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Foliar Nutrient Content of 'Starkspur Supreme Delicious' on Nine Clonal Apple Rootstocks

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Abstract

The influence of nine apple rootstocks on foliar mineral content was evaluated in Arkansas (AR), Massachusetts (MA), and Ontario (ONT), as part of the NC-140 1980-81 cooperative project. Nutrient content of vegetative leaves was analyzed for differences among rootstocks, locations, and years. Rootstock affected foliar mineral content in some years but differences were small and no rootstock resulted in nutrient levels in a deficiency range. However, in low pH soil of the AR site, the rootstocks MAC.9 and M.27 EMLA had high leaf Mn levels and expressed Mn toxicity. Rootstock did not affect foliar N level when data were averaged across sites but there were significant rootstock differences in ONT and a significant rootstock by year interaction in MA. Site was the greatest source of variation for N and Mg content while sampling year caused the greatest variation for K and Ca. Across all sites, there were no rootstock by year interactions. In AR, sampling year accounted for the greatest percentage of variance in N, P, K, Ca, Mg, and B content while rootstock was the greatest source of variation for Mn content.

Introduction

Proper orchard fertility management is essential for optimal growth and crop yield. Fruit tree nutrient status typically is monitored by periodic soil and plant tissue analysis (5, 14). Leaf tissue analysis to diagnose apple orchard fertility is based upon the assumption that the leaf is the basic site of plant metabolism and reflects changes in nutrient supply. Foliar nutrient levels vary with leaf position, time of sampling, cropping, tree injury, pest infection/infestation, and genotype. Because of the tree compound genetic system comprising commercial apple trees, variation due both to scion cultivar and to rootstock can occur (2, 8, 9, 12, 13, 15, 16, 17, 18). This paper reports variations in foliar mineral content of 'Starkspur Supreme Delicious' in the NC-140 Cooperative apple rootstock planting in Arkansas (AR), Massachusetts (MA) and Ontario (ONT).

Materials and Methods

General

'Starkspur Supreme Delicious' apple trees were planted in 1980 and 1981 on nine rootstocks, MAC.24, OAR 1, M.7 EMLA, M.26 EMLA, O.3, M.9 EMLA, M.9, MAC.9, and M.27 EMLA, in 17 locations as part of the NC-140 Cooperative Rootstock Trial. Five replications were planted in each 1980 and 1981. Details of the planting, design, rootstocks, growth and cropping have been reported (11).

Soil samples were obtained at planting from each test site and analyzed at the Ohio Agricultural Research and Development Center, Wooster, OH (Table 1) to determine nutrient status. Additional soil samples were taken annually at the AR site. Leaf tissue was sampled at AR, MA, and ONT as described below.

Site Specific Methods

AR The orchard soil was a rocky, sandy loam soil of the Linker series with a 1-3 percent western slope. Trees

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received annual N fertilizer from urea or ammonium nitrate (1988 only),. applied at a rate of approximately 67-200 g N per tree with the same amount given to all trees in a given year. Boron and calcium chloride were applied as a foliar spray at a rate of 0.1-0.2 g/l and 0.3 g/l, respectively, in 1987 and 1989. Potassium chloride fertilizer (0-0-60) was applied at 115 g K/tree in 1986. Soil pH was not adjusted either before or after planting. Trees received supplemental trickle irrigation.

Foliar nutrient content was analyzed from current season mid-shoot leaves sampled between July 25 and August 15 each year. In 1981, the five replicates planted in 1980 were sampled. In 1982, three replicates each from the 1980 and 1981 blocks of the study were sampled. In 1983-1989, all replicates were sampled. Samples were rinsed with tap water, forced-air dried at 70-80 C and ground to pass through a number 15 mesh screen. Leaf nitrogen was assayed after a sulfuric acid/peroxide digest and distillation by micro-Kjeldahl techniques (1982-1988) or combustion by a LECO FP 228 Nitrogen Determinator (1989). Foliar K, Ca, and Mg were analyzed after sulfuric acid/peroxide digest by atomic absorption spectrophotometry (1982-1988) or after a nitric acid/peroxide digest by inductively coupled plasma-spectrophotometer (Thermal Jarrell Ash Model 300 ICP) in 1989. Phosphorus was analyzed after a sulfuric acid/peroxide digest using ascorbic acid molybdate colorimetric method (1982-1988) or the ICP (1989). Manganese, Cu, and Zn analysis used a nitric acid/peroxide digest followed by atomic absorption (1982-1987) or ICP (1989). Boron was determined colormetrically using a azomethine-H procedure (1982-1988) or ICP (1989). Data were analyzed as a randomized complete block, split-plot for planting year (1980 vs. 1981 replicates). No interactions between planting year (tree age) and rootstock were significant (data not presented).

MA The orchard soil was a fine sandy loam of the Scituate series with a 3-8 percent western slope. Trees received annual N fertilizer from urea applied at a rate of 200 g N per tree per year beginning one year after planting. Boron was applied to the soil around each tree in 1986 and 1989 as borax at a rate of 12g B per tree. From 1984-1989, K was applied to the soil around each tree as potassium chloride at the rate of 270 g K per tree per year. Lime was not applied to adjust soil pH after planting.

Foliar mineral nutrient content of mid-shoot, current season leaves was sampled between August 1 and 15 each year. Following washing, drying at 70 C and grinding, samples were measured for N by micro-Kjeldahl method and K, Ca, Mg, Mn, and Zn by atomic absorption spectrophotometry. Data were analyzed as a randomized complete block, split-plot for planting year, with interactions between rootstock and sample year as a model parameter.

ONT Trees were planted on a Bookton soil series of a loam to very fine sandy loam character with a 2 percent slope. Trees received differential amounts of urea fertilizer (200-450 g/tree) depending upon tree age, tree vigor, productivity and foliar N level to maintain uniform growth, cropping and nutrient level. Sprinkler irrigation was supplied as required based upon tensiometer measurement of root-zone soil moisture. Foliar mineral analysis followed previously reported procedures (4). Data were analyzed as a randomized complete block.

Statistical Analysis

Data from each site was analyzed separately. The AR and ONT data were analyzed as a randomized complete block with mean separation within sample years by the Duncan-Waller k-ratio test, 5% level. The MA data were analyzed as a randomized com plete block, split plot for year. Mean separation of the significant rootstock by year interaction for the elements N, K, Ca, Mg, B, and Zn and of the main effect of rootstock for Mn was performed by Duncan's New Multiple Range Test (P = 0.05). Data within a location were further analyzed for the main effects of rootstock (average across sample years) and year (average across rootstocks) with mean separation performed by Duncan's New Multiple Range Test (P = 0.05).

Data from all locations were pooled, and analyzed for the main effects of rootstock, location, and year, using site as blocks, with mean separation performed by Duncan's New Multiple Range Test (P = 0.05). The data from individual sites and years are presented so that comparisons can be made relative to specific climatic or edaphic conditions. The pooled data analyzed for the main effects of rootstock, location, and year are presented to address specific questions about variation in the overall cooperative study.

Results

Site Characteristics AR had the lowest soil pH of the three sites and soil pH in the tree-row root zone decreased from 5.7 to 4.9 during the trial (Table 1). The AR site although low in P had similar levels of K, Mg, Zn, and B relative to MA and ONT. Massachusetts had approximately 10% of the soil Mn as the other sites and the least percent Ca base saturation. The ONT site had soil Ca contents nearly twice that of other sites. Cation exchange capacity was similar at all sites.

Analysis of Variation in Mineral Content Sources of foliar mineral content variation were evaluated from the analysis of variance sums of squares of the three sites pooled data (Table 2). Replicate and plot were not considered in the analysis. Rootstock variation was significant for K, Ca, and Mg but did not cause significant variation in N. Site caused significant variation in N, K, and Mg and was the greatest source of variation for N (63%) and Mg (43%). Sample year resulted in significant variation in N, K, Ca, and Mg and was the greatest variation of K (44%) and Ca (51%). There were no rootstock by location interactions for N, Ca and Mg. However, a significant rootstock by location interaction was apparent for K although the interaction accounted for the least variation. The rootstock by year interactions were not significant.

Variation in foliar mineral levels within a site was evaluated from AR and MA data (Table 3). In AR, replication, rootstock, year, and rootstock by year interaction were significant variation sources, except for N where rootstock effects were nonsignificant, and Mn and B where rootstock by year interactions were nonsignificant. Sample year was the greatest source of variation and accounted for from 44 to 78 percent of the experimental variation for N, P, K, Ca, Mg, and B. Rootstock was the greatest source of Mn variation. In MA, rootstock, year, and rootstock by year interactions were significant at the 1% level for all elements with the following exceptions: K for which rootstock was significant at 5% level; Ca

Table 1. Soil characteristics of NC-140 cooperative rootstock planting sites in Arkansas, Massachusetts, and Ontario, 1980.

		Pounds per Acre							% Base Saturation			CEC
Site	pH	P	K	Ca	Mg	Mn	Zn	B	Ca	Mg	K	%
Arkansas												
1981	5.7	11	150	910	155	160	2.8	.53	34	10	2.9	7
1988	4.9	13	129	909	110	--	--	--	--	--	--	--
Massachusetts	5.9	303	90	740	248	15	5.4	.78	16	9	1.0	11
Ontario	6.1	237	148	2180	114	180	7.2	.82	64	6	2.2	9

Table 2. Sources of variation in foliar mineral content of 'Starkspur Supreme Delicious' apple on nine rootstocks grown in Arkansas, Massachusetts, and Ontario, 1980-1989.

Source	Sums of Squares, as % of total, from Analysis of Variance N	K	Ca	Mg
Rootstock	3	15**	21*	17**
Site	63**	16**	3	43**
Year	22**	44**	51**	15**
Rootstock*Site	4	10**	12	9
Rootstock*Year	8	15	13	16

*significant at 5%, **significant at 1%.

stock was significant at 5% level; Ca for which the rootstock by year interaction was significant at the 5% level; and, Mn and B for which the rootstock by year interaction was nonsignificant.

Nitrogen Content Foliar N level varied significantly in several sample years, but when rootstock effects were averaged across years, rootstock did not affect foliar N in AR (Table 4). In MA, a significant rootstock by year interaction occurred. A trend was apparent that trees on M.9 generally had among the highest N while trees on MAC.9 generally had the lowest N levels. Trees on O.3 and M.7 EMLA varied in N content during the study. In ONT, trees on OAR 1 had significantly higher N than on Ottawa 3, M.9 EMLA, M.26 EMLA, and MAC.9. Trees on O.3 and MAC.9 had lower N than other rootstocks except in 1983 and 1985 when rootstock did not affect N content.

When data from all sites were combined (main effects), rootstock did not consistently affect foliar N level in 6 of 8 years and averaged across all years (Table 4). Trees in the AR site typically had lower foliar N with the exception of 1988 and 1989 when AR had higher levels than MA. ONT had the highest foliar N.

Potassium Content Trees on MAC.24 consistently had greater K contents than other rootstocks in most years and across all years in AR and ONT. Potassium content decreased with time in AR. Trees on M.27 EMLA were lowest in foliar K in AR while M.9 EMLA and O.3 tended to be lowest in ONT. No consistent trend of K in MA was observed. When the main effects of rootstock were evaluated across all sites, only in 1982 and 1987 did rootstocks affect K level. MAC.24 had significantly higher levels of K than all other treatments. Trees on M.9 EMLA had lowest K levels, although there were no significant differences between M.9 EMLA and 5 other rootstocks.

Table 3. Sources of variation in foliar mineral content of 'Starkspur Supreme Delicious' apple on nine rootstocks grown in Arkansas and Massachusetts, 1980-1989.

Source	N	P	K	Ca	Mg	Mn	B	Zn
Arkansas, 1982-1989								
	Sums of Squares, as % of total, from Analysis of Variance							
Replication	3.5*	5.8*	8.9**	3.9**	4.5*	14.5	7.3*	54.5
Rootstock	2.0	5.8*	21.2**	7.2**	15.1**	50.5***	22.8**	45.2
Year	78.4***	62.5***	44.0***	72.3***	53.8***	28.7***	65.6**	--[z]
Rootstock*Year	15.8*	25.9**	25.7*	16.3**	26.4**	6.3	4.2	--
Massachusetts, 1987-1989								
	Analysis of Variance Significance Levels							
Rootstock	**	--[x]	*	***	***	***	***	***
Year	***	--	***	***	***	***	***	***
Rootstock*Year	*	--	***	*	***	ns	ns	***

*significant at 5%, **significant at 1%, *** = 0.1%, ns = nonsignificant.
[z]Zn sampled only one year.
[x]P not sampled.

Table 4. The influence of nine rootstocks on foliar nitrogen (N) and potassium (K) content in Arkansas, Massachusetts, and Ontario, 1982-1990.

	N (% dry wt.)									K (% dry wt.)								
Stock	1982	1983	1984	1985	1986	1987	1988	1989	Avg.[x]	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Arkansas[z]																		
MAC.24	2.15	2.42a	2.20ab	1.65	2.08ab	1.94	2.22ab	2.51	2.15	2.13a	1.85a	1.74a	1.36a	1.43ab	1.68a	1.51	1.34	1.59a
OAR 1	2.03	2.39a	2.19ab	1.62	1.87abc	1.84	1.96b	2.52	2.05	1.43ab	1.41cd	1.26d	1.17ab	1.48ab	1.32bc	1.32	1.13	1.30bcd
M.7 EMLA	2.09	2.33ab	2.29a	1.66	2.09a	1.83	2.48a	2.48	2.17	1.80ab	1.38cd	1.33cd	1.28a	1.32abc	1.32bc	1.12	1.16	1.30cd
M.26 EMLA	2.19	2.42a	1.99bcd	1.61	1.85abc	1.8	2.16ab	2.35	2.05	1.99a	1.71ab	1.62ab	1.34a	1.57a	1.39b	1.25	1.38	1.48ab
O.3	2.69	2.41a	1.95cd	1.86	1.85abc	1.87	2.25ab	2.40	2.16	1.11b	1.27d	1.35abc	1.11abc	1.22abc	1.22bcd	1.13	1.19	1.21cd
M.9 EMLA	2.07	2.27ab	2.01bcd	1.71	2.10a	1.88	2.12ab	2.45	2.07	1.42ab	1.62abc	1.35cd	0.96c	1.21bcd	1.19bcd	1.20	1.25	1.27cd
M.9	2.23	2.22ab	1.95d	1.67	1.63c	1.96	2.17ab	2.35	2.02	2.03a	1.75a	1.55abc	1.16ab	1.51a	1.16cd	1.16	1.15	1.39bc
MAC.9	2.15	2.28ab	1.98bcd	1.60	1.81bc	1.75	2.14ab	2.39	2.01	1.75ab	1.57bcd	1.30cd	1.12abc	1.09cd	1.00d	1.06	1.30	1.25cd
M.27 EMLA	2.14	2.09b	2.04bcd	1.84	1.95ab	1.88	2.23ab	2.68	2.11	1.73ab	1.34cd	1.29cd	0.84c	1.00d	1.03d	1.30	1.10	1.16d
	ns			ns		ns		ns	ns	ns						ns	ns	
Average[x]	2.19b	2.31b	2.07c	1.69c	1.91d	1.86d	2.19b	2.46a		1.71a	1.54b	1.42bc	1.15e	1.31cd	1.26de	1.23de	1.22de	
Massachusetts[y]																		
OAR 1					2.19bc	2.22	2.10ab	2.28ab	2.20					1.20ab	1.38a	1.28c	1.00a	1.21
M.7 EMLA					2.21bc	2.23a	2.25a	2.22ab	2.23					1.36a	1.17b	1.31bc	1.16a	1.25
M.26 EMLA					2.22abc	2.37a	2.13ab	2.15b	2.22					1.20ab	1.12bc	1.28c	1.07a	1.17
O.3					2.38a	2.38a	1.90cd	2.27ab	2.23					1.30a	1.26a	1.46abc	1.12a	1.29
M.9 EMLA					2.23abc	2.26a	2.10ab	2.20b	2.20					1.24a	1.10bc	1.28c	1.05a	1.16
M.9					2.25abc	2.37a	2.03bc	2.37a	2.26					1.20ab	1.06c	1.49ab	1.00a	1.19
MAC.9					2.15c	2.29a	1.82d	2.17b	2.11					0.95c	1.07c	1.51a	0.97a	1.12
M.27 EMLA					2.34ab	2.37a	2.13ab	2.15b	2.25					1.03bc	1.37a	1.31bc	1.04a	1.20
Average					2.25a	2.31a	2.06b	2.23b						1.19b	1.19b	1.37a	1.05c	
Ontario[z]																		
MAC.24	2.61ab	2.76	2.71a	2.75	2.36bc	2.45ab			2.61ab	2.08a	1.89a	2.06a	1.93a	1.68a	1.83a			1.91a
OAR 1	2.49abc	2.85	2.73a	2.82	2.60a	2.52a			2.67a	1.97ab	1.89a	1.96ab	1.44b	1.52ab	1.56abc			1.72b
M.7 EMLA	2.71a	2.79	2.59ab	2.76	2.32bc	2.38ab			2.59ab	1.74bcd	1.54b	1.68cd	1.50b	1.58ab	1.38bcd			1.57bcd
M.26 EMLA	2.41abc	2.74	2.55ab	2.71	2.37bc	2.38ab			2.53bc	1.89abc	1.51b	1.66d	1.44bcd	1.28cd	1.18d			1.49cd
O.3	2.25c	2.74	2.16c	2.80	2.12d	2.30b			2.40c	1.57d	1.49b	1.39e	1.31cd	1.46abc	1.66ab			1.48d
M.9 EMLA	2.47abc	2.62	2.54ab	2.79	2.24cd	2.32b			2.50bc	1.66cd	1.55b	1.66d	1.39bcd	1.37bcd	1.25cd			1.48d
M.9	2.52abc	2.84	2.49b	2.77	2.45ab	2.40ab			2.58ab	1.87abc	1.75a	1.74cd	1.30d	1.18d	1.17d			1.50cd
MAC.9	2.37bc	2.55	2.27c	2.57	2.32bc	2.36b			2.41c	2.00ab	1.81a	1.68cd	1.52b	1.44bc	1.40bcd			1.64bc
M.27 EMLA	2.23c	2.80	2.67ab	2.85	2.60a	2.37b			2.59ab	1.92abc	1.80a	1.81bc	1.49bc	1.47abc	1.47bcd			1.66b
		ns		ns														
Average	2.45bc	2.74a	2.52b	2.76a	2.38c	2.39c				1.89a	1.69b	1.74b	1.48c	1.44c	1.43c			

Table 4. (Continued).

	N (% dry wt.)									K (% dry wt.)								
Stock	1982	1983	1984	1985	1986	1987	1988	1989	Avg.[x]	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Main Effects[w]																		
MAC.24	2.38	2.59	2.46a	2.20bcd	2.22	2.20	2.22	2.51	2.34	2.11a	1.87	1.90	1.65	1.56	1.76a	1.51	1.34	1.75a
OAR 1	2.26	2.62	2.46a	2.22abcd	2.22	2.19	2.03	2.40	2.29	1.70abc	1.65	1.61	1.31	1.40	1.42b	1.30	1.07	1.43b
M.7 EMLA	2.40	2.56	2.44a	2.21abcd	2.21	2.15	2.37	2.35	2.32	1.77abc	1.46	1.51	1.39	1.42	1.29bc	1.22	1.16	1.40bc
M.26 EMLA	2.30	2.58	2.27abc	2.16cd	2.15	2.18	2.15	2.25	2.24	1.94ab	1.61	1.64	1.39	1.35	1.23bc	1.27	1.23	1.44b
O.3	2.47	2.58	2.06c	2.33ab	2.12	2.18	2.08	2.34	2.25	1.34c	1.38	1.37	1.21	1.33	1.38bc	1.30	1.16	1.31c
M.9 EMLA	2.27	2.45	2.28abc	2.25abc	2.19	2.15	2.11	2.33	2.24	1.54bc	1.59	1.51	1.18	1.27	1.19bc	1.24	1.15	1.32c
M.9	2.38	2.53	2.22abc	2.22abcd	2.11	2.24	2.10	2.36	2.26	1.95ab	1.75	1.65	1.23	1.30	1.13c	1.33	1.08	1.40bc
MAC.9	2.26	2.42	2.13bc	2.09d	2.09	2.13	1.98	2.28	2.17	1.88ab	1.69	1.49	1.32	1.16	1.16c	1.29	1.14	1.36bc
M.27 EMLA	2.19	2.45	2.36ab	2.35a	2.30	2.21	2.18	2.42	2.30	1.83ab	1.57	1.55	1.17	1.17	1.29bc	1.31	1.07	1.35bc
	ns	ns			ns	ns	ns	ns	ns		ns	ns	ns	ns		ns	ns	
Site																		
Arkansas	2.19b	2.31b	2.07b	1.69b	1.91b	1.86c	2.19a	2.46a	2.09c	1.71	1.54	1.42b	1.15b	1.31ab	1.26b	1.22	1.22a	1.36b
Massachusetts	—	—	—	—	2.25a	2.31b	2.06b	2.23b	2.21b	—	—	—	—	1.19b	1.19b	1.37	1.05b	1.20c
Ontario	2.45a	2.74a	2.52a	2.76a	2.38a	2.39a	—	—	2.54a	1.86	1.69	1.74a	1.48a	1.44a	1.43a	—	—	1.61a
										ns	ns					ns		
Year	2.32b	2.53a	2.30b	2.22bc	2.18bc	2.18bc	2.13c	2.35b		1.78a	1.62b	1.58b	1.31c	1.32c	1.30c	1.29c	1.14d	

[z]Mean separation within columns by Duncan-Waller k-ratio test, 5% level.
[x]Mean separation within columns and site, or across rows within an element for Average by Duncan New Multiple Range Test, 5% level.
[y]Mean separation of rootstock by year interaction of MA data by Duncan New Multiple Range test, 5% level.
[w]Main effects for pooled data of the three sites. Mean separation within columns for Stock and Site, and across rows for Year by Duncan New Multiple Range test, 5% level.
ns = not significantly different.

The ONT site had higher K levels than other sites. Across all sites and stocks, K level decreased during the study with the highest levels being observed in 1982 and the lowest in 1989.

Calcium and Magnesium Content Trees in AR had similar leaf Ca content in 1982, 1985 and 1987 but significant rootstock differences occurred in other years (Table 5). Trees on M.9 EMLA, M.9, and MAC.9 had the highest Ca contents and M.7 EMLA and MAC.24 the lowest. In MA, trees on M.27 EMLA and MAC.9 had highest Ca while trees on OAR 1 were lowest. In ONT, trees on M.9 EMLA and M9 had significantly higher Ca than most stocks and trees on O.3 had the lowest Ca.

When data from all sites were combined (Table 5), rootstock did not affect foliar Ca level in most years. When averaged across years, however, trees on M.9 had the highest Ca level, MAC.24 the lowest with other rootstocks intermediate. Site did not significantly affect Ca level averaged across all years.

Trees on M.26 EMLA consistently had the highest leaf Mg at all sites (Table 5). The same trend occurred when data from all sites and years are combined. Trees in MA had higher Mg levels than trees in other sites.

Other Nutrients Foliar Mn content of trees from AR was approximately 5 to

Table 5. The influence on nine rootstocks on foliar calcium (Ca) and magnesium (Mg) content in Arkansas, Massachusetts, and Ontario, 1981-1990.

	Ca (% dry wt.)									Mg (% dry wt.)								
Stock	1982	1983	1984	1985	1986	1987	1988	1989	Avg.[x]	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Arkansas[z]																		
MAC.24	1.35	1.13bc	1.45abc	0.65	1.07bc	0.89	1.09bc	0.81c	1.06b	0.25b	0.34	0.32bc	0.30	0.32	0.27a	0.34bc	0.22d	0.30abc
OAR 1	1.55	1.44a	1.38abc	0.86	1.42a	1.06	1.05bc	0.95abc	1.21a	0.31ab	0.30	0.30c	0.26	0.26	0.23bc	0.28d	0.23cd	0.27c
M.7 EMLA	1.47	1.04c	1.20c	0.80	1.02c	0.96	1.19ab	0.83c	1.06b	0.31ab	0.34	0.34abc	0.29	0.28	0.27a	0.37ab	0.27a	0.31ab
M.26 EMLA	1.61	1.09bc	1.29bc	0.69	1.24abc	1.03	1.23ab	0.89abc	1.13ab	0.28ab	0.34	0.33bc	0.30	0.33	0.28a	0.38a	0.27a	0.32a
O.3	1.20	1.10bc	1.42abc	0.82	1.31ab	1.01	1.51abc	0.94abc	1.16ab	0.35ab	0.30	0.30c	0.27	0.26	0.25abc	0.31cd	0.22d	0.28bc
M.9 EMLA	1.73	1.24abc	1.53a	0.98	1.02c	1.07	1.31a	1.04a	1.24a	0.26b	0.31	0.34abc	0.29	0.29	0.28a	0.31cd	0.25abc	0.29abc
M.9	1.98	1.33ab	1.50ab	0.83	1.32ab	1.02	1.03bc	0.90abc	1.24a	0.27ab	0.33	0.36ab	0.25	0.25	0.22c	0.29c	0.21d	0.27c
MAC.9	1.54	1.26abc	1.25bc	0.70	1.42a	1.05	1.09bc	0.98ab	1.15ab	0.24b	0.32	0.30c	0.27	0.28	0.26ab	0.24e	0.23cd	0.27c
M.27 EMLA	1.58	1.10bc	1.44abc	0.74	1.18abc	1.05	0.93c	0.83bc	1.11ab	0.39a	0.33	0.38a	0.26	0.29	0.28a	0.29d	0.24bcd	0.31ab
	ns			ns		ns					ns		ns	ns				
Average[x]	1.56a	1.19c	1.38b	0.79e	1.22c	1.02d	1.16c	0.91d		0.30bc	0.32a	0.33a	0.28cd	0.28bc	0.26de	0.31ab	0.24e	
Massachusetts[y]																		
OAR 1					1.25d	0.99c	0.91d	0.99c	1.04e					0.35b	0.36c	0.37bc	0.35a	0.36b
M.7 EMLA					1.31d	1.01c	0.97cd	0.95c	1.06de					0.33b	0.42ab	0.42ab	0.35a	0.38b
M.26 EMLA					1.40cd	1.17bc	1.06bcd	1.07bc	1.18cd					0.43a	0.46a	0.46a	0.40a	0.44a
O.3					1.25d	1.16bc	0.93d	1.12bc	1.12cde					0.32b	0.37bc	0.34cd	0.35a	0.35b
M.9 EMLA					1.40cd	1.26b	1.14bc	1.11bc	1.23bc					0.37b	0.38bc	0.38bc	0.36a	0.27b
M.9					1.55bc	1.43a	1.18b	1.22ab	1.34ab					0.37b	0.38bc	0.31d	0.35a	0.35b
MAC.9					1.67ab	1.57a	1.08bcd	1.31a	1.41a					0.43a	0.42ab	0.33cd	0.36a	0.39b
M.27 EMLA					1.75a	1.47a	1.37a	1.19ab	1.45a					0.44a	0.35c	0.35cd	0.35a	0.37b
Average					1.45a	1.26b	1.08c	1.12c						0.38a	0.39a	0.27a	0.36a	
Ontario[z]																		
MAC.24	1.10bc	1.06c	0.90f	0.90de	1.01c	1.76bc			1.12cd	0.26ab	0.26d	0.23d	0.28e	0.27bc	0.38bcd			0.28cd
OAR 1	1.24ab	1.04c	1.06de	0.84e	1.12bc	1.44d			1.12cd	0.27ab	0.23e	0.23d	0.27e	0.24c	0.33e			0.26d
M.7 EMLA	1.16b	1.04c	1.09cd	1.02bcde	1.13bc	1.78bc			1.20bcd	0.28a	0.27cd	0.27bc	0.32cd	0.31b	0.39bcd			0.31b
M.26 EMLA	1.04bc	1.09c	1.16cd	1.14bc	1.39ab	1.81bc			1.27bc	0.28a	0.32a	0.33a	0.41a	0.37a	0.45a			0.36a
Ottawa 3	0.92c	1.06c	0.92ef	0.94de	1.05c	1.61cd			1.08d	0.21b	0.23e	0.22d	0.30de	0.29b	0.34de			0.27d
M.9 EMLA	1.41a	1.40a	1.33ab	1.24b	1.48a	2.17a			1.51a	0.27ab	0.29bc	0.29b	0.35bc	0.29b	0.42ab			0.32b
M.9	1.24ab	1.75a	1.20bc	1.08bcd	1.54a	2.01ab	1.47a	0.22ab	0.26d	0.29d	0.32bcd	0.29b	0.40abc	0.30bc				
MAC.9	1.12bc	1.17bc	1.35a	1.49a	1.32ab	1.75bc			1.37ab	0.26ab	0.31ab	0.30ab	0.36b	0.28bc	0.36cde			0.31b
M.27 EMLA	1.12bc	1.01c	1.14cd	1.04bcde	1.45a	1.77bc			1.26bc	0.23ab	0.26d	0.24cd	0.28de	0.28bc	0.35de			0.27cd
Average	1.15bc	1.19bc	1.13c	1.08c	1.28b	1.79a				0.25d	0.27d	0.27d	0.32b	0.29c	0.28a			

Table 5. (Continued).

Stock	Ca (% dry wt.) 1982	1983	1984	1985	1986	1987	1988	1989	Avg.[x]	Mg (% dry wt.) 1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Main Effects[w]																		
Stock																		
MAC.24	1.23cd	1.10	1.18	0.78	1.04	1.33	1.09	0.81	1.08c	0.26	0.30	0.28	0.29	0.30b	0.33bc	0.34b	0.22c	0.29b
OAR 1	1.40abc	1.24	1.22	0.85	1.26	1.16	0.98	0.97	1.14abc	0.29	0.27	0.27	0.27	0.28b	0.31c	0.33bc	0.29b	0.29b
M.7 EMLA	1.32bcd	1.04	1.15	0.91	1.15	1.25	1.08	0.89	1.11bc	0.30	0.31	0.31	0.31	0.31b	0.36ab	0.40a	0.31ab	0.32b
M.26 EMLA	1.33abcd	1.09	1.23	0.92	1.34	1.34	1.15	0.98	1.19abc	0.28	0.33	0.33	0.36	0.38a	0.40a	0.42a	0.34a	0.36a
O.3	1.01d	1.08	1.17	0.88	1.20	1.26	1.22	1.03	1.13abc	0.28	0.27	0.26	0.29	0.29b	0.32bc	0.33bc	0.29b	0.29b
M.9 EMLA	1.55ab	1.32	1.43	1.11	1.30	1.50	1.23	1.08	1.33ab	0.27	0.30	0.32	0.32	0.32b	0.36ab	0.35b	0.31ab	0.32b
M.9	1.61a	1.54	1.35	1.00	1.47	1.49	1.11	1.06	1.34a	0.25	0.30	0.33	0.29	0.30b	0.33bc	0.30bc	0.28b	0.30b
MAC.9	1.33abcd	1.22	1.30	1.10	1.47	1.46	1.09	1.15	1.28abc	0.25	0.32	0.30	0.32	0.33ab	0.35bc	0.29c	0.30b	0.31b
M.27 EMLA	1.34abc	1.06	1.29	0.89	1.46	1.43	1.15	1.01	1.23abc	0.31	0.30	0.31	0.27	0.34ab	0.33bc	0.32bc	0.30b	0.31b
		ns	ns	ns	ns	ns	ns	ns		ns	ns	ns	ns					
Site																		
Arkansas	1.56a	1.19	1.39a	0.79b	1.22b	1.02c	1.16	0.91b	1.15	0.30	0.32a	0.33a	0.29b	0.29b	0.26b	0.31b	0.24b	0.29b
Massachusetts	—	—	—	—	1.45a	1.26b	1.08	1.12a	1.23	—	—	—	—	0.38a	0.39a	0.37a	0.35a	0.38a
Ontario	1.15b	1.18	1.13b	1.07a	1.27b	1.79a	—	—	1.27	0.25	0.27b	0.27b	0.32a	0.29b	0.38a	—	—	0.29b
		ns					ns	ns	ns	ns								
Year	1.35a	1.19abc	1.27ab	0.93d	1.31ab	1.36a	1.12bc	1.01cd		0.27c	0.30bc	0.30bc	0.30bc	0.32ab	0.34a	0.34a	0.29bc	

[z]Mean separation within columns and site by Duncan-Waller k-ratio test, 5% level.
[x]Mean separation within columns and sites, across rows within an element for Average by Duncan New Multiple Range Test, 5% level.
[y]Mean separation of rootstock by year interaction of MA data by Duncan New Multiple Range test, 5% level.
[w]Main effects for pooled data of the three sites. Mean separation within columns for Stock and Site, and across rows for Year by Duncan New Multiple Range test, 5% level.
ns = not significantly different.

10-fold higher than MA (Table 6). In AR, trees on M.27 EMLA, and MAC.9 typically had higher Mn levels than other rootstocks, approaching 1.5 times the average while trees on M.7 EMLA and OAR 1 had the lowest Mn content. In MA, trees on M.27 EMLA had significantly higher and trees on O. 3 were significantly lower Mn than other rootstocks.

Trees on OAR 1 had significantly higher B levels than trees on other rootstocks in AR (each year and average across years) and MA (average across years) (Table 6). Trees on M.26 EMLA, M.9 EMLA, and M.9 typically had the lowest B levels.

Foliar P was sampled only in AR (Table 7). Trees on M.7 EMLA had a trend of the highest P contents, M.9 and OAR 1 the lowest while trees on other rootstocks were intermediate. There were no rootstock effects in 1985, 1986, and 1989.

In MA trees on M.26 EMLA typically were highest in Zn and on M.7 EMLA were lowest (Table 7). Similarly, in AR, trees on M.7 EMLA and MAC.24 had lowest Zn levels (data not presented).

Table 6. The influence of nine rootstocks on foliar manganese (Mn) and boron (B) content in Arkansas and Massachusetts.

	Mn (ppm)						B (ppm)			
Rootstock	1984	1986	1987	1988	1989	Avg.	1987	1988	1989	Avg.
Arkansas										
MAC.24	268bc[z]	200b	310b		249b	257bc	54.5ab		35.7b	45.1b
OAR 1	223c	184b	306b		260b	241c	60.0a		41.2a	50.1a
M.7 EMLA	227c	193b	299b		225b	236c	50.5bc		34.9b	43.1bc
M.26 EMLA	315abc	229b	296b		249b	274bc	44.6cd		33.8b	39.2cd
O.3	302abc	214b	356b		252b	285bc	50.4bc		34.5b	43.0bc
M.9 EMLA	287abc	191b	301b		244b	259bc	46.4bcd		34.0b	40.2bcd
M.9	227ab	226b	348b		271b	296b	39.4d		32.5b	36.0d
MAC.9	378a	306a	509a		396a	392a	50.0bc		35.2b	43.8bc
M.27 EMLA	276a	363a	522a		422a	415a	49.3bc		32.3b	41.7bc
Massachusetts										
OAR 1		48	86	60	62	64d	58	52	48	53a
M.7 EMLA		45	78	54	54	58d	46	40	42	42cd
M.26 EMLA		56	91	65	65	70b	46	39	42	42cd
O.3		37	66	37	49	47e	47	41	39	42cd
M.9 EMLA		39	76	47	56	56d	44	39	40	41cd
M.9		41	79	43	58	55d	45	40	39	41d
MAC.9		46	78	43	57	56d	50	43	41	45c
M.27 EMLA		95	110	95	98	100a	55	42	48	48b

[z]Mean separation within columns and sites by Duncan's New Multiple Range test, 5% level. Main effects of rootstock (Avg.) mean separation statistics are shown for MA. ns = not significantly different.

Correlations between mineral content, yield and growth were calculated for AR (Table 8). Although individual mineral element contents were significantly related to each other, to yield, and to trunk cross-sectional area (TCSA), none accounted for more than 36 percent of the variation (N * Zn, r = -.60). It is interesting to note significant negative correlations between yield and the elements K, Ca, Mn, and B, and between TCSA and Ca, Mg, and Mn.

Discussion

Site-specific management and soil characteristics account for some differences in tree nutrient content. Site was the largest source of variation for N (Tables 2 and 4). This variation in N could have been due to the different rates of annual N fertilizer applications at each site (see methods) or climatic and/or edaphic conditions (Table 1). In most years, less N fertilizer was applied in AR than either MA or ONT. The AR site, with low soil pH, may also have had limited N availability and thus low leaf N compared to other sites.

Soil pH of the AR sites may have affected other nutrient levels. Trees in AR were low in P (Table 6), perhaps below sufficiency ranges (14), due to low pH as well as low soil P (Table 1). Low foliar Zn (average 14.8 ppm) and Cu (average 5.2 ppm) in AR may be attributed to soil pH. Conversely, trees in AR had very high Mn levels (Table 6) and expressed symptoms of Mn toxicity-induced internal bark necrosis (3). Manganese toxicity had been associated with low soil pH. Massachusetts had low soil Mn content and Mn levels substantially lower than AR.

Although ONT had higher soil Ca levels (Table 1), trees did not necessarily have higher Ca levels when data of rootstocks and years were averaged (Table 3).

Table 7. The influence of rootstock on foliar nutrient content of phosphorous (P) in Arkansas, and zinc (Zn) in Massachusetts.

Rootstock	1982	1983	1984	1985	1986	1987	1988	1989	Avg.
Arkansas[z]					P (%)				
MAC.24	0.11ab[z]	0.12ab	0.11c	0.11	0.11	0.05d	0.130a	0.11	0.108bc
OAR 1	0.08cd	0.12ab	0.11c	0.11	0.11	0.04d	0.115bcd	0.11	0.102c
M.7 EMLA	0.11ab	0.12ab	0.15a	0.12	0.11	0.09a	0.127ab	0.12	0.119a
M.26 EMLA	0.13a	0.13a	0.11c	0.11	0.11	0.09a	0.121ab	0.11	0.110abc
O.3	0.09bcd	0.11ab	0.14b	0.12	0.11	0.04d	0.118abc	0.12	0.111abc
M.9 EMLA	0.07d	0.13a	0.14b	0.11	0.11	0.07abc	0.118abc	0.12	0.112ab
M.9	0.11ab	0.11ab	0.11c	0.11	0.11	0.07c	0.103bcd	0.11	0.102c
MAC.9	0.10abc	0.12ab	0.10c	0.10	0.11	0.07bc	0.108cd	0.10	0.105bc
M.27 EMLA	0.11abc	0.10b	0.11c	0.11	0.10	0.09a	0.105d	0.11	0.105bc
				ns	ns			ns	
Massachusetts					Zn (ppm)				
O.3					56cd	55bc	30b	27cd	39
M.7 EMLA					52d	34d	32b	24d	35
M.9 EMLA					66ab	48b	33b	29cd	42
M.26 EMLA					63abc	46bc	38ab	27cd	43
M.27 EMLA					73a	64a	45a	53a	58
M.9					66ab	63a	39ab	34bc	50
MAC.9					67ab	64a	33b	40b	51
OAR 1					62bc	38cd	33b	24d	38

[z]Mean separation within columns for Arkansas data and for rootstock by year interaction for Massachusetts data by Duncan's New Multiple Range test, 5% level. ns = not significantly different.

Foliar mineral content was affected to a greater extent by location and/or year than by rootstock when sites were compared or comparisons were made within sites. The interactions of rootstock and year or location were minimal or non existent when data from all sites were pooled. The rootstock by year interaction was significant for several elements (N, K, Ca, Mg) in AR and MA, but accounted for a smaller percentage of the variation than did year. Other reports have indicated weak or no interaction between rootstocks and cultivars (2, 13, 15, 16, 17, 18). Together, these observations and reports indicate that the variation due to rootstock is a consistent phenomena and foliar nutrient content is attenuated by cultivar, location, and year.

While rootstocks did affect nutrient content in some years and sites, N, K, Ca, Mg, B and Zn levels were within a range considered adequate or sufficient (14) and no rootstock resulted in a specific nutrient deficiency. However, in low pH soil of AR, the rootstocks MAC.9 and M.27 EMLA resulted in Mn levels twice that of reported sufficiency levels (14).

As was observed in this study, other reports noted variation of some nutrient contents due to rootstock. Generally, rootstock has been reported to have minimal or no consistent effect on N and K levels across a number of sites, years, and cultivars (2, 13, 15, 16, 17, 18). Reports of rootstock variation in N and K ranged from 5 to 10 percent of the mean within studies and may have been due to differences in crop load, vegetative growth, or variability in sampling. In AR, K, Ca, and Mg were most variable with coefficients of variation of 24, 28 and 21 percent (across years and replications), respectively. These were greater than the variation for N, P, and Mn.

Previous reports indicated that trees on M.9 had higher foliar Ca and Mg

Table 8. Correlation Coefficients (r) for foliar mineral contents, yield and growth of 'Starkspur Supreme Delicious' on nine apple rootstocks grown in Arkansas during the period 1981-1989.

Variables	Correlation Coefficients (r) Variables													
Variables	P	K	Ca	Mg	Mn	Zn	B	Cu	Yield	TCSA	Inc. TCSA	% Inc. TCSA	Yield Eff.	Incr. Yield Eff.
N	.28°°	ns	ns	.09°	ns	-.60°°	ns	ns	.30°°	ns	.09°°	ns	.17°°	.13°°
P		.16°°	.17°°	.30°°	-.19°°	-.56°°	ns	ns	.13°°	-.09°	ns	.31°°	.13°°	ns
K			.36°°	.10°	ns	.22°	ns	ns	-.21°°	ns	ns	.29°°	-.27°°	-.21°°
Ca				.24°°	ns	.28°°	ns	ns	-.19°°	-.27°°	-.19°°	.16°°	-.21°°	-.11°°
Mg						.24°°	ns	ns	ns	-.11°	-.10°	.20°°	ns	ns
Mn						.20°	ns	ns	-.19°°	-.34°°	-.39°°	-.30°°	ns	ns
Zn							--	.34°°	ns	ns	ns	ns	ns	ns
B								--	-.44°°	ns	ns	-.34°°	-.42°°	-.28°°
Cu									ns	ns	ns	ns	-.58°°	ns
Yield										.70°°	.40°°	-.27°°	.77°°	.32°°
TCSA											.75°°	-.29°°	.40°°	.14°°
Inc. TCSA												.14°°	.13°°	ns
% TCSA													-.36°°	-.25°°
Yield Efficiency														.48°°

TCSA = total trunk cross sectional area; Incr. TCSA = Increase in TCSA each year; % Inc. TCSA = percent increase in TCSA each year. Eff. = Yield efficiency (kg/cm² TCSA); Incr. Eff. = increment yield efficiency (kg fruit/incr. TCSA).
°° = significant at 1% level, ° = significant at 5% level, ns = not significant.

than trees on M.7 (16, 18). Data pooled across sites and years suggest that trees on M.9 had significantly higher Ca, and M.9 EMLA and MAC.9 had 14 to 17% greater leaf Ca than M.7 EMLA (Table 5). But, no differences were observed for leaf Mg. Trees on MAC.9 had among the highest leaf Ca compared to trees on other rootstocks and the greatest difference between MAC.9 and other trees on other stocks (except M.9) was observed in MA. It is interesting to note that Autio et al. (1) reported that fruit from MAC.9 had higher Ca levels and were firmer in storage than trees on other rootstocks.

The rootstocks M.9 and M.9 EMLA were compared in this trial and did not significantly differ in nutrient contents. Bould and Campbell (6) reported that virus-free trees had higher nutrient content than infected trees in the first year growth but by the third year the differences were not significant. MAC.9, a seedling of M.9, had nutrient contents similar to M.9 and M.9 EMLA.

When nutrient element content is compared to tree size and production data previously published (11), no consistent relationships between tree size, productivity and nutrient content were apparent. Likewise, correlations from the AR site demonstrated that although some relationships exist, tree size and yield explain very little variation in nutrient content. This observation concurs with Dzamic et al., (7) who, working with 'Golden Delicious' on 4 rootstocks, reported no difference in leaf mineral content attributable to rootstock vigor. Lockard and Schnieder (10) did not attribute rootstock-controlled tree size and precocity traits to rootstock differences in mineral nutrition.

In conclusion, it is horticulturally important to be aware of rootstock caused variation in nutrient content. However, differences caused by rootstock were small and less variable than either annual variation or between-site variation.

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Micropropagation of Cold Hardy Dwarfing Apple Rootstocks

Micropropagation was achieved readily with P.22 and O.3 with shoot production and rooting increasing to high levels following subculture for 6-9 months. With P.2 shoot production and rooting was low in spite of subculture for 38 months. Nevertheless some improvement in shoot production on culture medium with phloroglucinol (PG) and increased cytokinin, and 80-90% of shoots rooted on medium with PG. With B.9 shoot production was similar to that with O.3 but rooting remained poor in spite of subculture for 39 months. In a line of B.9 subcultured for 4 years, 73% rooting was achieved *in vitro* on medium with PG and 96% by direct transfer of shoots to sand following a dip in IBA.

From Webster and Jones. 1991. *J. Hort. Sci.* 66:1-6.