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EFFECTS OF THREE ROOTSTOCKS ON PHOTOSYNTHESIS, LEAF MINERAL NUTRITION, AND VEGETATIVE GROWTH OF "BC-2 FUJI" APPLE TREES

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ABSTRACT

Net photosynthesis (Pn), leaf nutrition, and current terminal shoot (CTS) growth of 'BC-2 Fuji' apple [*Malus sylvestris* (L.) Mill var. *domestica* (Borkh.) Mansf.] trees on three rootstocks, Budagovski (Bud.) 9, Ottawa 3, and M.7 EMLA under field conditions were studied in 1998 and 1999. Rootstock affected the scion leaf Pn, leaf mineral concentrations, and vegetative growth. Leaves of trees on Bud.9 had lower Pn than those on the other rootstocks, and the differences were significant in 1999. Scion leaves on Bud.9 had higher calcium (Ca) and manganese (Mn) but lower potassium (K) concentrations than those on the other rootstocks. Leaves of trees on M.7 EMLA had significantly higher magnesium (Mg), K, and copper (Cu) concentrations than those on the other rootstocks in both years. Trees on Ottawa 3 had significantly lower leaf Cu concentrations than

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those on the other rootstocks during both 1998 and 1999. Trees on Bud.9 rootstock had shorter limbs and terminal shoots than those on the other rootstocks in 1998 and 1999.

INTRODUCTION

Numerous studies have shown that rootstocks can affect tree growth (1, 2), spur and flower development (3), yield (4, 5), and fruit quality (6) of different apple cultivars. Several researchers have shown that scion leaves of trees on more vigorous rootstocks have higher Pn than those on size-controlling rootstocks (4–8). Ferree and Barden (7) found that current leaf Pn of 'Delicious' apple trees grown on seedling rootstocks was higher than that on Malling-Merton (MM) 106. Baugher et al. (8) indicated that shoot leaf Pn of 'Golden Delicious' apple trees on M.7 EMLA or MM.111 EMLA was higher than that on M.9 EMLA rootstock. However, Barden and Ferree (9) reported that Pn and dark respiration of container-grown 'Delicious' trees were unaffected by rootstocks.

Numerous studies have shown that rootstocks affect scion leaf mineral concentration in apples (10–15). Abdalla et al. (12) reported that 'Delicious' apple trees on dwarfing rootstocks had more yield efficiency and higher leaf Mn but lower leaf K than trees on vigorous rootstocks. Fallahi et al. (13) observed that 'Starkspur Golden Delicious' apple tree on M.26 had higher leaf Mg than those on the other tested rootstocks.

Ottawa 3 rootstock was released from a Canadian rootstock-breeding program and Budagovski 9 (Bud.9) was introduced from Russia. M.7 EMLA is considered as a semi-vigorous rootstock, while Ottawa 3 and Bud.9 are less vigorous.

In spite of numerous reports on the effects of rootstock on various aspects of Pn and tree growth of several apple cultivars, little information exists in the literature on the effects of rootstocks on 'Fuji' tree Pn, nutrition, and growth characteristics. Therefore, the goal of this experiment was to study the effects of three rootstocks on leaf Pn, leaf mineral concentrations, and tree vegetative growth of 'BC-2 Fuji' apple.

MATERIALS AND METHODS

Plant Materials

'BC-2 Fuji' apple trees grafted on Budagovski 9 (Bud.9), Ottawa 3, M.7 EMLA rootstocks were planted at a 2.43×4.87 m spacing at the University of Idaho Parma Research and Extension Center, Parma in May 1995. The trees were trained as a central leader in which the top of the leader was bent in a zig-zag pattern to control growth. A 3.65-m supporting post was pounded into the soil next to each tree. Trees were attached to the posts with flexible plastic ties. 'Snow drift' crabapple trees were used as pollinizers. The experimental plot was arranged as a randomized complete block design with three rootstocks and four blocks and two replications of trees within each block.

Photosynthesis and Leaf Area Measurement

Net photosynthesis (Pn), stomatal conductance (g_s), intercellular CO_2 concentration (Ci), and transpiration (Tr) rates were measured between 8 am and 12 pm during growing seasons in 1998 and 1999. Recently matured fully expanded shoot leaves exposed to full light were measured using a LI-6200 portable photosynthesis system (LI-6200, LI-COR Inc., Lincoln, NE) and quantum sensor held horizontally to the sun. All measurements were made at a photosynthetic photon flux (*PPF*) greater than 1000 $\mu mol\, m^{-2} s^{-1}$ conditions. A closed 4-liter chamber with maximum flow rate was used for measurement of gas exchange parameters. The CO_2 reference point was set at 379 mg L^{-1}. After measuring Pn, g_s, Ci, and Tr, leaf areas (LA) were measured with a leaf area meter (LI-3000, LI-COR Inc., Lincoln, NE) to calculate the rate of the measurements per certain area (per cm^2).

Mineral Analysis

In 1998 and 1999, 30 leaves were collected from the mid-region of current-season shoots after terminal bud formation in mid-August. Leaves were washed in Liqui-Nox detergent, rinsed in deionized water, dried at 65°C, and ground in a grinder (Cyclotec 1093, Teactor, Inc., Hoganas, Sweden) to pass through a 40-mesh screen. 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. One gram of each of the dried leaf samples was weighed and ashed at 500°C in an ashing furnace for 5 hours. The ashed samples were digested with 10% nitric acid. The concentration of calcium (Ca), magnesium (Mg), potassium (K), iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn) were measured by atomic absorption spectrophotometry (Perkin-Elmer 1100 B, Norwalk, CT) as described by Jones (16).

Vegetative Growth Measurement

To determine tree growth characteristics, two limbs, one from the east side and one from the west side of each tree were selected. Lengths of limbs and current terminal shoots (CTS) were measured, and numbers of branches and current side shoots were counted after terminal buds were formed in late August of 1998 and 1999. Data were analyzed using the general linear model (GLM) procedure, and means were separated with LSD test at p 0.05 level (SAS Institute, Inc., Cary, NC).

RESULTS AND DISCUSSION

Net Photosynthesis

Current shoot leaves of trees on Bud.9 rootstock tended have lower Pn, g_s, Ci, Tr, and LA than those on the other rootstocks in 1998 and 1999, and the differences were sometimes significant (Table 1). Nitrogen is involved in the structure of chlorophyll. Leaves of trees on Bud.9 rootstock had lower leaf N (Table 2) and perhaps lower chlorophyll, resulting in lower Pn. 'BC-Fuji' trees on vigorous rootstock M.7 EMLA had significantly larger leaves than those on Bud.9 during both 1998 and 1999 (Table 1). In earlier studies, Baugher et al. (8) and Schechter et al. (17) observed that leaf Pn rates of 'Golden Delicious' and 'Starkspur Supreme Delicious' on vigorous rootstocks were higher than those on dwarfing rootstocks. However, the results of our study showed that Pn rates were not necessarily affected by the vigor of rootstock. For example, trees on Ottawa 3 rootstock had smaller canopy growth, but statistically similar leaf Pn as compared to those on M.7 EMLA (Tables 1 and 3). These contradictions are perhaps due to cultivar differences.

Table 1. The Influence of Rootstock on Net Photosynthesis (Pn), Stomatal Conductance (g_s), Intercellular CO_2 Concentration (Ci), Transpiration (Tr), and Leaf Area (LA) of 'BC-2 Fuji' Apple Leaves in 1998 and 1999

Rootstock	Pn (μmol m^{-2} s^{-1})	g_s (mol m^{-2} s^{-1})	Ci (μmol mol^{-1})	Tr (mol m^{-2} s^{-1})	LA (cm^2)
1998					
Bud.9	10.24 a^z	0.14 b	190.07 b	3.46 b	25.65 b
Ottawa 3	10.96 a	0.15 ab	204.01 a	3.57 ab	26.54 ab
M.7 EMLA	10.35 a	0.18 a	204.00 a	3.89 a	27.85 a
1999					
Bud.9	9.18 b	0.12 b	201.41 b	2.91 b	27.41 b
Ottawa 3	10.19 a	0.15 a	209.27 ab	3.28 a	29.97 a
M.7 EMLA	9.87 a	0.15 a	213.56 a	3.25 a	31.25 a

^{z}Mean separation within columns of each year by LSD at $p \leq 0.05$.
Each value represents the average of three measurements in the middle of June, July, and August, with four blocks of two-tree replications in each month of each year.

Table 2. The Influence of Rootstock on Current Shoot Leaf Mineral Concentration of 'BC-2 Fuji' Apple in 1998 and 1999

	Element Concentration (Based on Dry Weight)							
Rootstock	N (%)	Ca (%)	Mg (%)	K (%)	Fe (μg g⁻¹)	Zn (μg g⁻¹)	Cu (μg g⁻¹)	Mn (μg g⁻¹)
1998								
Bud.9	2.28 b[z]	1.809 a	0.238 b	1.199 c	79.01 ab	16.81 a	8.95 b	59.81 a
Ottawa 3	2.36 ab	1.407 b	0.223 b	1.509 b	85.51 a	14.74 b	8.17 c	40.78 c
M.7 EMLA	2.42 a	1.128 c	0.264 a	1.929 a	76.61 b	14.85 b	11.04 a	53.64 b
1999								
Bud.9	2.09 a	1.440 a	0.263 b	1.336 c	61.77 b	12.95 a	6.60 b	43.84 a
Ottawa 3	2.21 a	1.331 a	0.257 b	1.484 b	60.69 b	11.05 a	6.12 c	27.88 b
M.7 EMLA	2.17 a	1.210 b	0.301 a	1.749 a	70.33 a	12.96 a	7.26 a	39.78 a

[z]Mean separation within columns of each year by LSD at $p \leq 0.05$.

Table 3. Limb Length, Number of Branch, Number of Current Side Shoot (CSS), and Current Terminal Shoot (CTS) Length of 'BC-2 Fuji' Apple Trees in 1998 and 1999 as Influenced by Rootstock

Rootstock	Limb Length (m)	No. Branch	No. CSS	CTS Length (cm)
1998				
Bud.9	2.01 c[z]	2.74 b	3.31 c	32.58 c
Ottawa 3	2.34 b	3.50 ab	6.68 b	41.03 b
M.7 EMLA	2.72 a	4.39 a	14.98 a	51.26 a
1999				
Bud.9	1.70 c	4.33 b	4.96 b	18.57 c
Ottawa 3	1.76 b	5.18 a	6.17 b	27.26 b
M.7 EMLA	2.52 a	6.95 a	10.17 a	41.73 a

[z]Mean separation within columns of each year by LSD at $p \leq 0.05$.

Leaf Mineral Analysis

Rootstock affected concentrations of mineral elements in the scion leaves (Table 2). Leaf N of trees on Bud.9 rootstock was significantly lower in 1998 and slightly lower in 1999 than that on M.7 EMLA. Trees on M.7 EMLA had significantly higher leaf Mg, K, and Cu than those on Ottawa 3 and Bud.9 rootstocks in both 1998 and 1999. Trees on Ottawa 3 had significantly higher leaf K, but lower Cu and Mn than those on Bud.9. The higher leaf K in the trees on M.7 EMLA could be related to the fact that both 1998 and 1999 seasons were considered beginning years of production (3 and 4 years after planting, respectively). As a result of lower yield of these trees, and thus less fruit demand for K, more accumulation of K in the leaves was possible. Therefore, further study in the area of K partitioning is necessary when trees on M.7 EMLA reach their full production. The higher K in the leaves of 'Fuji' on M.7 EMLA in this study agrees with the results of Abdalla et al. (12) in 'Delicious' apple.

Vegetative Growth

Trees on M.7 EMLA had greater numbers of branches and side shoots and longer limbs and CTSs than those on the other rootstocks, followed by those on Ottawa 3 and Bud.9 in both 1998 and 1999 (Table 3). Less vigor of trees on Bud.9 rootstock could be due to their lower leaf N concentration (Table 2) and lower leaf Pn (Table 1). The more vigorous growth of trees on M.7 EMLA rootstock is similar to the results in 'McIntosh' (18) and 'Golden Delicious, 'Granny Smith', and 'Delicious' (19). Relative tree growth of trees on Bud.9 and M.7 EMLA in this study is also in agreement with the results on 'Starkspur Supreme Delicious' apple, tested as the North Central Regional Cooperative Project (20). Barritt et al. (19) reported that the rate of growth in 'Golden Delicious' apple trees on Ottawa 3 was between those of M.7 EMLA and Bud.9, which is consistent with the results of this study.

Less growth of 'Fuji' apple trees on Bud.9 and Ottawa 3 rootstocks enables growers to plant a higher number of these trees per hectare, resulting in earlier production and higher yield efficiency.

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