DESIRABLE NUTRITION AND ROOTSTOCK FOR OPTIMUM FRUIT QUALITY AND YIELD IN 'FUJI' APPLE

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INTRODUCTION

In recent years, 'Fuji' apple has become highly popular with consumers because of its excellent flavor. Thus, there is an increasing trend in 'Fuji' production in the Northwestern USA to meet market demand. The fruit, however, has poor red skin color which makes them less attractive for fresh market. Rootstock and leaf and fruit concentrations of nitrogen (N) and calcium (Ca) are among the most important preharvest factors that influence tree growth, fruit quality, and storage life in apples (Bramlage et al., 1985; Fallahi and Simons, 1993 a and 1993 b; Fallahi et al., 1996; Ferguson and Watkins, 1989; Greene and Smith, 1979; Poovaiah et al., 1988; Sharples, 1980).

Our objective was to study the effects of various rootstocks and different fertigation regimes and various quantities of ground and foliar applications of N on tree growth, yield, fruit quality, and leaf mineral nutrition in 'Fuji' apple.

MATERIALS AND METHODS

Fertigation, Strain, and Rootstock Experiment (This experiment is not completed at this time, and only preliminary results are reported here): 'TAC 114 Fuji', 'BC-2 Fuji', and 'Nagafu-6 Fuji' on several rootstocks were planted in a high density orchard at 8 ft x 16 ft (2.4 m x 4.8 m) spacing at the University of Idaho Parma Research and Extension Center, Parma, Idaho, in April, 1995. 'TAC 114 Fuji' on M.7EMLA, M.26EMLA, M.9-337, Bud118, and EMLA 111 were planted in a randomized complete block design with 8 replications, two trees per replication. 'Nagafu-6' and 'BC-2 Fuji', each on M.9-337, Bud 9, Ottawa 3, M.26EMLA, and M.7EMLA were planted in a complete split block design, with five fertigation zones or strains as main blocks (either fertigation or strain can be used as the main effect), and rootstocks as sub-plots, with six replications of two trees per plot. Starting 1997, only effects of 'BC-2 Fuji' has been studied (rootstock-fertigation experiment), and 'Nagafu-6' was eliminated from this experiment because rootstock effects on this strain seemed to be similar to those on 'Nagafu-6 Fuji'. Therefore, the design for this portion of the project is a randomized complete block split plot, with fertigation as the main effects and rootstocks as sub-plots. 'Snow drift' crab apple was planted as a pollinizer in this experiment.

Fertigation zones are established to deliver different amounts of nutrients. Five nutrient treatments are injected through the irrigation water (fertigation). Two tanks are installed for storing UN-32 nitrogen and K fertilizers. From these tanks, nutrients are pumped into the sub-main lines.

In 1998 the five-fertigation treatments were as follows:

1) 20 lbs/A (22.5 kg/ha) N per year;
2) 80 lbs/A (89.8 kg/ha) N per year;
3) 80 lbs/A (89.8 kg/ha) N plus 70 lbs/A (78.6 kg/ha) K per year;
4) 140 lbs/A (157.2 kg/ha) N per year;
5) 140 lbs/A (157.2 kg/ha) N plus 70 lbs/A (78.6 kg/ha) K per year.

Root Competition at different Densities and Rootstocks Experiment (not completed and only preliminary data presented here): In this experiment, Nagafu-6 'Fuji' on P-22, M.9, and M.7 were planted at three densities, 4 and 8 ft (1.2 and 2.4 m) in row and 16 ft (4.8m) between rows, to study the effects of root competition on mineral uptake. In this study, trees are fertigated with 80 lbs/A (89.8kg/ha) N plus 70 lbs/A (78.6 kg/ha) K per year. The experimental design in this experiment was a complete randomized block, split-split plot with rootstock as the main effect, tree spacing as a sub-plot, and N fertilizer distance from the trunk as sub-sub plots with 6 replications. This study will clarify the N requirement "on a tree basis" as well as on a "per area" basis under different rootstocks and two tree densities.

Experimental Orchard for ground and foliar applications: 'Red Fuji' (B.C-2) apple (*Malus domestica* Borkh.) trees on M.7 EMLA, M.9 NAKBT337, and M.26 EMLA were planted in the spring of 1991 at 2.4 m x 4.9 m spacing at the University of Idaho Parma Research and Extension Center experimental orchard, north of Parma, Idaho, USA. The soil is a sandy loam with about 7.5 pH. Trees were irrigated with a pressurized system laid along the rows, with one micro-jet set for every tree on the row.

In the ground application experiment, the experimental design was a complete randomized block split-split-plot with rootstocks as main plots and five levels of ground applied N (urea with 46% N) as sub-plots and two times of application (spring and fall) as sub-sub plots with 4 two-tree plots per replication. For spring application, each level of the five quantities of N was split in half. One half was applied in early spring and the second half was applied in late spring of 1992 through 1997 seasons. In 1992, the rate of actual N per tree per year was 27.2 g, 77.0 g, 126.9 g, 176.9 g, and 226.7 g. In 1993 through 1997, the rate of actual N per tree per year was 31.7 g, 99.7 g, 167.8 g, 235.8 g, and 303.9 g.

In foliar application of nitrogen, the influence of three foliar applications and one ground application nitrogen on tree growth, precocity, fruit quality at harvest and after storage, and leaf mineral concentrations in young 'Fuji' apple trees on the above-mentioned rootstocks were studied.

In both ground and foliar-applied experiments, yields were recorded, and samples of fruit were evaluated for fruit color, average fruit weight, soluble solid concentrations (SSC), starch, and firmness at harvest and after storage, and leaves were analyzed for various mineral elements as described by Fallahi et al. (1996).

RESULTS AND DISCUSSION

Fertigation, Strain, and Rootstock: In 1997, significant differences were found between rootstocks (data not shown). Part of these differences could be attributed to the crop load effects. Leaf mineral concentrations were affected by different fertigation regimes (Table 1) and rootstocks (Table 2) in 1997. The low N treatment showed lower leaf N in 1997.

In 1998, crop load was satisfactory. Fruit from 20 lbs/A (22.5 kg/ha) N zones were smaller than those with higher N application. Fruit color of the lowest N fertigation regime was significantly better than all other fertigation treatments (Table 3), due to the low leaf N concentration of this fertigation zone (Table 1).

In 1998, trees on Ottawa-3 had higher yield than those on B.9, M.26, and M.7 (data not shown).

In 1998, application of N at 20 lbs/A (22.5 kg/ha) reduced leaf area and photosynthesis (data not shown) due to reduction of leaf N in 1997 (Table 1) and 1998 (data not shown). In this year, leaves of trees on M.7 and M.26 had larger spur leaf area than those on other rootstocks, but rootstock did not affect photosynthesis (data not shown).

In tree spacing experiment, trees on M.7 had higher shoot leaf area and photosynthesis than those on other rootstocks (data not shown). Trees of 8 ft (2.4m) spacing had significantly higher photosynthesis than those of 4 ft (1.2 m) spacing (Figure 1). Fruit quality and mineral elements of trees from the tree spacing and regrafting experiments are being analyzed at this time.

Ground Application of Nitrogen: Trees on M.7 EMLA rootstock were the most vigorous with the largest trunk cross sectional area in 1992, 1993, and 1994, and trees on M.9 NAKBT337 were the smallest (data not shown). Trees on M.26 EMLA were smaller than those on M.7 EMLA but larger than those on M.9 NAKBT 337. Yield and yield efficiency in M.9 NAKBT337 and M.26 EMLA were higher than those on M.7 EMLA three years after planting. Trees on M.7 EMLA rootstock had larger fruit size than those on M.9 NAKBT 337 or M.26 EMLA in 1994 (data not shown). This could be due to lower production, thus higher leaf to fruit ratio of trees on M.7 EMLA in 1994. Trees on M.7 EMLA had a higher leaf percent dry weight, potassium (K), and copper (Cu) than those on other rootstocks in 1993 and 1994 (data not shown). The trees on this rootstock had not reached their full production, thus a lower number of fruit could have resulted in more K accumulation in the leaf (Fallahi and Simons, 1993b). Trees on M.7 EMLA had a leaf N concentration of 2.33% with 0.37 lbs (168 g) of N, while trees on M.9 NAKBT337 and M.26 EMLA had 2.34 or 2.33% leaf N with only 0.22 lbs (100 g) of ground-applied N (Table 4). This is because trees on M.7 EMLA have more extended tree canopy than those on the other two rootstocks, thus it takes higher N to change its leaf N concentration.

Tree growth was not affected by different N quantities in 1992 and 1993. In 1994, trees with the least N application were smaller in size. Severity of sunburn was not affected by the amount of N application. The lowest N application resulted in smaller and firmer fruit with more red color, but lower SSC at harvest (Table 5) and after storage (data not shown).

Fruit red color was decreased with every incremental increase in N application (Tables 5) because leaf N was increased in these applications (Tables 5). Leaf magnesium (Mg) and manganese (Mn) also increased, but leaf K decreased with every incremental increases in N application up to 235.8 g actual N/tree (Table 5), perhaps because of the antagonistic effects between N (as NH_4^+) and K, and synergistic effects between N and Mg and Mn.

This long-term experiment showed that the optimum concentrations of leaf N for production of high quality fruit are between 1.88% to 2.14 % dry weight in off years (years with light crops) and between 2.20% to 2.40% dry weight during on years (data not shown).

Foliar Application of Nitrogen: Trees that received a total of 197 g (7 oz) urea, 90.6 g (3.4 oz) actual N, as a ground application over three growing seasons had greater trunk cross-sectional area (TCA), yield per tree, and yield efficiency than trees which received one of three rates of foliar applications. Trees receiving ground-applied or foliar-applied urea at the highest rate had the heaviest fruit. Fruit firmness was greatest in the lowest foliar treatment. Ground application resulted in greater than average leaf N in 1994 and the greatest leaf Ca and lowest percentage leaf dry weight, leaf K, Zn, and Cu in both 1993 and 1994. Trees on M.9 NAKBT337 were more precocious and smaller in size than those on M.7 EMLA. Trees on M.7 EMLA had lower yield efficiency and greater leaf K than trees on either M.9 NAKBT337 or M.26 EMLA.

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Table 1
Effects of Fertigation on Mineral of 'BC-2 Fuji' in 1997

Fertigation Zones	% DWT Zn (ppm)	N (%) Cu (ppm)	Ca (%) Mn (ppm)	Mg (%)	K (%)	Fe (ppm)
30 lbs N/acre (33.7 kg N/ha)	62.00 a 16.99 a	2.13 b 10.04 a	1.05 ab 66.91 b	0.26 c	2.00 a	87.26 b
70 lbs N/acre (78.5 kg N/ha)	62.47 a 14.31 ab	2.14 b 10.02 a	1.07 a 72.85 ab	0.28 a	1.96 a	90.01 ab
70 lbs N/acre + 70 lbs K/acre (78.6 kg N/ha + 73.6 kg K/ha)	62.03 a 14.80 b	2.21 ab 9.39 a	1.05 ab 72.19 ab	0.28 ab	2.00 a	94.82 ab
110 lbs N/acre (123.5 kg N/ha)	62.76 a 13.46 c	2.24 ab 9.39 a	1.03 ab 71.85 ab	0.26 bc	1.94 a	95.35 a
110 lbs N/acre + 70 lbs K/acre (123.5 kg N/ha + 78.6 kg K/ha)	61.95 a 13.82 c	2.29 a 10.01 a	0.98 b 74.71 a	0.27 abc	1.87 b	94.68 ab

Table 2.
Effects of Rootstock on Mineral of 'BC-2 Fuji' in 1998

Rootstock	% DWT Zn (ppm)	N (%) Cu (ppm)	Ca (%) Mn (ppm)	Mg (%)	K (%)	Fe (ppm)
B9	60.37 b 13.72 b	2.16 c 9.91 b	1.24 a 71.58 b	0.25 c	1.63 c	87.42 b
M9	62.56 a 13.69 b	2.22 ab 9.98 b	1.04 b 66.48 c	0.26 bc	1.92 b	90.66 b
O-3	62.52 a 13.12 b	2.25 a 9.17 c	0.93 c 61.18 d	0.26 c	1.98 b	96.21 a
M26	62.85 a 16.27 a	2.18 bc 9.51 c	0.94 c 93.87 a	0.31 a	2.10 a	95.93 a
M7	62.94 a 16.23 a	2.22 ab 11.02 a	1.03 b 65.21 cd	0.27 b	2.14 a	91.85 ab

Table 3
Effects of Fertigation on Yield and Fruit Quality of 'BC-2 Fuji'

Fertigation Zones	Yield (kg/tree)	Avg fruit wt (g)	Fruit color (1-5)
20 lbs N/acre (22.5 kg N/ha)	9.25 b	198.46 b	3.80 a
80 lbs N/acre (89.8 kg N/ha)	9.64 ab	205.45 a	3.14 b
80 lbs N/acre + 70 lbs K/acre (89.8 kg N/ha + 78.6 kg K/ha)	11.93 a	194.56 b	3.05 bc
140 N/acre (157.2 kg N/acre)	9.26 b	206.29 a	2.86 c
140 lbs/acre + 70 lbs K/acre (157.2 K/ha + 78.6 kg K/ha)	10.48 ab	207.36 a	2.88 c

Table 4
Effects of Rootstock and Applied Interactions on 'Fuji' Color

Rootstock	M9	M9	M9	M26	M26	M26	M7	M7	M7
Applied N (lb/tree)	0.07	0.22	0.37	0.07	0.22	0.37	0.07	0.22	0.37
Leaf N (%)	2.23	2.34	2.34	2.18	2.33	2.39	2.10	2.23	2.33
Color Rating *	3.80	3.19	2.89	3.55	2.55	2.53	3.88	3.48	2.90

* Color rating: 5 = Red; 1 = Green

Table 5
Effects of Various Amounts of Nitrogen on Fruit Quality at Harvest and Leaf Minerals in 'BC-2 Fuji' Apple in 1994[z]

N Applied	Fruit Ave Wt	Color	Soluble Solids	Firmness	Leaf minerals (dry wt basis)			
(g/tree)	(g)	(1-5)	(% Brix)	(N)	N (%)	K (%)	Mg (%)	Mn (ppm)
31.7	270 b	3.4 a	14.7 b	82 a	2.20 c	1.54 a	0.28 c	57 e
99.7	288 a	2.9 b	148 ab	78 ab	2.39 b	1.37 c	0.30 b	75 d
167.8	295 a	2.7 b	15.2 a	77 b	2.44 ab	1.41 bc	0.30 b	90 c
235.8	288 a	2.9 b	15.0 ab	79 ab	2.47 a	1.41 bc	0.31 b	129 b
303.9	280 ab	2.4 c	15.1 ab	79 ab	2.46 ab	1.49 ab	0.33 a	148 a

[z]Mean separation within columns by Duncan's Multiple Range Test at 0.05