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Effects of Rootstocks and Microsprinkler Fertigation on Mineral Concentrations, Yield, and Fruit Color of 'BC-2 Fuji' Apple

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Abstract

Mineral concentrations in shoot leaves, spur leaves, mixed-buds, and fruit tissue, and yield, and fruit color of 'BC-2 Fuji' apple (*Malus domestica* Borkh.) trees as affected by five rootstocks, B.9, M.9 NAKBT337, O.3, M.26 EMLA, and M.7 EMLA, and five nutrition treatments, applied through a microsprinkler system, were evaluated during 1998 and 1999. Nutrient treatments were 22.4 kg N/ha (low N), 89.7 kg N/ha (medium N), 156.9 kg N/ha (high N), 89.7 kg N/ha plus 78.5 kg K/ha (medium N + K), and 156.9 kg N/ha plus 78.5 kg K/ha (high N + K). Trees on B.9 had lower K and higher Ca in the shoot and spur leaves, and had higher fruit Ca than other rootstocks in both years. Shoot and spur leaves, and fruit tissues of trees on M.7 EMLA had significantly higher K concentrations than those on other rootstocks. Shoot leaves and mixed-buds of trees on M.26 EMLA had higher Mg concentrations than trees on most other rootstocks during the two years. Fruits of trees on B.9 had significantly higher Ca and Zn concentrations than those on other rootstocks during both years. Trees on B.9 were more yield-efficient (yield/trunk cross-sectional area) than those on M.26 EMLA and M.7 EMLA in both years. Trees receiving low N had lower N but higher K concentrations in all tested tissues, except in mixed-buds, compared to trees in other nutrient treatments. Fruits from trees with low N had better color than those from trees receiving higher N. Addition of K with N fertigation treatments had little effect on K concentrations of tree tissues.

Introduction

Numerous studies have shown that rootstocks affect scion leaf (1, 2, 6, 10, 14, 17, 19, 22, 25, 27) and fruit mineral concentration (7, 8, 9) of apples (*Malus domestica* Borkh.). Fallahi et al. (7) reported that trees on Oregon Apple Rootstock 1 (OAR 1) had lower fruit N concentrations than those on most other rootstocks. Autio et al. (2) reported that Ca content of fruit from 'Starkspur Supreme Delicious' trees on Michigan Apple Clone 9 (MAC.9) was higher, but fruit Ca concentrations on OAR 1 was lower than those on several other rootstocks. Abdalla et al. (1) reported that 'Delicious' apple trees on dwarfing rootstocks had higher yield efficiency and higher leaf Mn concentrations but lower leaf K concentrations than trees on vigorous rootstocks. Williams and Billingsley (28) studied the relationship between quantity of applied N, leaf N, and fruit color in 'Golden Delicious' apple and concluded that maximum yields of high-quality fruit were obtained when leaf N were from 1.9 to 2.1% dry weight. They observed that the green color of fruit increased as its quantity of N and leaf N concentration increased. The inverse relationship between leaf and fruit color has also been reported for 'Starkspur Golden Delicious' (8) and 'Golden Delicious' (15). Recently, the inverse relationship between leaf and fruit N concentrations with fruit quality has also been reported by Raese and Drake (20) and Fallahi et al. (11).

In spite of the economic significance of 'Fuji' apple, limited information is available on the effect of rootstock or fertiga-

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tion on mineral concentrations in various tissues of this cultivar. Therefore, the objective of this study was to examine the effect of five rootstocks and five nutrition treatments applied through a microspinkler fertigation system on mineral concentrations in shoot leaves, spur leaves, mixed-buds, and fruit tissues, and yield, and fruit color of 'BC-2 Fuji' apple trees, during 1998 and 1999.

Materials and Methods

Plant Material and Fertigation (Nutrition) Levels

The experimental orchard was located at the University of Idaho Parma Research and Extension Center near Parma, Idaho. 'BC-2 Fuji' trees on B.9, M.9 NAKBT337, O.3, M.26 EMLA, and M.7 EMLA rootstocks were planted at 2.4 x 5.9 m in May 1995. 'Snowdrift' crabapple trees were planted as pollinizers. Trees were trained as a central leader by bending the top of the leader in a zig-zag pattern to control growth (3). The soil was sandy loam and at the depth of 0-58.8 cm, the soil characteristics were as follow: pH 7.1 to 7.3, NO_3-N 2.74 to 3.14 $\mu g.g^{-1}$, NH_4-N 1.45 to 1.09 $\mu g.g^{-1}$, P 8.0 to 12.4 $\mu g.g^{-1}$, K 306 to 319 $\mu g.g^{-1}$, CEC 16.6 to 18.3, and organic matter 0.48 to 1.03%.

Five nutrition treatments with the same amount of water were delivered through the microsprinkler irrigation system (fertigation). Urea-ammonium nitrate (UAN-32) nitrogen (N) and liquid potash fertilizers (0-0-13 K2O) were used as nutrient sources in the experiment. The nutrient treatments were 22.4 kg N/ha (low N), 89.7 kg N/ha (medium N), 156.9 kg N/ha (high N), 89.7 kg N/ha plus 78.5 kg K/ha (medium N + K), and 156.9 kg N/ha plus 78.5 kg K/ha (high N + K). Each of these nutrient treatments was applied in four equal quantities on May 31, June 8, June 15, and June 23 in 1998, and on May 20, May 27, June 4, and June 10 in 1999.

Tissue Sampling and Mineral Analysis

After terminal buds were formed on August 31, 1998 and August 25, 1999, 30 leaves with petioles attached, from mid-section of the current season shoots and five spurs, which had no fruit, were collected randomly on each tree. Twelve mixed-buds from each tree were collected on March 27, 1999 and March 24, 2000, when they were at developmental stages between 0 (dormant stage) and 2 (bud swell-first green stage), based on the bud development chart in Crop Protection Guide for Tree Fruits in Washington (5). For fruit mineral analysis, seven fruits were randomly sampled from each tree at commercial harvest time on October 20, 1998 and October 18, 1999. Fruit color was rated visually on a scale of 1 to 5, where 1 = 20% pinkish-red progressively to 5 = 100% pinkish-red. Each fruit was cut longitudinally into four equal sections. Thin longitudinally wedges from each section were taken and combined. Seeds, endocarp, mesocarp, exocarp, and pith tissues were removed from core sections, leaving the cortex with peel tissues for analysis.

Samples were washed with a mild solution of Ligui-Nox detergent (Alocnox, Inc., New York, NY), 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 concentration of each sample was measured by LECO Protein/Nitrogen Analyzer (FP-528, LECO Corp., St. Joseph, MI). The concentration of Ca, Cu, Fe, Mg, Mn, K, and Zn were measured by atomic absorption spectrophotometry (Perkin-Elmer 1100 B, Norwalk, Connecticut) as described by Jones (1977).

Experimental Design

The experimental plot was arranged as a randomized complete block split plot design with five fertigation (nutrient) treatments as the main plots and five rootstocks as sub-plots. Four blocks and two replications of trees within each sub-plot (total 200 trees) were used in this study. Data were analyzed using general linear model (GLM) procedures. Fisher's protected LSD ($\alpha \leq 0.05$) was used to separate treatment means. Statistical analyses were

Table 1. Effect of rootstock on mineral element concentrations of 'BC-2 Fuji' apple shoot leaves in 1998 and 1999.

	Element concentrations (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								
B.9	2.34 b[z]	1.81 a	0.24 b	1.19 d	79.0 ab	16.8 a	9.0 b	59.8 b
M.9 NAKBT337	2.38ab	1.39b	0.22 b	1.52 c	81.3 a	16.0 b	9.2 b	53.3 c
O.3	2.36 ab	1.41 b	0.22 b	1.51 c	85.5 a	14.7 c	8.2 c	40.8 d
M.26 EMLA	2.35 ab	1.22 c	0.35 a	1.66 b	72.4 c	15.9 b	9.0 b	75.7 a
M.7 EMLA	2.42 a	1.13 d	0.26 b	1.93 a	76.6 bc	14.9 c	11.0 a	53.6 c
1999								
B.9	2.21 b	1.44 a	0.26 d	1.34 d	61.8 b	12.9 a	6.6 bc	43.8 b
M.9 NAKBT337	2.28a	1.35 b	0.28 c	1.55 b	59.9 b	12.2 ab	6.9 ab	43.6 b
O.3	2.21 b	1.33 b	0.26 d	1.48 bc	60.7 b	11.1 b	6.1 b	27.9 d
M.26 EMLA	2.28 a	1.30 b	0.36 a	1.44 c	59.6 b	11.9 ab	6.4 cd	58.9 a
M.7 EMLA	2.17 b	1.21 c	0.30 b	1.75 a	70.3 a	12.9 a	7.3 a	39.8 c

[z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

computed by SAS (SAS Institute Inc., Cary, N.C.).

Results and Discussion

Assumption of normality was checked by computing univariate analysis for all tree responses in this study. There were no significant interactions between rootstocks and fertigation treatments for any portion of this study.

Rootstock Effect

Shoot leaves: Rootstocks affected the scion shoot leaf concentrations of all nutrients analyzed (Table 1). The concentration of N was significantly lower in leaves from trees on B.9, O.3, and M.7 EMLA than those on M.9 and M.26 EMLA in 1999. Shoot leaves from trees on B.9 had the highest Ca concentrations in 1998-1999 and the highest Zn concentrations in 1998. Shoot leaves of trees on B.9 had the lowest K concentration among all trees in both years. Trees on M.7 EMLA had relatively higher leaf K and Cu concentrations than those on other rootstocks in both

Table 2. Effect of rootstock on mineral element concentrations of 'BC-2 Fuji' spur leaves in 1998 and 1999.

	Element concentrations (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								
B.9	2.12 c[z]	2.82a	0.32 ab	0.94 d	115.1 bc	37.9 a	12.9 ab	59.8 b
M.9 NAKBT337	2.19 a	2.33 b	0.31 b	1.18 c	123.9 a	35.0 ab	14.9 a	50.3 c
O.3	2.15 abc	2.38 b	0.30 b	1.17 c	113.4 bc	30.3 c	12.0 b	38.1 e
M.26 EMLA	2.16 ab	2.07 c	0.34 a	1.13 b	109.6 c	29.9 c	11.5 b	76.8 a
M.7 EMLA	2.13 bc	1.98 c	0.27 c	1.68 a	118.3 ab	30.7 bc	12.5 b	43.8 d
1999								
B.9	2.12 bc	2.44 a	0.36 c	1.00 c	100.0 ab	24.8 a	9.5 c	49.3 b
M.9 NAKBT337	2.19 a	2.28 ab	0.39 b	1.19 b	94.5 bc	22.3 b	10.1 b	44.8 bc
O.3	2.09 cd	2.38 a	0.38 bc	1.12 b	89.9 c	21.4 b	9.1 c	29.9 d
M.26 EMLA	2.18 ab	2.12 b	0.48 a	1.09 bc	100.3 ab	23.0 ab	9.2 c	67.9 a
M.7 EMLA	2.04 d	2.12 b	0.41 b	1.39 a	105.5 a	24.7 a	10.7 a	41.5 c

[z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

Table 3. Effect of rootstock on mineral element concentrations of 'BC-2 Fuji' mixed-buds in 1999 and 2000.

	Element concentrations (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)
1999								
B.9	2.28 a[Z]	2.16 a	0.186 c	0.98 a	101.8 bc	58.4 a	33.7 a	22.7 cd
M.9 NAKBT337	2.21 a	2.03 a	0.206 b	0.94 a	107.4 abc	51.4 bc	30.1 b	25.1 b
O.3	2.25 a	1.85 b	0.192 c	0.95 a	108.5 ab	46.8 c	22.8 c	21.3 d
M.26 EMLA	2.24 a	1.79 b	0.222 a	0.99 a	98.7 c	48.2 bc	24.6 c	27.6 a
M.7 EMLA	1.94 b	2.09 a	0.222 a	0.87 b	114.3 a	52.8 b	32.8 a	23.4 c
2000								
B.9	2.38 b	1.78 a	0.218 c	1.02 b	82.1 a	57.0 ab	40.3 b	25.3 b
M.9 NAKBT337	2.35 bc	1.77 ab	0.224 c	1.03 b	83.9 a	55.8 ab	40.6 b	25.5 b
O.3	2.31 bc	1.68 bc	0.229 bc	1.04 b	74.7 b	51.8 c	31.2 c	19.7 d
M.26 EMLA	2.27 c	1.73 ab	0.254 a	1.05 b	87.7 a	55.5 bc	32.6 c	28.0 a
M.7 EMLA	2.49 a	1.60 c	0.239 b	1.14 a	74.5 b	59.4 a	47.9 a	25.3 b

[Z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ ($n = 40$).

years. Trees on M.7 EMLA had not reached full production in 1998 and 1999; therefore, the fruits required less K, resulting in a higher concentration of K in the leaves. This situation may or may not change as trees become more mature. The higher leaf K concentration in trees on more vigorous rootstock in this study was similar to results with 'Delicious' by Abdalla et al. (1) and in 'Fuji' by Fallahi et al. (10). Trees on M.26 EMLA had higher shoot leaf Mg and Mn concentrations than those on other rootstocks in both years. The higher leaf Mg associated with M.26 EMLA was consistent with the results for 'Starkspur Golden Delicious' (8) and 'Starkspur Supreme Delicious' (21). Higher leaf Mn in 'Fuji' leaves on M.26 EMLA rootstock was similar to the results in 'McIntosh' (19). Leaves of trees on O.3 had significantly lower Cu and Mn concentrations than did those on most of other rootstocks. Lower leaf Mn in the trees on this rootstock agrees with the results on

Table 4. Effect of rootstock on mineral element concentrations of 'BC-2 Fuji' apple fruits in 1998 and 1999.

	Element concentrations (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								
B.9	0.259 b[Z]	0.034 a	0.033 a	0.75 c	4.9 ab	1.37 a	3.1 b	1.8 a
M.9 NAKBT337	0.285 a	0.028 c	0.032ab	0.83 b	4.8 ab	1.12 b	3.1 b	1.6 bc
O.3	0.253 b	0.031 b	0.034 a	0.81 b	5.1 a	1.19 b	2.6 c	1.5 bc
M.26 EMLA	0.223 c	0.026cd	0.031 b	0.79 bc	4.4 b	1.15 b	2.7 c	1.6 ab
M.7 EMLA	0.274 ab	0.025 d	0.035 a	0.91 a	5.2 a	1.19 b	3.9 a	1.4 c
1999								
B.9	0.210 a	0.024 a	0.028 bc	0.73 d	5.8 b	1.07 a	3.1 b	1.7 a
M.9 NAKBT337	0.222 a	0.019 b	0.029 b	0.81 b	5.2 b	0.81 b	3.3 b	1.4 bc
O.3	0.184 b	0.018 b	0.027 c	0.76 cd	5.7 b	0.85 b	2.5 c	1.1 d
M.26 EMLA	0.168 b	0.019 b	0.028 bc	0.77 bc	5.6 b	0.84 b	2.6 c	1.4 b
M.7 EMLA	0.232 a	0.017 b	0.031 a	0.91 a	7.1 a	0.83 b	4.3 a	1.2 cd

[Z]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ ($n = 40$).

Table 5. Effect of rootstock on yield, yield efficiency, and fruit skin color of 'BC-2 Fuji' apple fruits in 1998 and 1999.

Rootstock	Yield (kg/tree)	Yield efficiency[Z] (kg/cm²)	Fruit color rating (1-5)[Y]
	Element concentrations (based on dry weight)		
1998			
B.9	9.4 bc[X]	0.76 a	3.01 bc
M.9 NAKBT337	11.0 ab	0.60 b	3.36 a
O.3	12.2 a	0.50 c	3.18 b
M.26 EMLA	9.3 c	0.33 d	3.17 bc
M.7 EMLA	8.6 c	0.20 e	3.00 c
1999			
B.9	7.3 c	0.40 a	3.08 ab
M.9 NAKBT337	12.9 b	0.32 ab	2.94 b
O.3	12.2 b	0.29 ab	3.25 a
M.26 EMLA	21.6 a	0.26 b	2.84 bc
M.7 EMLA	10.4 bc	0.12 c	2.66 c

[Z]Yield efficiency = yield per tree (kg/trunk cross-sectional area (cm²).
[Y]Fruit color rating: 1 = green progresing to 5 = uniform red.
[X]Mean separation within columns of each year by LSD at $\alpha \leq$ 0.05 (n = 40).

'Starkspur Supreme Delicious' grown in Massachusetts (21).

Spur leaves: Most mineral elements of spur leaves were significantly affected by rootstocks in both years (Table 2). Spur leaf N and K concentrations of trees on B.9 were significantly lower than those on M.9 in both years. Spur leaves of trees on B.9 had higher concentration of Ca than those on other rootstocks in 1998 and than those on M.26 EMLA and M.7 EMLA in 1999. Spur leaves of trees on M.26 EMLA had significantly higher Mg and Mn concentrations than those on other rootstocks in both years, with exception of Mg concentration of those on B.9 in 1998. The higher Mg and Mn concentrations in spur leaves of trees on M.26 EMLA is similar to the result observed for shoot leaves (Table 1), and as discussed earlier, the result agrees with reports on other apple cultivars (8, 21). Spur leaves of trees on M.7 EMLA rootstock had significantly higher concentrations of K than those on other rootstocks during 1998 and 1999. The higher leaf K in these trees is similar to the results of the shoot leaves, and is perhaps due to the later fruit production of these trees, resulting in less demand by the fruit, and therefore, more accumulation of K in the leaves. Generally, it is safe to assume that for K status same rootstock differences were apparent whether shoot or spur leaves were analyzed.

Mixed-buds: Mixed-buds of trees on M.26 EMLA had significantly higher Mn

Table 6. Effect of fertigation on mineral element concentrations of 'BC-2 Fuji' apple shoot leaves in 1998 and 1999.

Fertigation[Z]	N (%)	Ca (%)	Mg (%)	K (%)	Fe (µg·g⁻¹)	Zn (µg·g⁻¹)	Cu (µg·g⁻¹)	Mn (µg·g⁻¹)
	Element concentrations (based on dry weight)							
1998								
Low N	2.19 b[y]	1.31 b	0.29 a	1.79 a	79.2 a	16.9 a	9.5 a	50.2 b
Medium N	2.31 ab	1.46 a	0.24 a	1.54 b	77.7 a	15.9 ab	8.9 a	55.4 ab
High N	2.45 a	1.48 a	0.25 a	1.47 b	78.8 a	14.9 b	9.3 a	89.4 a
Medium N + K	2.41 a	1.40 ab	0.24 a	1.52 b	79.4 a	15.4 ab	9.6 a	58.6 a
High N + K	2.49 a	1.30 b	0.28 a	1.49 b	76.7 a	15.1 b	9.2 a	59.6 a
1999								
Low N	1.93 c	1.13 b	0.26 b	1.89 a	65.5a	13.0 a	6.3 a	35.4 b
Medium N	2.25 b	1.43 a	0.30 a	1.42 b	62.9 ab	11.8 a	7.2 a	44.9 a
High N	2.37 a	1.39 a	0.31 a	1.39 b	59.7 c	11.4 a	7.2 a	47.9 a
Medium N + K	2.24 b	1.32 a	0.29 a	1.46 b	63.4 ab	12.1 a	6.5 a	41.7 a
High N + K	2.38 a	1.37 a	0.31 a	1.39 b	60.8 bc	12.9 a	6.1 a	45.3 a

[Z]Fertigation (nutrition) treatments: Low N, 22.4 kg N/ha; Medium N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg N/ha plus 78.5 kg K/ha.
[y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

Table 7. Effect of fertigation on mineral element concentrations of 'BC-2 Fuji' apple trees in 1998 and 1999.

	Element concentrations (based on dry weight)							
Fertigation[Z]	N (%)	Ca (%)	Mg (%)	K (%)	Fe ($\mu g \cdot g^{-1}$)	Zn ($\mu g \cdot g^{-1}$)	Cu ($\mu g \cdot g^{-1}$)	Mn ($\mu g \cdot g^{-1}$)
1998								
Low N	2.01 c[Y]	2.15 b	0.29 b	1.46 a	118.9 a	34.8 a	12.8 a	48.1 b
Medium N	2.14 b	2.38 a	0.31 ab	1.21 b	117.5 a	31.9 a	13.4 a	54.7 a
High N	2.23 a	2.42 a	0.32 a	1.12 b	109.9 a	31.0 a	13.3 a	58.1 a
Medium N + K	2.18 ab	2.33 ab	0.32 a	1.22 b	117.8 a	30.9 a	12.9 a	53.0 ab
High N + K	2.20 ab	2.31 ab	0.31 ab	1.25 b	116.2 a	35.3 a	11.4 a	55.2 a
1999								
Low N	1.84 c	2.06 b	0.37 b	1.52 a	92.4 a	26.6 a	9.5 a	37.1 b
Medium N	2.19 b	2.34 a	0.41 ab	1.08 b	96.0 a	21.6 b	10.4 a	46.8 a
High N	2.26 a	2.37 a	0.43 a	1.02 b	98.2 a	22.0 b	9.6 a	52.7 a
Medium N + K	2.16 b	2.29 a	0.41 a	1.10 b	104.7 a	24.1 ab	9.5 a	48.1 a
High N + K	2.25 a	2.30 a	0.42 a	1.08 b	98.9 a	21.9 b	9.6 a	48.3 a

[Z]Fertigation (nutrition) treatments: Low N, 22.4 kg N/ha; Medium N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg N/ha plus 78.5 kg K/ha.
[Y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

concentrations than those on other rootstocks in both years (Table 3). These mixed-buds also had significantly higher Mg than those on the other rootstocks except M.7 EMLA in 1999 and than those on all rootstocks in year 2000. Since shoot leaves of trees on M.26 EMLA also had higher Mg and Mn in 1998 and 1999 (Table 1), one could predict the status of Mg and Mn in the next season's mixed-buds by the previous August shoot leaf concentrations, and this subject deserves further study. Mixed-buds of trees on B.9 tended to have higher Ca concentrations, and the differences were sometimes significant. Mixed-buds of trees on M.7 EMLA had the lowest N and K concentrations in 1999, but the highest levels of

Table 8. Effect of fertigation on mineral element concentrations of 'BC-2 Fuji' mixed-buds in 1999 and 2000.

	Element concentrations (based on dry weight)							
Fertigation[Z]	N (%)	Ca (%)	Mg (%)	K (%)	Fe ($\mu g \cdot g^{-1}$)	Zn ($\mu g \cdot g^{-1}$)	Cu ($\mu g \cdot g^{-1}$)	Mn ($\mu g \cdot g^{-1}$)
1999								
Low N	1.99 b[y]	2.23 a	0.196 c	0.89 a	109.5 a	54.0 a	30.7 a	23.6 a
Medium N	2.12 ab	1.93 b	0.202 bc	0.93 a	106.6 a	48.4 a	27.3 a	24.2 a
High N	2.36 a	1.83 b	0.216 a	0.99 a	102.7 a	50.3 a	28.3 a	24.2 a
Medium N + K	2.25 ab	2.00 ab	0.206 abc	1.00 a	104.8 a	50.5 a	29.7 a	24.2 a
High N + K	2.20 ab	1.94 b	0.209 ab	0.92 a	107.2 a	54.6 a	28.3 a	24.0 a
2000								
Low N	2.24 b	1.78 a	0.215 b	1.05 a	71.5 b	56.0 a	41.0 a	22.2 c
Medium N	2.41 a	1.79 a	0.230 ab	1.06 a	76.3 b	56.9 a	40.0 ab	23.5 bc
High N	2.43 a	1.68 a	0.240 a	1.05 a	86.4 a	54.2 a	37.3 b	25.8 a
Medium N + K	2.28 b	1.69 a	0.238 a	1.02 a	85.7 a	56.5 a	37.3 b	24.7 ab
High N + K	2.43 a	1.67 a	0.241 a	1.09 a	83.1 a	55.9 a	37.1 b	24.9 ab

[Z]Fertigation (nutrition) treatments: Low N, 22.4 kg N/ha; Medium N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg N/ha plus 78.5 kg K/ha.
[y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

these minerals in year 2000. This trend reversal was perhaps due to the increasing tree maturity and greater crop load of trees on M.7 EMLA in year 2000 (data not shown).

Fruit: Fruit from trees on M.9 had significantly higher N than those on O.3 and M.26 EMLA in both years (Table 4). Fruits from trees on B.9 had significantly higher concentrations of Ca and Zn and relatively lower concentration of K than those on other rootstocks in both 1998 and 1999. Similar to the situation in other tested tissues, fruit K concentration of trees on M.7 EMLA was significantly higher than those on other rootstocks during both years.

Yield, yield efficiency, and fruit color:
Trees on B.9 had lower yield per tree than those on O.3 in 1998 and than those on M.26 EMLA in 1999 (Table 5). However, higher yield efficiency of trees were inversely related to their trunk cross-sectional areas (TCA, data not shown), vegetative growth (4), and shoot leaf K (Table 1). Trees on B.9 had smaller TCA, greater yield efficiency, and lower shoot leaf K than those on more vigorous rootstocks of M.7 EMLA and M.26 EMLA in both 1998 and 1999 (Table 1 and 5). Fruits from trees on M.9 had better color than those on M.26 EMLA, although the differences were only significant in 1998 (Table 5). Fruits from trees on M.7 EMLA had poorer color than those on other rootstocks, because these trees had larger canopies that resulted in less light penetration which is essential for color development.

Fertigation (Nutrition) Effects
Shoot and spur leaves: Shoot leaf N and Mn increased with every incremental increase in the amount of N applied, and the differences became more pronounced in the second year of application (Table 6). Shoot leaves of trees receiving low N had significantly lower Ca but higher K concentrations than those on trees with medium N and high N in both 1998 and 1999. Based on 'BC-2 Fuji' leaf N thresholds developed by Fallahi et al. (11), leaf N concentrations in the trees receiving the low N treatment was marginally adequate in 1998 and deficient in 1999 (Table 6). Similarly to the shoot leaves, spur leaves on trees with low N always had lower N and Mn, but higher K concentrations than those with medium N and high N treatments during both years (Table 7). Other than N, mineral concentrations of shoot and spur leaves on trees with the medium

Table 9. Effect of fertigation on mineral element concentrations of 'BC-2 Fuji' apple fruits in 1998 and 1999.

	Element concentrations (based on dry weight)							
Fertigation[Z]	N (%)	Ca (%)	Mg (%)	K (%)	Fe ($\mu g \cdot g^{-1}$)	Zn ($\mu g \cdot g^{-1}$)	Cu ($\mu g \cdot g^{-1}$)	Mn ($\mu g \cdot g^{-1}$)
1999								
Low N	0.199 d[Y]	0.031 a	0.036 a	0.89 a	5.1 a	1.34 a	3.6 a	1.6 a
Medium N	0.265 bc	0.028 bc	0.032 b	0.79 b	4.5 a	1.18 b	3.0 bc	1.6 a
High N	0.302 a	0.026 c	0.032 b	0.80 b	4.6 a	1.15 b	2.7 c	1.5 a
Medium N + K	0.250 c	0.029 ab	0.033 ab	0.81 b	5.2 a	1.15 b	3.1 b	1.7 a
High N + K	0.281 ab	0.028 bc	0.031 b	0.78 b	4.9 a	1.12 b	2.9 bc	1.5 a
2000								
Low N	0.155 c	0.020 a	0.028 a	0.89 a	5.4 c	1.03 a	3.3 a	1.2 b
Medium N	0.181 b	0.019 ab	0.028 a	0.77 b	5.4 c	0.89 b	3.1 ab	1.3 ab
High N	0.225 a	0.018 b	0.029 a	0.80 b	5.7 bc	0.80 c	3.1 ab	1.4 a
Medium N + K	0.204 ab	0.019 ab	0.029 a	0.79 b	6.6 a	0.85 bc	3.0 b	1.3 ab
High N + K	0.221 a	0.019 ab	0.028 a	0.80 b	6.1 ab	0.81 c	3.1 ab	1.4 a

[Z]Fertigation (nutrition) treatments: Low N, 22.4 kg N/ha; Medium N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg N/ha plus 78.5 kg K/ha.

[Y]Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

N were similar to those with high N or medium N plus K treatments.

Application of K together with N at the levels applied under conditions of this study was not beneficial. Lack of K absorption could have been due to two reasons: 1) the NH_4^+ ions in the urea nitrogen in the medium and high N plus K treatments could have competed with K^+ at the site of absorption (16), leading to lack of K increase in tissues; 2) the cover crop sod took up most of the added K due to slow movement of K in the soil.

Mixed-buds: Mixed-buds on trees receiving low N had significantly lower N and Mg levels than those on trees receiving high N in both years (Table 8). Since the shoot leaves on trees with low N treatment also had low N during previous seasons, status of the following season's mixed-bud N could perhaps be predicted by analysis of shoot leaves with or without fruit tissues. This prediction will provide an excellent tool and sufficient time for fruit growers to take a corrective measure if mixed-bud N deficiency is predicted during August of the previous season. Further research should be conducted on development of such predictive models.

Fruit: Fruits on trees receiving low N had relatively higher Ca, K, Zn, and Cu, but lower N concentrations than those receiving other treatments (Table 9). Higher fruit Ca concentration and smaller size of fruit in trees receiving low N resulted in higher fruit firmness in both years (data not shown). Regardless of treatments, variations between years were observed in some fruit minerals, particularly in fruit N, Ca, Mg, Zn, and Mn concentrations (Tables 4 and 9). Year-to-year crop load variation is believed to be the main reason for inconsistent effects of a given treatment (18, 23). Ferguson and Watkins (12) found that fruit from light-cropping trees had lower Ca and higher K concentrations than did fruit from trees with heavy crop loads. Temperature could also affect the rate of spring shoot and fruit growth, and thus could also influence mineral composition of fruit tissue (23, 26).

Table 10. Effect of fertigation on yield, yield efficiency, and fruit skin color of 'BC-2 Fuji' apple fruits in 1998 and 1999.

	Element concentrations (based on dry weight)		
Fertigation^z	Yield (kg/tree)	Yield efficiency^y (kg/cm^2)	Fruit color rating (1-5)^x
1998			
Low N	9.2 b^w	0.45 a	3.80 a
Medium N	9.6 ab	0.44 a	3.14 b
High N	9.3 b	0.50 a	2.86 c
Medium N + K	11.9 a	0.52 a	3.05 bc
High N + K	10.5 ab	0.49 a	2.88 c
1999			
Low N	7.6 b	0.19 a	3.85 a
Medium N	15.3 a	0.31 a	2.88 b
High N	13.6 a	0.29 a	2.60 b
Medium N + K	14.3 a	0.28 a	2.79 b
High N + K	13.3 a	0.32 a	2.64 b

^{z}Fertigation (nutrition) treatments: Low N, 22.4 kg N/ha; Medium N, 89.7 kg N/ha; High N, 156.9 kg N/ha; Medium N + K, 89.7 kg N/ha plus 78.5 kg K/ha; High N + K, 156.9 kg n/ha plus 78.5 kg K/ha.
^{y}Yield efficiency = yield per tree (kg/trunk cross-sectional area (cm^2).
^{x}Fruit color rating: 1 = green progresing to 5 = uniform red.
^{w}Mean separation within columns of each year by LSD at $\alpha \leq 0.05$ (n = 40).

Yield, yield efficiency, and fruit color: Yield per tree, in trees with low N treatment trees, tended to be lower in 1998 and significantly lower in 1999 than other treatments (Table 10). Fruit from trees receiving low N had significantly more red color than those from trees receiving any of the other fertigation treatments, which is in agreement with previous reports on 'Starkspur Golden Delicious' (8) and 'Fuji' (11). Under conditions of this study, fertigation of N at a rate between 22.4 kg.ha^{-1} and 89.7 kg.ha^{-1} may be optimum, as indicated by fruit color and yield (Table 10) and fruit size (4).

Conclusions

Rootstock affected mineral concentrations of various tissues in 'BC-2 Fuji'. Trees on M7. EMLA had generally higher K concentrations in various tissues of the scion cultivar. Trees on B.9 had relatively higher yield efficiency, and Ca concentrations but relatively lower K concentration, except for mixed-bud tissues. Fertigation of 22.4 kg N/ha resulted in lower N concentrations in every tissue, but higher K in all tissues except mixed-buds, and the differences were often significant. Fertigation of 156.9 kg N/ha decreased fruit color without increasing yields, and thus is not recommended as a commercial practice under similar conditions. Addition of K with N fertigation treatments had little effect on mineral concentrations in 'BC-2 Fuji' apple trees in either year. Mineral composition in apple trees is affected by many factors, particularly, rootstocks, applied nutrients, and crop load conditions. The relationships among these factors should be taken into account when interpreting nutrient analysis data.

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Thin Peaches According to Canopy Light

Leaving higher peach density in the upper canopy with one fruit every 15 cm versus one fruit every 30 cm resulted in large fruit size. In the lower canopy leaving one fruit every 45 cm versus one fruit every 30 cm resulted in larger fruit. Adjusting fruit density according to light level resulted in higher yield efficiency, reduced variability of size and soluble solids and shortened the harvest window. From Caruso et al 2001 Hort Technology 11(3):412-415.