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Leaf Elemental Concentrations as Influenced by Growth Habit and Strains of 'Delicious' Apples

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Abstract

Leaf elemental concentrations and leaf fresh and dry weights and their relationship with yield efficiency in twenty-eight strains of 'Delicious' apple (*Malus domestica* Borkh.) with two types of growth habit (spur and standard) were evaluated over two years. Cluster analysis of leaf elemental concentrations divided strains into groups approximately corresponding to growth habit. 'Starkspur Ultrared' and 'Wellspur,' which are classified as spur types, tended to group with the standard type strains on the basis of elemental concentration. Strains with a spur type growth habit had more fluctuation in yield from year to year and had higher leaf fresh and dry weights, leaf Ca, Mg, Zn, Mn, and Cu, but lower leaf K than standard type strains. 'Early Red One,' 'Starkspur Supreme,' 'Starkspur Ultrared,' and 'Redchief' had higher concentrations of leaf N, while 'Aomori,' 'Apex,' 'Classic Red,' 'Improved Ryan Spur,' and 'Red King Oregon Spur' had lower leaf N than many other strains. 'Aomori' had a higher leaf K and lower leaf Ca, but 'Hardi-Brite Spur' had lower K and higher leaf Ca than other strains. 'Imperial' and 'Improved Ryanred' were among strains with high leaf Fe and 'Improved Ryan Spur' and 'Ace' had low Fe. 'Silverspur' had the highest leaf Zn and Mn, making it desirable for areas with deficiencies of these elements. 'Spured Royal' had a higher concentration of leaf Cu than most other strains.

Introduction

The original 'Delicious' apple was discovered in 1879. Today, there are over 100 strains (13) and 'Delicious' constitutes 37% of the apples grown in the world (3). It is also the major apple cultivar grown in Idaho (15).

'Delicious' strains are mainly selected for growth habit (spur or standard type), yield, fruit color and fruit shape (4, 5, 9, 13, 14, 16, 19, 20, 21, 25, 27, 28, 29). Warrington et al. (26) reported that spur type strains had higher spur densities (spur/meter of branch), spur leaf number, leaf area per spur, area per leaf, and terminal bud diameters than standard type strains. They also found a positive correlation between spur density and yield efficiency. Productivity of 'Delicious' strains has been reported in Alabama (6), Idaho (9), Ohio (11, 12), Michigan (26), Washington, (20), and West Virginia (2, 26). 'Starking' had the largest trunk cross-sectional area in Idaho (9), Oregon (28) and Michigan (26). Lord et al. (21), in a study of nine 'Delicious' strains, reported that cumulative yields per tree of most standard strains were higher than those of spur strains.

The effect of major apple cultivars on leaf elemental concentration has been reported by several researchers (1, 7, 24). Emmert (7) reported that 'Delicious' apple had higher leaf N, P, K, and Mg than 'McIntosh' or 'Cortland.' Awad and Kenworthy (1) found that leaf N and B were higher in 'Delicious' than in 'Jonathan,' 'McIntosh,' and 'Northern Spy' apple.

Very few researchers have studied the elemental status of various 'Delicious' strains. Westwood et al. (28) compared four sports of 'Delicious' apple for their growth and leaf elemental concentrations and reported that 'Starking' had less leaf N than 'Chelan Red,' 'Starkrimson,' and 'Idaho Spur.' In their report, leaf P, K, Mg, B, Mn, and Zn were similar in all strains. Westwood and Zielinski (30) found that 'Starkrimson' had higher leaf N and chlorophyll than 'Starking' with

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other elements showing no significant differences.

In spite of the importance of 'Delicious' apple, no comprehensive information is available concerning effects of spur vs. standard growth habit on mineral content. Our objective was to measure the leaf fresh and dry weights and elemental concentrations of twenty-eight strains of 'Delicious' with spur and standard growth habits and to investigate relationships between elemental concentrations and yield efficiency.

Materials and Methods

Twenty-eight strains of 'Delicious' on M.7 rootstock were planted at the University of Idaho Parma Research and Extension Center in 1980. Tree spacing was 3.6 x 6.1 m. Trees were trained as a modified central leader and pruned in late February every year. The orchard was irrigated with an under tree sprinkler system every 10 days during the growing season and weeds were controlled chemically. Fruit were thinned chemically with carbaryl (Sevin 50 WP) at the rates of 150-300 ppm, 15-20 days after full bloom. Fruit were also hand thinned in early June if needed. Nitrogen (urea, 46% N) was applied annually in early spring at the rates of 45 to 318 g actual N per tree, depending on the age of the trees. Zinc-50 (50% Zn, 4.5% S, derived from $ZnSO_4$) was sprayed annually at late dormant stage at the rate of 22.4 kg/ha. No other macro or microelements were applied to the trees during the course of this experiment to study the growth habit and strain effects. Other cultural practices were similar to those of commercial orchards.

The experimental design was a randomized complete block design with six blocks and single tree replications within blocks. Long term effects of strains on tree growth, yield and fruit quality and storability have been reported elsewhere (9). However, yield efficiencies for 1990 and 1991 (yield/trunk cross sectional area (TCSA) in 1991) and cumulative yield efficiency (cumulative yield over 1990 and 1991 seasons/1991 TCSA) are reported here to provide information on the relationship between various elements and yield. Biennial bearing index (BBI) was also calculated as: absolute value of 1990 minus 1991 yields divided by average yield over the 1990-91 seasons. Full bloom dates were 12 April 1990 and 25 April 1991.

Forty leaves per tree were sampled randomly in late August in 1990 and 1991 from the middle of current-season shoots. Leaves were weighed, washed in a mild Liqui-nox solution, rinsed with distilled water and dried in a forced air oven at 65° C to a constant weight.

Leaves were re-weighed after drying and the percentage dry weight was calculated. Dried leaves were then ground to pass a 40-mesh screen. The leaf tissue was analyzed for N by a Kjeldahl method (23), and for K, Ca, Mg, Fe, Zn, Mn, and Cu by dry ashing at 500° C, digestion and atomic absorption spectrophotometry (Perkin-Elmer 1100 B, Norwalk, Connecticut) as described by Jones (17). Mineral elements were expressed on a dry weight basis.

Preliminary univariate and multivariate analyses of variance were performed on all the responses using the SAS General Linear Models procedure (22). Year was considered a subplot factor and the model included the effects Block, Strain, Year, Block x Strain, and Strain x Year. Since the Strain x Year effect was significant, subsequent analyses were conducted separately for each year. Relationships among the strains were visualized by performing average-linkage cluster analyses (22) on the standardized leaf N, K, Ca, Mg, Fe, Zn, Mn, and Cu. Dendrograms were drawn using SAS macro. On the basis of the dendrograms from cluster analysis, groups of strains were identified, and hypotheses formulated about group membership. Hypotheses were tested by constructing single-degree-of-freedom comparisons in multivariate analyses of variance of the element concentration data.

Values over each of the spur or strain growth habits were pooled, and differences between growth habits were tested using the T test.

Analyses of variance (ANOVA) were computed for yield efficiency for 1990, 1991, and for the cumulative yield efficiency over the two years. Analyses of variance were also computed for leaf fresh and dry weights and leaf elemental concentrations for 1990 and 1991 and for the average of 1990 and 1991 growing seasons, using SAS (22). Least significant differences (LSD) at p 0.05 were computed for comparison of strains.

Results and Discussion

Multivariate Analysis: Cluster analysis based on 1990 elemental concentrations clearly divided the strains into two groups (Fig. 1). Group 1 consists of only spur type strains. Group 2 contains all standard type strains, plus two of the spur types, 'Wellspur' and 'Starkspur Ultrared.' Multivariate analysis of variance showed that these two strains were significantly different from other spur types with regard to leaf elemental concentrations ($p < 0.0001$). The standard type group, including the two atypical spur type strains, was significantly different from the main spur type group ($p < 0.0001$).

When cluster analysis was performed on the 1991 leaf elemental concentrations, three groups were discerned (Fig. 2). Group 1 consisted, again, of only spur types. Group 2 (the large

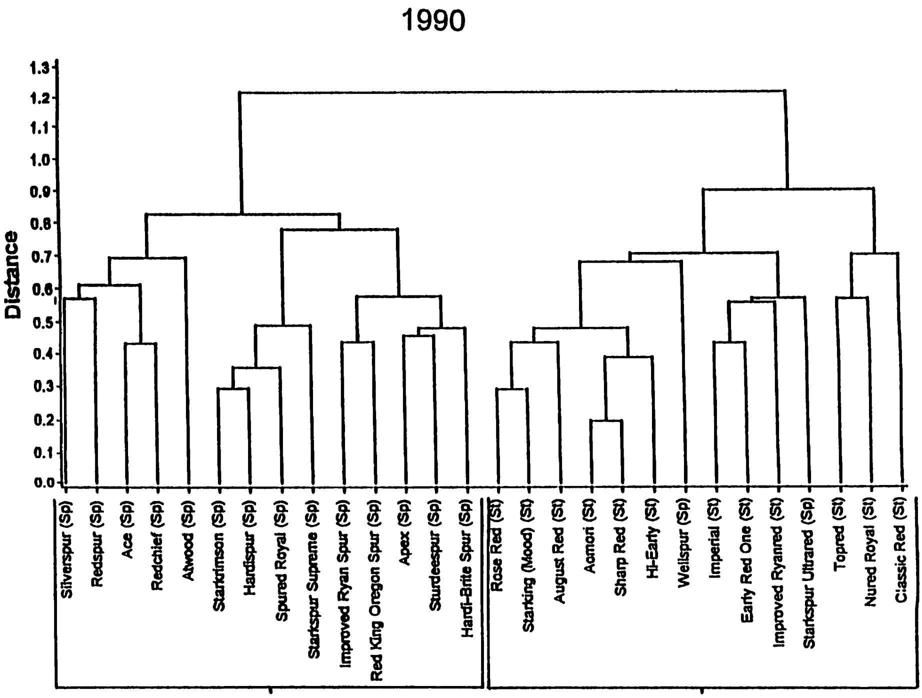

Figure 1. Dendrogram representing standardized distance between strains in average-linkage cluster analysis of leaf N, K, Ca, Mg, Fe, Zn, Mn and Cu concentrations of 28 'Delicious' strains in 1990.

group in the center of the dendrogram) contained all the standard types, plus four of the spur types. As in 1990, these included 'Wellspur' and 'Starkspur Ultrared.' In 1991, 'Redspur' and 'Starkrimson' also fell into group 2 (Fig. 2). These four spur type strains with atypical behavior were significantly different from the main group of spur types ($p < 0.002$). Group 3 consisted of 'Hardi-Brite Spur' (a spur type strain) which was clearly separated from all other strains. Multivariate analysis of variance of leaf elemental concentrations also showed 'Hardi-Brite Spur' to be different in behavior from all other strains jointly considered ($p < 0.0001$). The standard-like group, including the four atypical spur type strains, was again significantly different from the main spur type group ($p < 0.0001$).

'Wellspur' is a limb sport and 'Starkspur Ultrared' is a whole tree sport of 'Starking' (13). Several other strains in this study also originated from 'Starking.' The reason for these two spur type strains behaving nutritionally like standard types is not clear and warrants further study.

Effects Of Growth Habit: Yield (9) and yield efficiency of most strains were lower in 1991 than those of 1990 (Tables 1 and 2), because low temperatures in the Pacific Northwest in December 1990 and January 1991 damaged bud and wood tissues. This reduction was less severe in strains with a standard type growing habit than in spur type strains (Tables 1 and 2). Severity of biennial bearing in spur type strains may have also contributed to the 1991 yield reduction. Biennial bearing indices of 'Apex,' 'Atwood,'

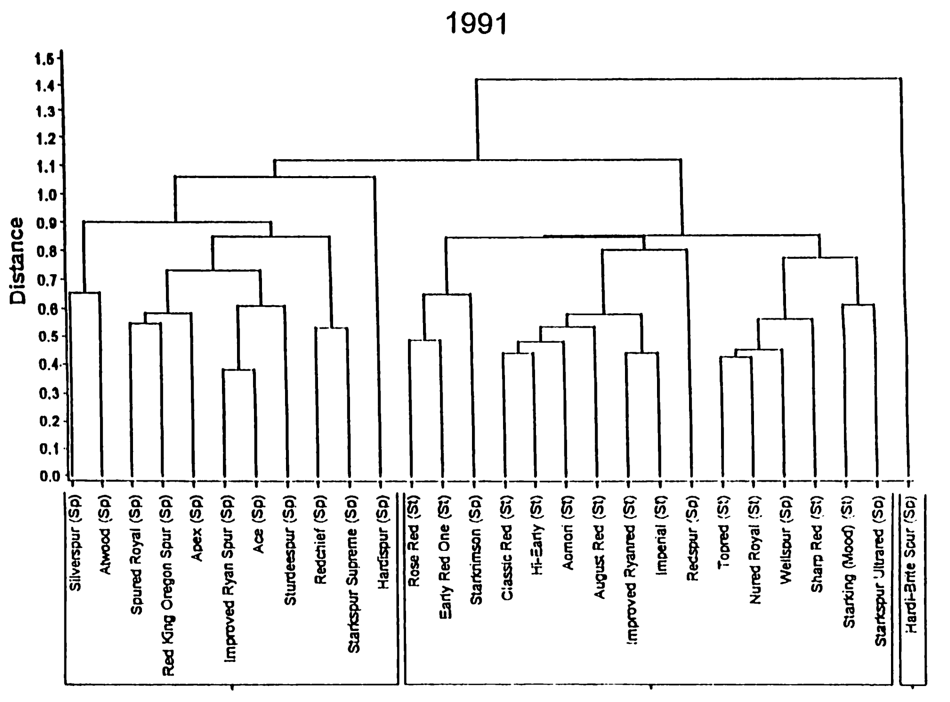

Figure 2. Dendrogram representing standardized distance between strains in average-linkage cluster analysis of leaf N, K, Ca, Mg, Fe, Zn, Mn and Cu concentrations of 28 'Delicious' strains in 1991.

Table 1. Yield efficiency, biennial bearing index (BBI), leaf weight and leaf elemental concentrations as influenced by two growth habits of 'Delicious' apple in 1990 and 1991.[z]

Growth habit	Yield efficiency (kg.cm^{-2}) '90	Cumulative '91	'90 & '91	BBI	Fresh wt/leaf (g) '90	'91	Avg	Dry wt/leaf (g) '90	'91	Avg	Leaf % Dry wt. '90	'91	Avg	N (%) '90	'91	Avg	K (%) '90	'91	Avg
Spur	0.80	0.26	1.06	1.09	.73	.74	.74	.28	.29	.29	62.1	60.3	61.2	1.84	1.76	1.80	1.42	1.69	1.56
Standard	0.50	0.39	0.89	0.67	.72	.65	.69	.27	.25	.26	62.3	60.7	61.5	1.78	1.81	1.80	1.78	1.72	1.75
Significance[y]	***	***	***	***	NS	***	**	NS	***	**	NS	NS	NS	**	NS	NS	***	NS	***

Table 1. (Cont.)

	Ca (%) '90	'91	Avg	Mg (%) '90	'91	Avg	Fe (ppm) '90	'91	Avg	Zn (ppm) '90	'91	Avg	Mn (ppm) '90	'91	Avg	Cu (ppm) '90	'91	Avg
Spur	1.27	1.40	1.33	.27	.30	.28	64.8	101.2	83.0	13.7	13.1	13.4	46.4	41.1	43.8	12.1	10.9	11.5
Standard	0.95	1.14	1.05	.25	.28	.27	64.7	112.3	88.5	11.1	12.0	11.6	36.6	38.7	37.6	11.5	10.0	10.7
Significance	***	***	**	***	***	***	NS	**	**	***	***	***	***	*	***	*	***	***

[z]Elements are expressed on a dry weight basis.
[Y]Means within the columns are significant at $P \leq 0.001$ if shown by ***; at $P \leq 0.01$ if shown by **; at $P \leq 0.05$ if shown by *; and not significant if shown by NS.

'Hardispur,' 'Improved Ryan Spur,' 'Redchief,' 'Redspur,' 'Silverspur,' 'Spured Royal,' 'Starkrimson,' and 'Sturdeespur,' all with a spur type growth habit, were more drastic than in other strains (Table 2).

Over-all, leaves of strains with a spur type growth habit had higher fresh weight and dry weight than leaves of standard strains in 1991, while percentage of dry matter in both types was similar in both 1990 and 1991 (Table 1).

In general, leaf N in spur type strains was higher than that in standard strains in 1990 (Table 1). However, there was no significant difference in leaf N between spur and standard types in 1991 or in the average value over the two seasons (Table 1).

Regardless of growth habit, leaf N levels in the 10 to 11 year-old trees in this study were about 30% lower (Tables 1 and 3) than those reported by Westwood and Zielinski (30) with 3- to 4 year-old trees. Leaf N differences between the 2 reports could in part be due to the age differences.

Over-all, strains with a spur type growth habit had lower leaf K and Fe, but higher leaf Ca, Mg, Zn, Mn, and Cu than standard types (Table 1).

Effects of Strains on Leaf Weight and Macroelements: Leaf fresh and dry weights were highest in 'Ace,' 'Hardi-Brite Spur,' 'Improved Ryan Spur,' and 'Red King Oregon Spur'; and lowest in 'Atwood,' 'Early Red One,' 'Imperial,' 'Improved Ryanred,' and 'Rose Red' over 1990 and 1991 seasons (Table 2). However, fewer differences were found among strains in their leaf percentage dry matter (Table 2). Leaves of 'Wellspur' had significantly higher average percent dry mat-

Table 2. Yield efficiency, biennial bearing index (BBI) and leaf fresh and dry weights of various strains of 'Delicious' apple in 1990 and 1991.

Strain	Growth Habit[z]	Yield efficiency (kg.cm^{-2})			BBI	Fresh wt/leaf (g)			Dry wt/leaf (g)			% Dry wt		
		'90	'91	Cumulative 90 & 91		'90	'91	Avg. 90 & 91	'90	'91	Avg. 90 & 91	'90	'91	Avg. 90 & 91
Ace	Sp	0.43	0.17	0.60	1.00	.782	.872.	827	.299	.364	.331	61.8	57.9	59.9
Aomori	St	0.38	0.38	0.76	0.54	.748	.708	.728	.286	.274	.280	61.9	61.3	61.6
Apex	Sp	0.89	0.18	1.07	1.41	.672	.761	.717	.250	.300	.275	62.9	60.4	61.7
Atwood	Sp	0.64	0.20	0.84	1.12	.588	.709	.649	.217	.283	.250	63.1	60.1	61.6
August Red	St	0.52	0.46	0.98	0.45	.772	.636	.704	.291	.253	.272	62.3	60.2	61.2
Classic Red	St	0.63	0.38	1.01	0.58	.779	.661	.720	.300	.261	.280	61.5	60.4	61.0
Early Red One	St	0.69	0.38	1.07	0.82	.683	.598	.641	.262	.229	.245	61.8	61.8	61.8
Hardi-Brite Spur	Sp	0.84	0.57	1.41	0.41	1.059	.771	.915	.402	.305	.353	61.8	60.3	61.0
Hardispur	Sp	0.92	0.11	1.03	1.59	.601	.715	.658	.228	.292	.260	62.4	59.3	60.8
Hi-Early	St	0.40	0.45	0.84	0.71	.771	.644	.708	.294	.248	.271	61.9	61.5	61.7
Imperial	St	0.57	0.29	0.85	0.83	.554	.594	.574	.207	.228	.218	62.7	61.6	62.1
Improved Ryanred	St	0.45	0.30	0.74	0.97	.618	.580	.599	.229	.226	.228	62.9	61.0	61.9
Improved Ryan Spur	Sp	0.96	0.31	1.27	1.09	.816	.930	.873	.307	.364	.336	62.3	60.8	61.6
Nured Royal	St	0.56	0.37	0.92	0.56	.837	.724	.781	.323	.288	.305	61.4	60.2	60.8
Redchief	Sp	1.13	0.36	1.50	1.06	.683	.680	.682	.264	.265	.265	61.3	60.8	61.1
Redspur	Sp	0.82	0.11	0.93	1.53	.588	.733	.661	.220	.286	.253	62.7	60.9	61.8
Red King Oregon Spur	Sp	0.91	0.39	1.30	0.79	.831	.794	.812	.323	.317	.320	61.3	60.0	60.7
Rose Red	St	0.51	0.31	0.82	0.66	.704	.591	.648	.264	.228	.246	62.6	61.3	61.9
Sharp Red	St	0.37	0.44	0.81	0.50	.694	.677	.685	.258	.269	.264	62.8	60.2	61.5
Silverspur	Sp	0.97	0.09	1.07	1.65	.697	.737	.717	.262	.292	.277	62.6	60.4	61.5
Spured Royal	Sp	0.78	0.22	1.01	1.24	.603	.698	.651	.225	.273	.249	62.9	60.8	61.8
Starking (Mood)	St	0.54	0.55	1.09	0.53	.811	.658	.735	.307	.264	.286	62.2	59.8	61.0
Starkrimson	Sp	0.74	0.19	0.93	1.18	.781	.702	.742	.304	.278	.291	61.3	60.3	60.8
Starkspur Supreme	Sp	0.67	0.34	1.01	0.78	.727	.668	.698	.279	.264	.272	61.7	60.5	61.1
Starkspur Ultrared	Sp	0.69	0.32	1.01	0.74	.797	.701	.749	.316	.280	.298	60.7	60.1	60.4
Sturdeespur	Sp	0.66	0.12	0.78	1.28	.764	.715	.740	.292	.275	.284	61.8	61.4	61.6
Topred	St	0.43	0.37	0.81	0.67	.726	.718	.722	.262	.292	.277	64.1	59.5	61.8
Wellspur	Sp	0.78	0.44	1.22	0.54	.697	.697	.697	.256	.270	.263	63.4	61.1	62.3
LSD at $P \leq 0.05$		0.32	0.18	0.37	0.52	.179	.101	.108	.072	.042	.044	1.5	2.2	1.5

[z]Growth habit abbreviations: Sp = Spur type; St = Standard type.

ter than those of 'Ace' and 'Starkspur Ultrared' (Table 2). No significant difference was observed between 'Starkrimson' and 'Starking' leaf weights (Table 2), which differs from an earlier report by Westwood and Zielinski (30) where 'Starkrimson' had a higher leaf dry matter than did 'Starking.'

Leaf N values in most strains did not change substantially between 1990 and 1991 (Table 3) in spite of the yield efficiency differences in these seasons (Table 2). Leaf N concentration in 'Starkrimson' was significantly higher than in 'Starking' in 1990 (Table 3) which agrees with the data of Westwood and Zielinski (30). 'Early Red One,' 'Starkspur Supreme,' 'Starkspur Ultrared,' and 'Redchief' had higher levels of leaf N, while 'Aomori,' 'Apex,' 'Classic Red,' 'Improved Ryan Spur' and 'Red King Oregon Spur' had lower leaf N than other strains over both seasons (Table 3). High leaf N in 'Early Red One' and 'Redchief' (Table 3) did not adversely affect the fruit color in these strains (9), although high leaf N and fruit color are often negatively correlated (10). Leaf N levels in none of the evaluated strains was exceedingly high (higher than 2.0%) either in 1990 or 1991, thus did not adversely affect the fruit color.

All of the 16 spur type strains had lower leaf K in 1990 than in 1991, and 13 of these strains were deficient (18) for leaf K in 1990 (Table 3). Biennial bearing indices of these 13 strains were high (Table 2), indicating a high yield fluctuation over 1990 and 1991 seasons (Table 2), leading to a strong correlation coefficient between leaf K and BBI ($r = -.34$ in 1990 and $r = .44$ in 1991). All standard strains had low yield fluctuations (Table 2), and thus low BBI and sufficient leaf K (18) in both 1990 and 1991 seasons (Table 3). A higher leaf-fruit competition (8) in 1990 could have contributed to K deficiency in 1990 (r value between yield efficiency and leaf K was -0.48 in 1990 and -0.49 in 1991). Therefore, fluctuation of leaf elements, particularly leaf K, as a result of yield variation must be taken into account for interpreting results of leaf analysis before any recommendation is made for K fertilizer application.

'Starkspur Ultrared' and 'Wellspur,' two of the spur type strains that appeared among the standard type strains in the cluster analysis (Figs. 1 and 2), were behaving like standard type strains, showing low BBI (Table 2) and sufficient leaf K (Table 3) in both seasons.

'Redchief' is one of the most commonly used strains in the Northwest, mainly because of its relatively high yield efficiency (smaller trees) (Table 2), and also good fruit color and typiness. However, leaf K concentrations in this strain were low to deficient in both 1990 and 1991 (Table 3) when compared with standard levels (18) and should, therefore, be closely monitored.

'Aomori' had a higher average leaf K and lower leaf Ca than most other strains, which could be due to its low average yield efficiency over the 1990 and 1991 seasons (Table 2) and/or low leaf N (Table 3). 'Hardi-Brite Spur' had lower leaf K and higher leaf Ca than all other strains (Table 3). Leaves of this strain had higher average fresh weight and dry weight than other strains (Table 2). Since Ca is immobile in the leaf tissue, a heavier and perhaps larger leaf of this strain could have led to a higher accumulation of leaf Ca.

Leaf K had significant positive correlations with fruit soluble solids after storage ($r = 0.53$ in 1990 and $r = 0.37$ in 1991). Leaf N was negatively correlated with both fruit soluble solids ($r = -0.36$ in 1990 and $r = -0.27$ in 1991) and leaf K ($r = -0.41$ in 1990 and 1991). The negative correlations between leaf N and K, therefore, could be in part responsible for the positive correlations between leaf K and fruit soluble solids.

Leaf Ca levels in most strains were higher and yield efficiency lower in

Table 3. Leaf macronutrient concentrations in various strains of 'Delicious' apple in 1990 and 1991.[z]

Strain	Growth[y] Habit	N (%) '90	N (%) '91	N Avg. 90 & 91	K (%) '90	K (%) '91	K Avg. 90 & 91	Ca (%) '90	Ca (%) '91	Ca Avg. 90 & 91	Mg (%) '90	Mg (%) '91	Mg Avg. 90 & 91
Ace	Sp	1.88	1.76	1.82	1.36	1.61	1.48	1.21	1.39	1.30	0.273	0.301	0.286
Aomori	St	1.67	1.76	1.72	1.93	1.91	1.92	0.90	1.06	0.98	0.246	0.261	0.253
Apex	Sp	1.79	1.70	1.74	1.45	1.81	1.63	1.29	1.45	1.37	0.280	0.289	0.284
Atwood	Sp	1.79	1.72	1.76	1.49	1.73	1.64	0.98	1.31	1.15	0.261	0.305	0.283
August Red	St	1.81	1.74	1.78	1.86	1.68	1.77	0.95	1.05	1.00	0.244	0.262	0.253
Classic Red	St	1.72	1.75	1.74	1.73	1.77	1.75	0.98	1.10	1.04	0.268	0.284	0.276
Early Red One	St	1.91	1.89	1.90	1.66	1.64	1.65	1.01	1.17	1.09	0.248	0.276	0.262
Hardi-Brite Spur	Sp	1.83	1.77	1.80	1.32	1.37	1.34	1.52	1.84	1.68	0.276	0.301	0.288
Hardispur	Sp	1.85	1.67	1.76	1.36	1.76	1.56	1.31	1.48	1.39	0.276	0.366	0.321
Hi-Early	St	1.72	1.78	1.75	1.82	1.74	1.78	0.97	1.10	1.04	0.258	0.257	0.257
Imperial	St	1.85	1.78	1.81	1.78	1.86	1.82	0.89	1.17	1.03	0.234	0.269	0.251
Improved Ryanred	St	1.83	1.85	1.84	1.81	1.81	1.81	0.94	1.17	1.05	0.261	0.276	0.268
Improved Ryan Spur	Sp	1.81	1.68	1.74	1.32	1.64	1.48	1.37	1.36	1.36	0.266	0.312	0.289
Nured Royal	St	1.85	1.83	1.84	1.57	1.61	1.59	0.92	1.25	1.09	0.269	0.286	0.277
Redchief	Sp	1.92	1.85	1.89	1.35	1.55	1.45	1.27	1.46	1.36	0.283	0.276	0.279
Redspur	Sp	1.92	1.69	1.81	1.48	1.89	1.68	1.21	1.20	1.21	0.253	0.286	0.269
Red King Oregon Spur	Sp	1.77	1.68	1.73	1.40	1.63	1.51	1.26	1.42	1.34	0.269	0.299	0.284
Rose Red	St	1.78	1.81	1.79	1.80	1.72	1.76	1.00	1.15	1.07	0.253	0.301	0.277
Sharp Red	St	1.68	1.82	1.75	1.85	1.69	1.77	0.90	1.11	1.01	0.247	0.297	0.272
Silverspur	Sp	1.87	1.72	1.80	1.38	1.97	1.68	1.25	1.25	1.25	0.266	0.308	0.287
Spured Royal	Sp	1.90	1.68	1.79	1.42	1.76	1.59	1.41	1.49	1.45	0.274	0.313	0.293
Starking (Mood)	St	1.76	1.88	1.82	1.84	1.63	1.73	0.98	1.11	1.04	0.239	0.264	0.251
Starkrimson	Sp	1.88	1.80	1.84	1.36	1.73	1.55	1.31	1.33	1.32	0.281	0.297	0.289
Starkspur Supreme	Sp	1.87	1.85	1.86	1.40	1.58	1.49	1.20	1.34	1.27	0.272	0.284	0.278
Starkspur Ultrared	Sp	1.80	2.00	1.90	1.54	1.68	1.61	1.11	1.32	1.21	0.248	0.251	0.249
Sturdeespur	Sp	1.86	1.72	1.79	1.40	1.73	1.56	1.49	1.48	1.48	0.278	0.304	0.291
Topred	St	1.80	1.81	1.80	1.72	1.56	1.64	1.01	1.24	1.13	0.264	0.296	0.280
Wellspur	Sp	1.72	1.84	1.78	1.63	1.64	1.65	1.09	1.26	1.17	0.250	0.300	0.275
LSD at $P \leq 0.05$		.12	0.19	0.11	0.22	0.23	0.15	.21	0.24	0.18	0.036	0.039	0.03

[z]Elements are expressed on a dry weight basis.
[y]Growth habit abbreviations: SP = Spur type; St = Standard type.

1991 than in 1990 (Tables 2 and 3). The leaf-to-fruit ratio in 1991 would force more partitioning of Ca into the leaves. 'Starkrimson' had significantly higher leaf Ca than 'Starking' (Table 3), supporting the observations of Westwood and Zielinski (30).

'Hardispur' had higher leaf Mg, and 'Aomori,' 'August Red,' 'Starking,' and 'Starkspur Ultrared' had lower Mg than most other strains in both 1990 and 1991 (Table 3). Pooling all strains, a significant negative correlation existed between leaf K and Mg in both 1990 (r = -0.47) and 1991 (r = -0.31). The high leaf K concentration in 'Aomori' could have resulted in an antagonistic effect, leading to a low leaf Mg in this strain (Table 3).

Effects of Strains on Leaf Micronutrients: Among all leaf micronutrients, Fe increased drastically in all strains in 1991 compared to 1990 (Table 4), although no Fe material was applied to these trees in 1990 or 1991. This increase could not only be due to the yield decrease in 1991, because 'Aomori,' 'Hi-Early,' 'Sharp Red,' 'Starking,' and 'Topred,' in spite of their low BBI also had an increased Leaf Fe (Table 2).

'Imperial' and 'Improved Ryanred' were among strains with high leaf Fe while 'Improved Ryan Spur' and 'Ace' had low leaf Fe (Table 4).

'Silverspur' had higher leaf Zn and Mn than most other strains in both 1990 and 1991 (Table 4). This is a desirable characteristic, as Zn deficiency is a common and serious problem in apples in the Northwest.

'Spured Royal' had higher leaf Cu, while 'Nured Royal' had lower leaf Cu than several strains both in 1990 and 1991 (Table 4). Since the use of copper-based fungicides on apples has been limited in the last few years, efficiency of Cu uptake is very important and a desirable characteristic for any strain.

Conclusions

On the basis of leaf elemental concentrations, the twenty-eight strains could be divided into groups that approximately coincided with spur and standard growth habits. Sporadically, certain spur type strains behaved like standard cultivars with respect to leaf elemental concentration. Two of these, 'Starkspur Ultrared' and 'Wellspur' behaved like standard types both years.

Over-all, leaves of strains with a spur type growth habit had higher fresh weight and dry weight than leaves of standard strains, while percentage of dry matter in both types was similar. Leaf N in spur type strains was higher than that in standard type strains in 1990. Strains with a spur growth habit often had lower leaf K and Fe, but higher leaf Ca, Mg, Zn, Mn, and Cu than standard types. The capability and/or demand for higher accumulation of these elements in spur type strains should be taken into account when interpreting results of leaf elemental concentrations for 'Delicious' apples.

'Early Red One,' 'Starkspur Supreme' and 'Redchief' had higher leaf N than most other strains. The levels were not excessive, however, and had no adverse effect on fruit quality (9). 'Aomori' had lower leaf N, Ca, Mg, but higher leaf K than many other strains. 'Imperial' had high leaf K and Fe but low leaf Mg. Drastic year-to-year variations were found in concentrations of some elements. Potassium was in the deficient range in a high cropping year, but was sufficient in the following year when the crop was reduced. 'Silverspur' had higher concentrations of leaf Zn and Mn, which is a desirable characteristic for any fruit tree grown in orchards with a high soil pH. 'Silverspur' was also among the strains with high yield, yield efficiency, fruit weight, soluble solids after storage, and slow starch degradation pattern (9). Considering all of these desirable pomological and nutritional factors, 'Silverspur' is a

Table 4. Leaf micronutrient concentrations in various strains of 'Delicious' apple in 1990 and 1991.[z]

Strain	Growth[y] Habit	Fe '90	Fe (ppm) '91	Fe Avg. 90 & 91	Zn '90	Zn (ppm) '91	Zn Avg. 90 & 91	Mna '90	Mna (ppm) '91	Mna Avg. 90 & 91	Cu '90	Cu (ppm) '91	Cu Avg. 90 & 91
Ace	Sp	61.5	88.3	74.9	13.9	12.4	13.1	47.9	41.8	44.9	11.0	11.8	11.4
Aomori	St	67.2	112.5	89.8	10.7	12.0	11.4	37.0	38.4	37.7	11.6	9.9	10.7
Apex	Sp	62.8	114.0	88.4	14.2	12.6	13.4	46.6	40.2	43.4	12.4	10.5	11.5
Atwood	Sp	66.6	88.1	77.3	13.7	13.9	13.8	52.1	45.1	48.6	11.2	11.6	11.4
August Red	St	63.8	119.8	91.8	10.7	11.8	11.3	37.9	40.1	39.0	11.0	9.7	10.4
Classic Red	St	62.8	116.0	89.4	10.3	11.7	11.0	31.5	36.2	33.8	10.2	10.4	10.3
Early Red One	St	69.0	114.9	92.0	11.8	12.2	12.0	38.0	40.1	39.1	11.9	11.0	11.5
Hardi-Brite Spur	Sp	62.8	96.0	79.4	13.7	14.1	13.9	39.3	40.5	39.9	12.3	11.2	11.8
Hardispur	Sp	68.7	108.3	88.5	14.3	13.7	14.0	50.5	43.5	47.0	13.1	10.2	11.6
Hi-Early	St	63.9	106.3	85.1	10.3	11.2	10.8	34.8	36.7	35.7	11.3	10.0	10.6
Imperial	St	68.4	124.2	96.3	11.2	12.6	11.9	38.0	36.0	37.0	12.3	10.2	11.2
Improved Ryanred	St	64.9	123.6	94.2	12.0	12.4	12.2	38.7	39.6	39.2	12.2	10.2	11.2
Improved Ryan Spur	Sp	57.6	91.9	74.7	12.6	12.7	12.7	41.3	40.7	41.0	11.9	11.3	11.6
Nured Royal	St	58.6	108.4	83.5	11.3	12.6	11.9	35.9	36.8	36.3	10.3	9.3	9.8
Redchief	Sp	63.9	92.4	78.1	14.0	12.9	13.4	46.3	39.5	42.9	11.9	11.2	11.5
Redspur	Sp	64.4	99.4	81.9	13.6	12.6	13.1	47.0	35.5	41.2	10.8	10.9	10.9
Red King Oregon Spur	Sp	58.2	100.1	79.1	13.0	13.4	13.1	46.8	38.6	42.7	12.8	10.8	11.8
Rose Red	St	68.0	118.6	93.3	11.3	12.0	11.7	36.8	42.0	39.4	11.6	10.7	11.2
Sharp Red	St	64.8	98.7	81.7	11.0	12.1	11.5	37.3	41.4	39.4	11.7	9.7	10.7
Silverspur	Sp	67.2	96.6	81.9	14.7	14.1	14.4	55.9	44.1	50.0	10.7	10.7	10.7
Spured Royal	Sp	66.4	113.2	89.8	14.7	13.4	14.1	47.3	39.3	43.3	13.1	11.7	12.4
Starking (Mood)	St	67.6	107.7	87.6	11.0	11.7	11.3	37.9	39.6	38.7	11.9	9.1	10.5
Starkrimson	Sp	70.8	116.3	93.6	14.6	13.5	14.1	47.1	43.4	45.2	12.6	11.2	11.9
Starkspur Supreme	Sp	71.2	94.4	82.8	13.3	13.8	13.6	46.5	42.5	44.5	12.1	10.3	11.2
Starkspur Ultrared	Sp	68.8	110.1	89.4	13.0	12.6	12.8	40.3	40.3	40.3	11.9	9.3	10.6
Sturdeespur	Sp	62.9	103.5	83.2	12.8	12.1	12.4	49.5	45.1	47.3	12.6	11.2	11.9
Topred	St	57.2	96.6	76.9	11.7	11.8	11.7	35.4	37.4	36.4	11.7	9.7	10.7
Wellspur	Sp	62.6	106.2	84.4	12.7	12.3	12.5	38.3	37.4	37.8	12.6	10.6	11.6
LSD at $P \leq 0.05$		6.6	21.6	11.9	1.5	1.4	1.1	7.7	7.4	6.6	1.8	1.6	1.2

[z]Elements are expressed on a dry weight basis.
[y]Growth habit abbreviations: SP = Spur type; St = Standard type.

good choice among 'Delicious' strains for planting under the climatic conditions of the Northwest United States and other similar places worldwide.

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