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Minimal Nutrient Flux in Leaves of 'Fuji' Apple Trees on Two Rootstocks

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Abstract

The goal of this study was to monitor the seasonal trends of different nutrients in 'Fuji' apple leaves on M.9 337 and M.7 EMLA rootstocks for two years, and to determine 'Fuji's' period of minimal flux using regression analyses. The effects of rootstock on 'Fuji' seasonal trends and the interactions among leaf and fruit minerals were examined. The period of minimum flux for nitrogen in 'Fuji' apple leaves occurred at 40-140 days after full bloom (DAFB). Nitrogen (% d.wt.), K (% d.wt.) and Zn (p.p.m.) concentrations in leaves from trees on both rootstocks decreased during both growing seasons. Calcium (% d.wt.) and Mn (p.p.m.) concentrations increased in leaves from trees on both rootstocks throughout both years. Magnesium, Fe and Cu trends were inconsistent from year to year. However, seasonal fluctuations in leaves from trees on both rootstocks were always similar regardless of differences between years. Trees on M.7 EMLA had lower leaf N, but higher leaf K and Ca, than those on M.9 337 throughout both growing seasons. Rootstock effect on K levels was significant during both years. Calcium concentrations were not affected by rootstock in 1995, when the crop load was very light, but in the heavy cropping year 1996, the effect was significant. The period of minimal flux of N in 'Fuji' leaves from mid-June until September is little affected by crop or rootstock. The stable sampling period for foliar analysis of 'Fuji' apple extends from 40-140 DAFB, providing growers more time to respond to analytical results than the August-only sampling period appropriate for some other cultivars.

Introduction

The period of minimal nutrient fluctuation within the growing season is the preferred time for foliar analysis. Mineral concentrations within the leaves are most variable during shoot growth and just before leaf abscission. Minimal flux was determined for 'Red Delicious' and a few other cultivars by examining the fluctuations of leaf nutrient elements over a number of full growing season (11, 22, 27).

Foliar nutrient element fluctuations during the growing season reflect specific physiological states. Apple leaf N concentrations are highest when leaves first appear (12, 14, 20). Apple leaf N levels generally stabilize as shoot growth ceases and shoot tips harden. 'Red Delicious' leaves have a distinctive increase in N concentrations from 45-65 days after full bloom (DAFB) (22, 27). This fluctuation in 'Red Delicious' shortens its period of minimal flux. However, most cultivars that have been examined do not exhibit this early summer N gain. After steeply dropping from spring highs, leaf N in 'Bramley's Seedling,' 'Lord Lambourne' and 'Golden Delicious' all have flat or declining trends throughout the summer (11, 12). 'McIntosh' leaf N declines from spring highs into a stable plateau period that lasts until early autumn (3, 4).

The period of minimal flux for 'Fuji' has not been determined. 'Fuji' apple has been widely planted and topworked onto older trees in the Pacific Northwest in the last ten years. Its unique flavor and texture characteristics make it a high value fruit, but its unique qualities make it among the most difficult apples to grow (17). 'Fuji's' fruit characteristics, including long life in common storage, are inherited from its 'Ralls Janet' parent, not 'Red Delicious' (1).

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Determining 'Fuji's' season-long nutrient fluctuations can improve management of this difficult cultivar. Observations of a second flush of shoot growth by growers in southwestern Idaho suggest a unique varietal characteristic that may effect seasonal nutrient levels. Rootstock effects on 'Fuji' August mineral concentrations have been examined (9). But, season-long mineral studies can provide fuller, cultivar-specific standards against which results from a single, annual analysis can be compared. In addition, a seasonal study will provide early measurements whose values and ratios can provide important information on tree nutrition and ultimate fruit quality characteristics. In this study, the main objectives were to investigate the seasonal fluctuations of N, K, Ca, Mg, Fe, Zn, Cu, and Mn in 'Fuji' apple leaves and to determine the period of minimal nutrient fluctuation that is appropriate for sampling. Interactions among leaf nutrient elements and between leaf and fruit minerals were also examined.

Materials and Methods

Leaves from 'BC-2 Red Fuji' apple trees on M.7 EMLA and M.9 337 rootstocks were analyzed for mineral composition throughout the growing seasons of 1995 and 1996. The orchard was established at the University of Idaho Research & Extension Center at Parma, Idaho, in April 1991. The soil was a sandy loam with a pH of about 7.5. Tree spacing is 2.4 x 4.9 meters. The trees were arranged in a completely randomized design with six single tree replications per rootstock. Each tree received identical annual treatments of fall-applied nitrogen at the rate of 90 g actual nitrogen, as urea. No micronutrients were applied in either year except Zn-50 (a zinc-containing compound with 50% actual Zn) was sprayed in the late dormant season and at stage 3 on the bud development chart (28), at a concentration of 3.1 g per liter to runoff. Trees were supported by a 3-wire trellis system and the orchard was irrigated with a solid set sprinkler system with each riser delivering 0.44 liter of water per minute. All other cultural practices were similar to commercial standards.

Fourteen leaves were randomly collected from the mid-shoot region of current-growth shoots of each tree from late May until the first week of November. In both 1995 and 1996, samples were taken every 14 days from the last week of May until early July. From mid-July until the end of August, samples were taken every 7 days. From September until early November, samples were taken approximately every two weeks in 1996; but no samples were taken in October, 1995. Trees were in full-bloom on April 27, 1995, and April 22, 1996.

Leaves were weighed immediately after sampling, then washed in a mild Liqui-nox detergent solution and rinsed with distilled water in three steps. Samples were then dried at 65°C in a forced air oven until they reached constant weight, and dry weights were recorded. The dried leaves were ground in a Cyclotec Sample Mill (Model 1093, Hoganas, Sweden) to pass through a 40-mesh screen. Samples were processed using a modified Kjeldahl procedure (24), and analyzed for N using a Milton Roy Spectronic 601 spectrophotometer. Measurement of the other leaf mineral constituents employed a Perkins-Elmer 1100B (Norwalk, CT) atomic absorption spectrophotometer after the tissues were ashed and chemically digested as described by Chaplin and Dixon (6) and Jones (13).

Various regression models were considered to evaluate the seasonal trends of specified elements across time for each year. Depending on the year and element being investigated, one of the following models provided an adequate fit to the data:

Cubic: $y=B_0+B_1x+B_2x^2+B_3x^3+\varepsilon$ (1),
Quadratic: $y=B_0+B_1x+B_2x^2+\varepsilon$ (2), or
Linear: $y=B_0+B_1x+\varepsilon$ (3),
where: y=nutrient element of interest,
x=DAFB (days after full bloom),
B_0, B_1, B_2, B_3=regression coefficients, and
ε=error term.

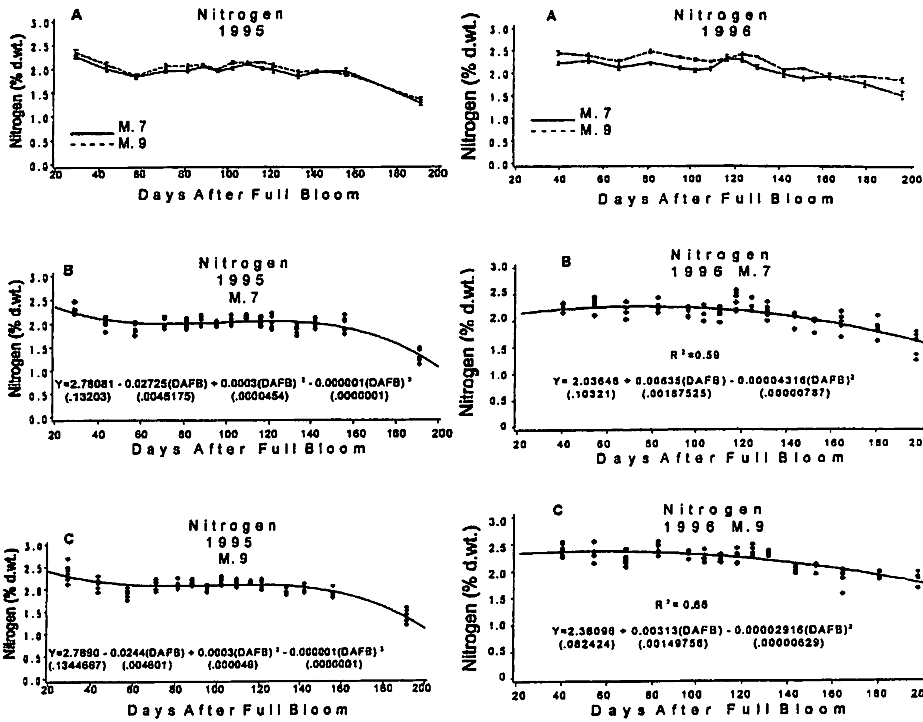

Fig. 1. 'Fuji' leaf nitrogen in 1995 (left) and 1996 (right). Left: 1995 seasonal trends (A), and cubic polynomial regression equations for M.7 EMLA (B) and for M.9 337 (C). Right: 1996 seasonal trends (A), and quadratic regression equations for M.7 EMLA (B) and for M.9 337 (C). Bars represent ± 1 standard deviation from sample means. Numbers in parentheses represent the standard errors of the estimates. August 1, 1995 = 95 DAFB; August 1, 1996 = 100 DAFB.

Model selection was based on the magnitude of residual mean squares, adjusted R2 and predicted sums of squares (21). A full model Dummy Variable Regression (DVR) contrast procedure (26), was used to compare parameter estimates of the two rootstocks in each year. Pearson first moment correlation coefficients among leaf minerals, and among leaf and fruit minerals were calculated to determine nutrient interactions. Statistical computations were carried out using SAS (23).

Results

Nitrogen: 'Fuji' leaves from trees on both rootstocks experienced an overall

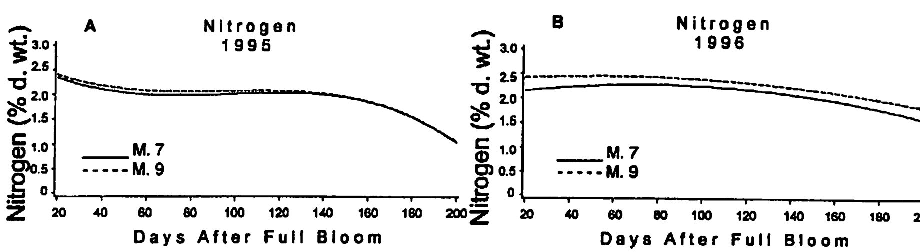

Fig. 2. Contrast of regression curves for 'Fuji' leaf nitrogen 1995 (A) and 1996 (B).

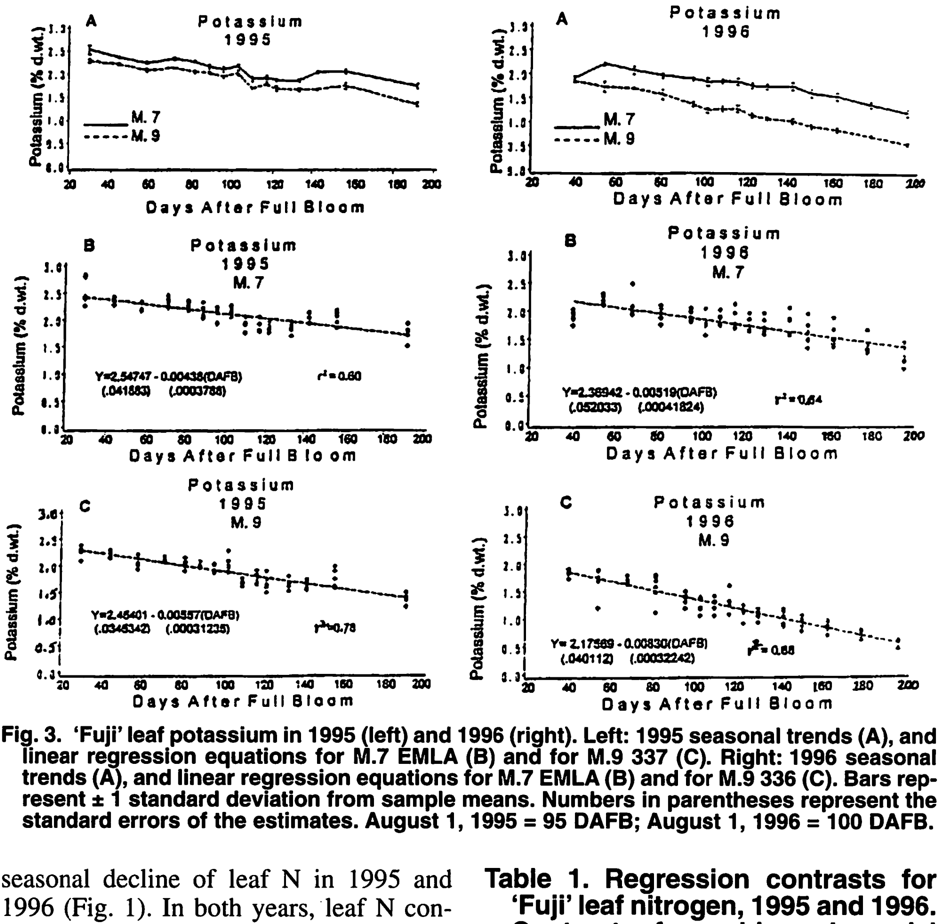

Fig. 3. 'Fuji' leaf potassium in 1995 (left) and 1996 (right). Left: 1995 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 337 (C). Right: 1996 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 336 (C). Bars represent ± 1 standard deviation from sample means. Numbers in parentheses represent the standard errors of the estimates. August 1, 1995 = 95 DAFB; August 1, 1996 = 100 DAFB.

seasonal decline of leaf N in 1995 and 1996 (Fig. 1). In both years, leaf N concentrations in trees on M.9 337 were greater than in those on M.7. EMLA rootstock. Concentrations during both years were generally within the sufficiency range of 2.0-2.39% d.wt. (8). Statistically significant rootstock effects on leaf N actually indicated only marginal differences. The period of minimal N flux in leaves from trees on both rootstocks occurred from about 40-140 DAFB, or from the second week of June to early September, although concentrations rose briefly at about 110 DAFB, especially in the heavy cropping year, 1996. Leaf N and fruit N, Ca, Zn and Mn correlations were almost as strong on June 14 as on August 2, 1996 (Table 3).

Table 1. Regression contrasts for 'Fuji' leaf nitrogen, 1995 and 1996. Contrasts for cubic polynomial lines and inflection points (B_2 & B_3) and rate of decline (B_1) parameters for 'Fuji' leaf nitrogen on M.7 EMLA and M.9 337 rootstocks in 1995 (C). Contrasts for quadratic lines and rate of decline (B_1 & B_2) parameters for 'Fuji' leaf nitrogen on M.7 EMLA and M.9 337 rootstocks in 1996 (D).

C	Contrast	DF	F	Pr > F
	Lines	4	3.22	0.014
	B_2 & B_3	2	0.12	0.883
	B1	1	0.20	0.659
D	**Contrast**	**DF**	**F**	**Pr > F**
	Lines	3	21.14	0.0001
	B_1 & B_2	2	0.97	0.3816

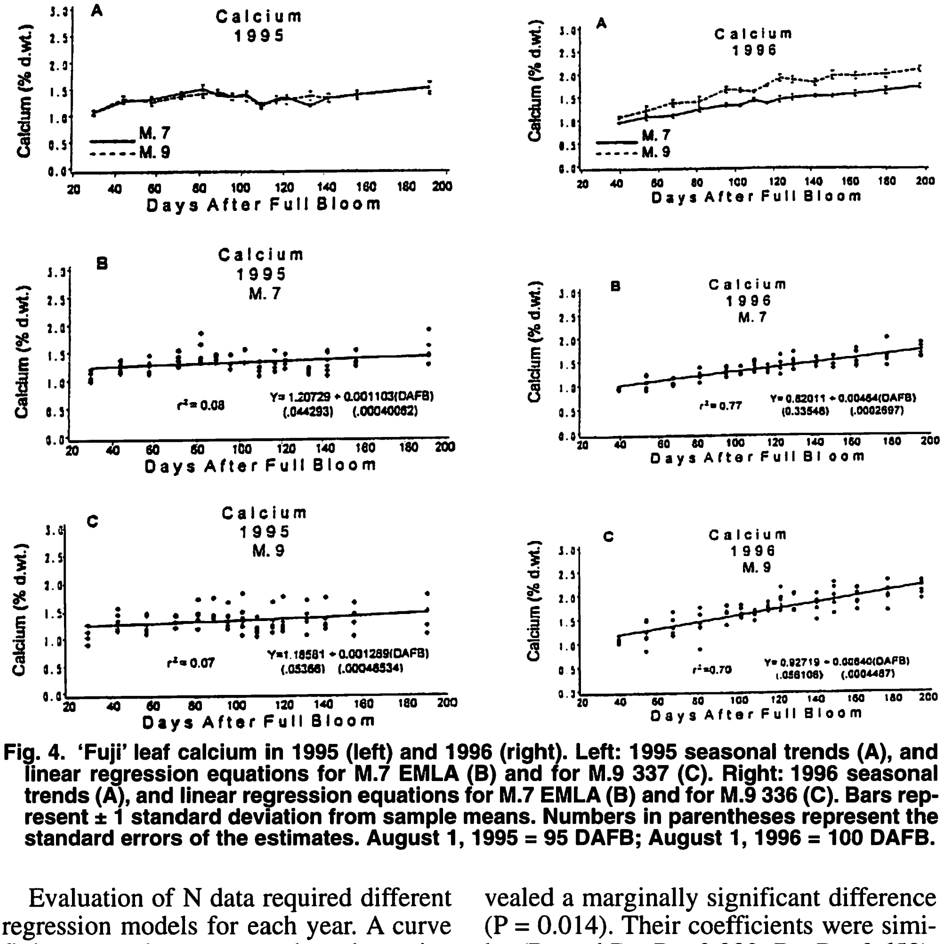

Fig. 4. 'Fuji' leaf calcium in 1995 (left) and 1996 (right). Left: 1995 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 337 (C). Right: 1996 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 336 (C). Bars represent ± 1 standard deviation from sample means. Numbers in parentheses represent the standard errors of the estimates. August 1, 1995 = 95 DAFB; August 1, 1996 = 100 DAFB.

Evaluation of N data required different regression models for each year. A curve fitting procedure was used to determine the most suitable model to describe the fluctuation of leaf N over the growing season. In 1995, the cubic polynomial equation provided the best fit (M.7 EMLA: R^2 = 0.71 and M.9 337: R^2 = 0.72) (Fig. 1 B & C). Coefficients maintained their expected signs (+ or -), and had similar magnitudes for both rootstocks. All coefficients in the model were significantly different from zero (P = 0.0001). Further analysis indicated that the residuals were uniformly and randomly scattered about zero, and that assumptions of normality were met. The DVR procedure contrasting the regression lines of both rootstocks in 1995 (Table 1) revealed a marginally significant difference (P = 0.014). Their coefficients were similar (B_2 and B_3: P = 0.883; B_1: P = 0.659), indicating similar seasonal nitrogen fluctuations regardless of rootstock.

The cubic polynomial regression model yielded a sigmoid curve with two inflection points indicating absolute dates of N seasonal fluctuation. Between these points of inflection lies the most stable period for leaf N concentrations, which were similar for leaves from trees on both rootstocks. The stable plateau delimited by the inflection points may be considered the period of absolute or statistical minimal fluctuation. This period began at 73.6 DAFB in trees on M.7 EMLA and 76 DAFB in trees on M.9 337. Absolute minimal flux ended on 120 DAFB for trees on

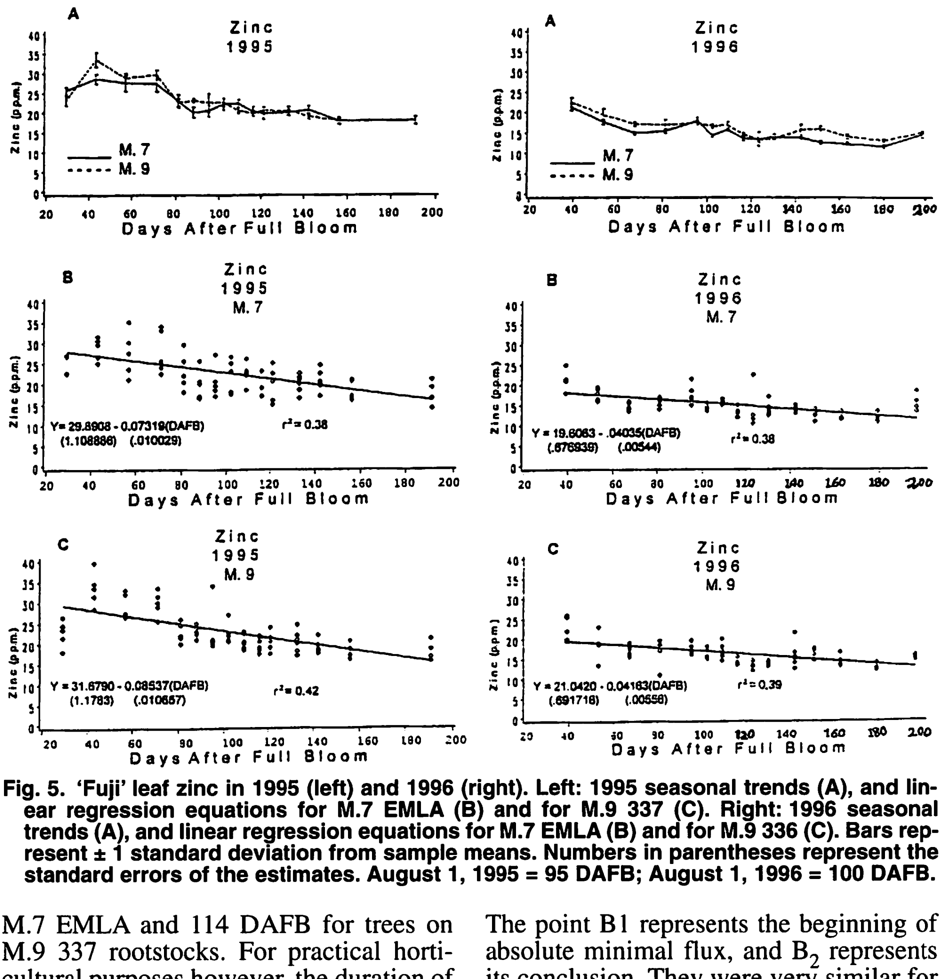

Fig. 5. 'Fuji' leaf zinc in 1995 (left) and 1996 (right). Left: 1995 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 337 (C). Right: 1996 seasonal trends (A), and linear regression equations for M.7 EMLA (B) and for M.9 336 (C). Bars represent ± 1 standard deviation from sample means. Numbers in parentheses represent the standard errors of the estimates. August 1, 1995 = 95 DAFB; August 1, 1996 = 100 DAFB.

M.7 EMLA and 114 DAFB for trees on M.9 337 rootstocks. For practical horticultural purposes however, the duration of physiological minimal flux is longer than that derived statistically.

In 1996, the quadratic model provided the best fit (Fig. 1 B & C). The cubic polynomial model applied to this year's data yielded insignificant parameter estimates, inconsistent signs (+ or -), and dissimilar magnitudes. The DVR procedure contrasting rootstock effect on seasonal leaf N concentrations (Fig.2 and Table 1), indicated that the predicted lines for each rootstock were different (P = 0.0001). The joint effects of B1 & B2 in the equation were similar (P = 0.3816), indicating similar timing of the two changes in N concentration trends that mark the season. The point B1 represents the beginning of absolute minimal flux, and B_2 represents its conclusion. They were very similar for both treatments. Leaf N values were consistently higher in leaves from trees on M.9 337 than in leaves from trees on M.7 EMLA rootstock.

Application of different linear regression models to 1995 and 1996 leaf N data underscores the variability across years that was also found in other foliar nutrients. Light fruit crop load in 1995, due to the effects of 'Fuji's' biennial bearing habit and spring frosts, and the heavy crop in 1996, strongly influenced leaf mineral concentrations. Although samples were first collected near the end of May in both years, the trees were more physiologically advanced in 1996 than in 1995. The de-

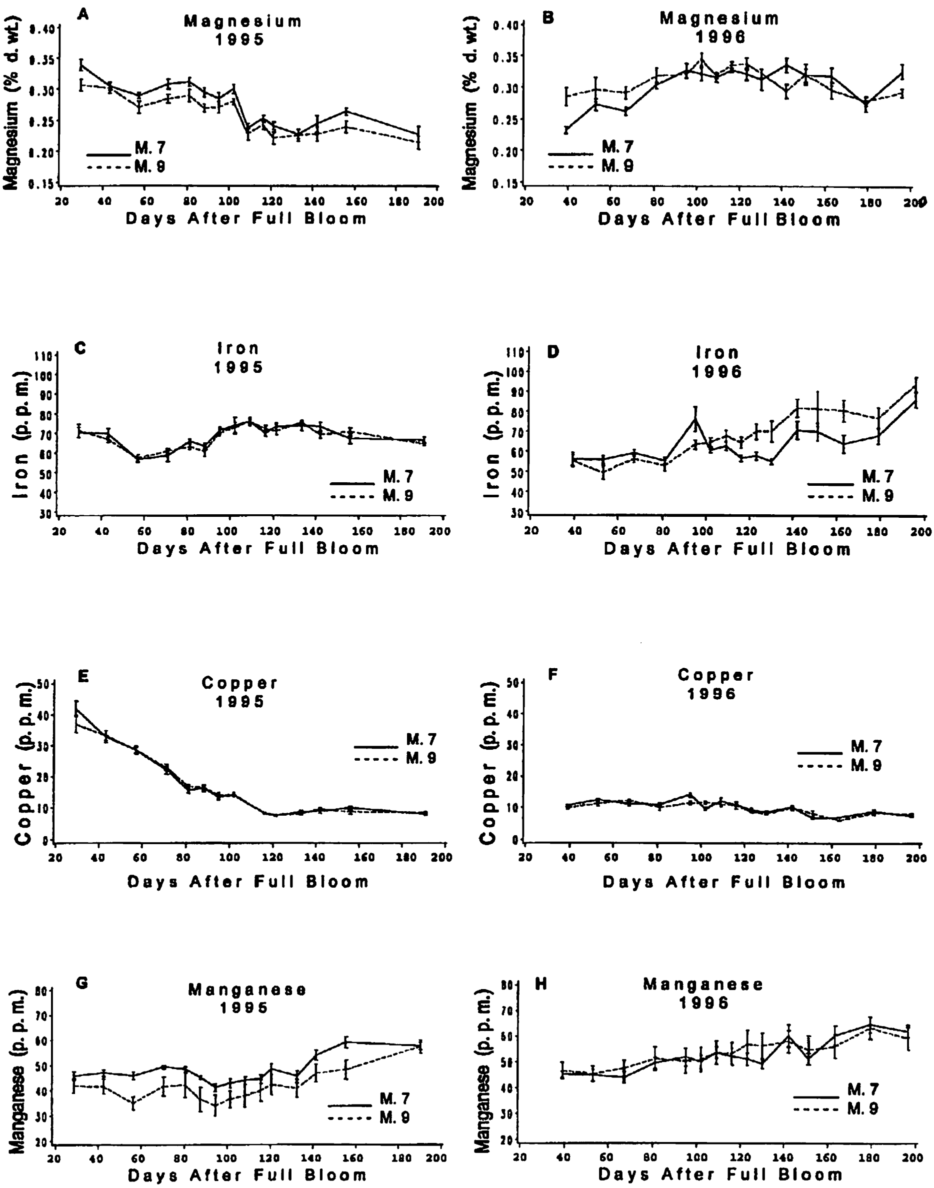

Fig. 6. Trends of 'Fuji' leaf magnesium (A & B), iron (C & D), copper (E & F) and manganese (G & H) in 1995 and 1996. Bars represent ± 1 standard deviation from sample means. Numbers in parentheses represent the standard errors of the estimates. August 1, 1995 = 95 DAFB. August 1, 1996 = 100 DAFB.

Table 2. Contrasts for regressions lines and slope parameters for 'Fuji' leaf K, Ca and Zn on M.7 EMLA and M.9 337 rootstocks in 1995 and 1996.

Element	Year	Contrast	DF	F	Pr > F
K	1995	Lines	2	57.30	0.0001
K	1995	Slopes	1	5.80	0.0164
K	1996	Lines	2	304.90	0.0001
K	1996	Slopes	1	34.76	0.0001
Ca	1995	Lines	2	0.05	0.9531
Ca	1995	Slopes	1	0.09	0.7681
Ca	1996	Lines	2	100.44	0.0001
Ca	1996	Slopes	1	11.44	0.0009
Zn	1995	Lines	2	0.74	0.4806
Zn	1995	Slopes	1	0.69	0.4064
Zn	1996	Lines	2	7.11	0.0011
Zn	1996	Slopes	1	0.03	0.8699

scent from early season high leaf N levels that occurred in late May 1995, is not reflected in 1996, and the data indicates the plateau of minimal flux had already been reached by the first sampling date.

Despite yearly N differences, there was very little contrast between rootstock treatments within years (Figures 1 & 2). During both years, leaf N concentrations rose briefly at about 110 DAFB. In 1995, this rise was modest. In 1996 however, N concentrations peaked in all leaves after passing through a period of decline over the previous three sample dates. In trees on M.7 EMLA rootstock, levels increased from 2.0% to 2.3% in 14 days. The peaks were experienced almost synchronously in leaves from trees on both rootstocks, and concentrations resumed their decline by 125 DAFB. The data points for this brief peak episode were of insufficient influence, and they are missed by the regression line that passes through the data clusters for all other sampling dates. These peaks may be considered statistically insignificant, although similar abrupt fluctuations occur in other nutrient elements at the same time. Minimal flux in 1996 precedes this event, and was 40-110 DAFB.

Potassium: 'Fuji' leaf K declined seasonally for trees on both rootstocks in both years (Fig. 3). In 1995, leaf K levels modestly increased prior to a sharp drop at about 110 DAFB. The periods before and after this event, 55-100 DAFB and 110-135 DAFB, may be considered times of minimal flux in 1995. In 1996, leaf K concentrations decreased more rapidly, marked by a brief stable period about 110 DAFB. Minimal flux for K in 1996 was approximately 100-140 DAFB. During both years, leaves from M. 7 trees had higher concentrations, as they did in a previous study (9), and in both years all leaf K levels were within a general sufficiency range of 1.2-2.0% (19).

Regression analysis employed the linear model in 1995 and 1996 (Fig. 3). Normality assumptions were tested by residual assessing techniques. The linear model fit was stronger for M. 9 339 in both years (1995: $r^2 = 0.78$; 1996: $r^2 = 0.88$) than for M.7 EMLA (1995: $r^2 = 0.60$; 1996: $r^2 = 0.63$). Rootstocks significantly affected leaf K during both years. Contrast analysis (DVR) disclosed highly significant differences of line and slope in 1995 and 1996 (Table 2). In 1995, the difference of rate of decrease due to rootstock was not great, but in 1996, leaf K levels decreased more rapidly in leaves from trees on M.9 337 rootstock than those from trees on M.7 EMLA. Leaf K did not correlate with most fruit minerals on June 14 and August 2 sampling dates, but on August 16, 1996, during the 110 DAFB episode, leaf K was strongly associated with fruit N, K, Ca, Mg, Zn, and Mn (Table 3).

Calcium: Leaf Ca levels increased throughout the growing season in trees on both rootstocks in 1995 and 1996 (Fig 4). Leaf Ca levels fluctuated little in 1995, except at about 110 DAFB. The only decline in Ca levels occurred over the one week prior to 110 DAFB. A 1995 mid-season minimal flux period for leaf Ca, 60-140 DAFB, was not duplicated in 1996. No period of true minimal flux appeared in 1996 because of the high rate of leaf Ca accumulation throughout the growing season. In 1996, leaf Ca levels in trees on M. 9 337 rootstock rose 0.30% within two weeks,

Table 3. Correlation coefficients for 'Fuji' leaf minerals and fruit minerals and yield in 1996.

	Correlation Coefficients		
Variable[z]	June 14	August 2	August 16
Leaf N vs Fruit N (% d.wt.)	0.687*	0.736[y]**	ns
Leaf N vs Fruit Ca (p.p.m.)	0.767**	0.803**	ns
Leaf N vs Fruit Mg (p.p.m.)	0.684*	ns	ns
Leaf N vs Fruit Zn (p.p.m.)	0.850**	0.843***	ns
Leaf N vs Fruit Mn (p.p.m.)	0.760**	0.772**	ns
Leaf N vs Fruit Ca (g/100g)	ns	ns	0.682**
Leaf N vs Fruit Mg (g/100g)	ns	ns	0.815***
Leaf N vs Yield (kg/tree)	ns	ns	0.573*
Leaf K vs Fruit (% d.wt.)	–0.669*	ns	–0.761**
Leaf K vs Fruit Ca (p.p.m.)	ns	–0.771*	–0.864***
Leaf K vs Fruit Mg (% d.wt.)	ns	ns	–0.779**
Leaf K vs Fruit Fe (p.p.m.)	ns	ns	–0.718**
Leaf K vs Fruit Zn (p.p.m.)	ns	ns	–0.794**
Leaf K vs Fruit Mn (p.p.m.)	ns	–0.730*	–0.785**
Leaf K vs Fruit K (g/100g	0.708*	0.818*	0.727**
Leaf K vs Fruit Ca (g/100g)	ns	ns	–0.644*
Leaf K vs Fruit N (% fresh wt.)	–0.716*	ns	–0.580*
Leaf K vs Fruit K (% fresh wt.)	ns	ns	0.641*
Leaf K vs Fruit Ca (% fresh wt.)	ns	–0.790*	–0.847***
Leaf K vs Fruit Mg (% fresh wt.)	ns	ns	–0.655*
Leaf K vs Fruit N (% d.wt.)	ns	ns	0.584*
Leaf Ca vs Fruit Ca (p.p.m.)	ns	0.762*	0.730**
Leaf Ca vs Fruit N (g/100g)	ns	–0.712*	ns
Leaf Ca vs Fruit K (g/100g)	ns	–0.818*	–0.841***
Leaf Ca vs Fruit Ca (% fresh wt.)	ns	0.756*	0.769**

[z]N = 6. Leaf minerals expressed as % d.wt.
[y]*, **, ***, ns: Significant at $P \leq 0.005$, ≤ 0.01, ≤ 0.001, or nonsignificant, respectively.

beginning at 110 DAFB. Leaf Ca levels were within or above the sufficiency range in both years (19).

Regression analysis employed the linear model in 1995 and 1996 (Fig. 4). Contrast analysis indicated that leaf Ca levels were unaffected by rootstock in 1995, when few fruit were present. In 1996, the slopes and lines were significantly different, with leaves from trees on M. 7 EMLA accumulating Ca (% d.wt.) at a slower rate than those from trees on M.9 337 rootstock.

Zinc: Leaf Zn concentrations declined over both growing seasons for trees on both rootstocks (Fig. 5). Leaf Zn levels declined at similar rates within each year, but rates between years were different. The most striking difference in the trends of Zn was an early season accumulation by both rootstocks in 1995 that was absent in 1996. Zinc concentrations appear to have been unaffected by the 110 DAFB event that influenced other minerals, although slight increases occurred about this time. Minimal flux for Zn occurred approximately 85-170 DAFB and concentrations remained stable until leaf fall. During 1995, Zn levels were at the lower end of the sufficiency range of 20-100 p.p.m., but in 1996, values fell below this range (19). Dummy variable regression indicated leaf Zn levels were unaffected by rootstock in 1995 (Table 2). In 1996, the lines are different but the slopes are similar, indicating identical rates of decrease but different concentrations (Fig. 5). Throughout both years, leaf Zn concentrations were slightly higher in leaves from trees on M.9 337 rootstock.

Magnesium: Leaf Mg concentrations were among the most erratic during both years (Fig. 6). In 1995 and 1996, Mg levels were within the sufficiency range of 0.25-0.45% d.wt. (19). The 1995 trend was generally downward, though Mg levels increased at times, especially prior to a steep drop just before 110 DAFB. Leaf Mg fluctuated the least during the period from 55-95 DAFB in 1995, but the entire season was very unstable. In 1996, seasonal foliar Mg increased over a somewhat less erratic course than in 1995, and minimal flux may be said to have occurred at 85-140 DAFB. Nevertheless, no period of true stability occurred for this element in either year.

Iron: Leaf Fe concentrations were very changeable in both years, although in 1995, the period 110-190 DAFB was stable and represents minimal flux for that year (Fig. 6). In 1996, the overall trend was of increasing values, whereas in 1995, the first and last leaf Fe concentrations were virtually identical. Neither rootstock maintained higher leaf Fe levels than the other throughout either season. The period of minimal fluctuation for Fe in 1996 was 40-80 DAFB. Leaf Fe fluctuations in trees on both rootstocks were alike in 1995. In 1996, leaf Fe fluctuations were different for each rootstock. Iron concentrations were within the 50-300 p.p.m adequacy range (19).

Copper: Leaf Cu trends were very different from year to year (Fig. 6). Concentrations on the first 1995 sampling date were about 40 p.p.m., well above the sufficiency range of 6-25 p.p.m (19). Levels subsequently fell to about 10 p.p.m. by about 120 DAFB, and remained stable until the end of the season. In 1996, leaf Cu concentrations were approximately 10 p.p.m. all season. Trends for leaves from trees on both rootstocks were very similar in both years. Minimal flux for Cu lasted the entire season in 1996, but because of early high levels in 1995, it began about 80 DAFB in that year.

Manganese: Trends for leaf Mn were erratic in 1995 and 1996, but overall both rootstocks had increasing Mn levels during both years (Fig. 6). Concentrations were within the adequacy range of 25-200 p.p.m (19). A relatively stable mid-season plateau was preceded and followed by increasing accumulations, and minimal flux was 80-135 DAFB. Fluctuations in 1995 were very similar for both rootstocks and leaves from trees on M. 7 EMLA had the highest concentrations throughout.

Discussion

Management of orchard N nutrition strongly affects horticultural and economic outcomes, and determining apple leaf N concentrations is often a priority concern of those using leaf analysis. The period of minimal nutrient fluctuation for N in 'Fuji' apple leaves was determined to last from 40-140 DAFB, weeks longer than for some other cultivars. Reliable N concentration data could be found by leaf analysis of 'Fuji' in mid-June. Positive correlations between leaf N and fall-harvested fruit N, Ca and Mg (% d.wt.) and Zn and Mn (p.p.m.) were found on June 14, 1996 (Table 3). 'Fuji' leaf N was weakly effected by rootstock regardless of year-to-year variations in climate or crop load.

Seasonal nutrient concentrations in leaves vary with the year and crop, and these influence some rootstock effects. Although leaf N curves were very different from year-to-year, within years, leaves from trees on both rootstocks exhibited very similar patterns (Fig. 1). In an earlier 'Fuji' study (9), foliar N was unaffected by three rootstocks in one out of two years. The rootstock effect on seasonal leaf K was the most significant difference found among all elements in this experiment and it was greatest in the year of abundant fruit. The absence of fruit may have suppressed expression of rootstock influence on other leaf minerals in 1995. In 1996, the rootstock effect on leaf Ca accumulation was significantly greater than rootstock differences produced in the low crop year of 1995. Leaf Zn was effected by rootstock in 1996, but not in 1995. No rootstock effect was found for

Fe, Cu, Mn and Mg levels in leaves during either year.

Erratic yearly trends were found among the micronutrients and Mg. Most foliar nutrient concentrations were determined to be within the adequacy range, but Fe and Zn were notably low, probably due to an abundance of Ca^{++} cations in the pH 7.5 soil. Nutrient element trends were the same for both rootstocks in both years except for Mg, Fe and Cu. Among Mg, Fe and Cu, overall seasonal trends were different in 1995 versus 1996, and in all three of these cases, the trend change was experienced in trees on both rootstocks.

The need for different regression models to describe leaf N for each year owes something to the advanced physiological state of the trees in 1996. The 1996 data does not include the earliest weeks of high concentrations that provide the early high values of the 1995 sigmoid curve. Comprehensive sampling should begin within 2 weeks of full bloom, to monitor the status of leaf N at early stage of a growing season. Unlike 'Red Delicious', which has increasing N concentrations from 45-65 DAFB (22, 27), 'Fuji' has already entered the plateau of minimal flux by 40 DAFB.

The season of maximum stability for N, K, Mg, and Ca was interrupted in one or both years by a brief fluctuation at about 110 DAFB. The impact of the 110 DAFB episode was greater for K and Mg and less so for Ca, and may be related to shoot growth periodicity in 'Fuji'. Habit varies among apple cultivars, and 'Fuji' has been found to produce fewer sylleptic shoots than four other cultivars, including 'Imperial Gala' and 'Granny Smith' (7). Sylleptic shoots are those that emerge from axillary buds while the apical shoot is also growing, especially in young, newly planted trees. These shoots become the low scaffold branches of modern orchard trees. This relatively weak sylleptic tendency is likely not 'Fuji's only cultivar-specific shoot growth trait.

Among the *Rosaceae,* recurrent shoot growth, known as lammas growth, has been reported in *Sorbus* (15, 16), *Prunus* (5, 25), and *Malus* (25). Apical growth ìresumed' on 'Ralls Janet' trees in the first week of August (20). In M.7 stoolbed rows, smooth seasonal trends of leaf K, Mg, and Ca were disrupted when recurrent growth was observed in late summer (18). Because of this physiological instability, Mason recommended leaf sampling for analysis in mid- or late September.

Given the very narrow range for foliar N, the 110 DAFB fluctuation could yield deceiving analytical results. While each element's abrupt fluctuation at this time is statistically insignificant, the combined weight of all occurring together signifies physiological significance, and the possible role of lammas growth should be considered. The second flush of shoot growth reported for 'Ralls Janet' was associated with a rapid decline in leaf N, (20). Growers in southwest Idaho have observed lammas growth on 'Fuji' trees, but no systematic examination of the phenomenon was undertaken in this study. Because of the increased fluctuations associated with shoot extension, it may be prudent for 'Fuji' growers to avoid sampling in the week preceding and following the 110 DAFB event (August 14, 1995 and August 9, 1996).

Nevertheless, a period of minimal nutrient flux for leaf N suitable for sampling 'Fuji' apple leaves was found from 40-140 DAFB. A stage of minimal flux for leaf K of 55-135 DAFB was interrupted by the 110 DAFB event in 1995. Minimal flux for leaf Ca in the light fruit crop year 1996 was 60-140 DAFB, but both K and Ca trends were much less stable with abundant fruit.

The finding of inconsistent rootstock effects that are influenced by crop and external factors suggests that long-range monitoring of nutrient trends in orchards has more value than an isolated analysis. Data logging that tracks nutrient levels from season to season over the course of years can be an effective warning system against developing imbalances in apple orchards (19). Because of cultivar variability in seasonal leaf mineral utilization, each requires a specific trend determination.

In a four year study (2), the correlation between leaf K+Mg/Ca and incidence of bitter pit was about as strong in early August ($r = 0.76$, $p = 0.0001$) as it was at harvest. Among fruit mineral concentrations (Table 3), fruit Ca levels were lower than the threshold of 'Starkspur Golden Delicious' (10). Nevertheless, no bitter pit was observed in the fruit from trees on either rootstock in 1996, perhaps indicating that 'Fuji' has a lower threshold for fruit Ca than other cultivars. Valuable nutritional data can be found in the analysis of leaf minerals before August, and June foliar N correlated well with some ultimate fruit mineral concentrations (Table 3).

The duration of N minimal flux in leaves on 'Fuji' apple trees extends the period during which valid leaf nutrient analysis can be conducted for this cultivar. Further studies of 'Fuji' seasonal mineral trends that commence sampling about 14 DAFB will test the validity of the cubic polynomial regression model as a reliable description of this cultivar's seasonal nutrient fluctuations. In addition, systematic examination of recurrent growth in 'Fuji' may reveal physiological information with important cultural implications.

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