MM 106	9.2 a	12.3 a	15.3 a	0.40 a	0.39 a	3.73 a
MM 109	9.3 a	12.0 a	14.8 a	0.39 a	0.35 a	3.69 a

*Means followed by the same letter in the same column are not significantly different (Duncan's multiple range test $P \leq 0.05$)

D.R.D. (Table 2). Rom et al. (1991) reported that no differences were observed for leaf Mg concentration when the Starkspur Supreme Delicious cv. was grafted on several rootstocks including M 7 EMLA, M 9, M 26 EMLA, and M 27 EMLA. The previous researchers also reported that trees on M 27 EMLA had higher Mn and B concentrations than those on M 9 and M 7 EMLA.

Flesh firmness at harvest, pH of juice at harvest, soluble solids content and titratable acidity at harvest and after 4 months of storage were not significantly influenced by the rootstocks tested (Table 3). After storage of fruits for a period of 4 months, soluble solids content increased whereas titratable acidity decreased in comparison to the respective values at harvest for all scion/rootstock combinations. Ebel et al. (1999) reported that soluble solids content and fruit firmness of the cv. Golden Delicious grafted on M 7A, seedling, MM 106 EMLA and MM 111 EMLA were not significantly different. Autio et al. (1996) studied the effect of seedling, M 7 EMLA and M 26 EMLA on soluble solids content and fruit firmness of the cv. Starkspur Supreme Delicious on several sites. They concluded that the effects of rootstock on soluble solids content and fruit firmness varied dramatically from site to site.

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Charakteristiky odrůdy jabloně (*Malus domestica* Borkh) Imperial Double Red Delicious naštěpované na pěti podnožích

ABSTRAKT: V práci bylo hodnoceno širší spektrum hospodářských charakteristik odrůdy jabloně Imperial Double Red Delicious (Imperial D.R.D.) naštěpované na následujících pěti podnožích: (*i*) semenáč, (*ii*) M 7, (*iii*) MM 104, (*iv*) MM 106 a (*v*) MM 109. Nejvyšší výnos ze stromu byl zaznamenán na semenné podnoži, zatímco nejnižší sklizně byly u stromů naštěpovaných na podnoži M 7. Specifická plodnost odrůdy Imperial D.R.D. byla nejvyšší na podnožích MM 106 a M 7, střední na semenáči a na podnoži MM 104 a nejnižší na podnoži MM 109. Nejvyšší intenzita fotosyntézy (Pn) byla naměřena po naštěpování na semenáči, který se však v této charakteristice významně nelišil od podnože MM 109. Obsah dusíku v listech této odrůdy naštěpované na podnožích M 7 a MM 106 byl významně nižší než na semenáči. V případě hodnocení plodů nebyly mezi hodnocenými podnožemi zjištěny žádné rozdíly v pevnosti dužniny v době sklizně, pH šťávy v době sklizně, obsahu refraktometrické sušiny a titrační kyselosti ať již v době sklizně, nebo po čtyřech měsících skladování.

Klíčová slova: jabloň; kvalita plodů; příjem živin; intenzita fotosyntézy; specifická plodnost; podnože

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