Influence of Nitrogen and Rootstock on Tree Growth, Precocity, Fruit Quality, Leaf Mineral Nutrients, and Fire Blight in ‘Scarlet Gala’ Apple

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SUMMARY. The influence of four rootstocks and four levels of nitrogen supply on tree growth, precocity, fruit quality (size and color), leaf mineral concentrations, and fire blight [*Erwinia amylovora* (Burrill) Winstow et al.] severity in ‘Scarlet Gala’ apple (*Malus domestica* Borkh.) trees was studied between 3 to 4 years. Trees that received an annual ground application of 0.15 lb (68 g) actual N as urea over four growing seasons had greater trunk cross-sectional area (TCA), higher yield, better fruit color, lower leaf N and less fire blight than those which received higher amounts of N. Trees on Malling (M.9) were more precocious and had higher yields in early years while trees on Malling-Merton 106 (MM.106 EMLA) and Malling-Merton 111 (MM.111 EMLA) had higher production 4 years after planting. Trees on Malling 26 (M.26 EMLA) had higher leaf Mg than those on other rootstocks. Trees on M.9 and M.26 EMLA had more fire blight damage than those on other rootstocks.

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Gala apple has gained popularity among consumers recently because of its distinctly pleasant taste. Consequently, ‘Gala’ constitutes a large portion of new apple plantings in the Pacific northwestern U.S. Although the influence of rootstock on yield, fruit quality, and mineral nutrition of several apple cultivars has been reported earlier (Autio et al., 1991; Autio and Southwick, 1993; Bould and Campbell, 1970; Fallahi et al., 1984, 1985; Fallahi and Simons, 1993; Ferree and Carlson, 1987; Granger et al., 1992; Rom et al., 1991; Schneider et al., 1978), only limited research information is available on fruit quality and mineral nutrition of ‘Gala’. In Japan, where ‘Fuji’ apple was developed, Tsuchiya et al. (1974) reported that ‘Fuji’, ‘Golden Delicious’, and ‘Starking Delicious’ apple trees on M.9 had smaller TCA and canopy volume (height and spread) than those on ‘Ralls Seedling’ or *Malus prunifolia* (Willd.) Borkh. 12 years after planting. Trees on M.9 were more precocious and had greater yield efficiency than those on other rootstocks. Average fruit weight from trees on M.9 was less than those from ‘Ralls Seedling’ or *M. prunifolia*. ‘Fuji’ fruit were firmer when grown on M.9 than on other rootstocks. In a different study, Tsuchiya et al. (1976) reported that ‘Fuji’ on M.26 had a greater cumulative yield than on M.4, MM.104, MM.106, or MM.111. In their study, ‘Fuji’ trees on M.26 had larger fruit than those on MM.106. Nagai and Ishii (1979) reported that ‘Fuji’ leaves had significantly greater N, P, K, Ca, Mg, Fe, and Mn than ‘Golden Delicious’ leaves and that trees on M.9 had similar levels of leaf N, K, Mg, and Mn, but less leaf P and greater leaf Ca and Fe than trees on M.7.

The effect of different rootstocks on the degree of fire blight susceptibility of apple scion cultivars has been well documented (Boyce, 1970; Mowry, 1969; Thompson, 1971; Van der Zwet and Keil, 1979). Several workers (Hildebrand and Heinicke, 1937; Link and Wilcox, 1936; Parker et al. 1961; Thomas and Ark, 1939) have reported that nitrogen nutrition of the trees was correlated with fire blight incidence and severity, especially through its effect on tree growth and vigor.

The objective of this research was to study the influence of four levels of ground applied nitrogen and four rootstocks on tree growth, precocity, fruit color, leaf mineral concentrations and fire blight severity in young ‘Scarlet Gala’ trees.

Materials and methods

The experimental orchard was established near Payette, Idaho. The orchard site had a uniform soil profile, and the soil type was sandy loam with a pH of about 7.5. Strips of soil 8 ft (2.4 m) wide along the tree rows were fumigated before planting, with metam sodium (Vapam) at 100 gal/acre (935.2 $L \cdot ha^{-1}$) on 29 Mar. 1992. Uniform size [trunk diameter 0.5 inch (1.3 cm)] ‘Scarlet Gala’ apple trees on M.9, M.26 EMLA, MM.106 EMLA, and MM.111 EMLA obtained from C & O Nursery, Inc. (Wenatchee, Wash.) were planted at 7.5 × 18 ft (2.29 × 5.49 m) spacing on 27 Apr. 1992. Planting holes were dug with a posthole auger. About 8 oz (227 g) of monoammonium phosphate was applied per planting hole and mixed well with soil. A solid-set sprinkler system was installed on tree rows, and the orchard was irrigated based on soil moisture monitoring with sensors.

Trees were topped after planting at 28 inches (71 cm) from the ground and were trained on a central leader system. Lateral branches were bent with strings and fastened to the main trunk at about a 55° angle from vertical to cause flower bud initiation.

Zinc-50 (a Zn-containing compound with 50% zinc) was sprayed late dormant season (late March) every year. Other cultural practices in this experimental orchard were similar to those used in commercial apple orchards.

Nitrogen treatments were started in 1993. Four rates of urea (46% actual N) were applied to the soil in a 1.5-ft (45-cm) radius in 1993, 2-ft (61-cm) radius in 1994, and 2.5-ft (76-cm) radius in 1995 and 1996 around the tree trunk. Nitrogen treatments were applied in two equal splits, one in mid-May and the other in mid-June of each year. At each application, the actual N

Table 1. Effect of soil applied nitrogen on tree growth, yield, fruit color and size, and fire blight severity of 'Scarlet Gala' apple (6.45 cm^2 = 1.0 $inch^2$; 0.45 kg = 1.0 lb; 28.35 g = 1.0 oz).[z]

Actual N per tree per year	Trunk cross-sectional area (cm^2)					Total yield (kg/tree)		Cumulative yield (kg/tree)	Color[y] (1–5)		Avg fruit wt (g)		Fire blight severity (% canopy
[lb (g)]	1992	1993	1994	1995	1996	1995	1996	1995–96	1995	1996	1995	1996	blighted)
0.15 (68)	1.51 a	2.27 a	5.61 a	10.16 a	15.06 a	1.59 a	10.87 a	12.46 a	3.68 a	3.16 a	147.5 a	110.5 b	26 c
0.30 (136)	1.55 a	2.22 a	5.27 ab	9.51 ab	14.13 ab	1.15 a	10.68 a	11.84 ab	2.80 b	2.90 ab	135.8 ab	112.2 ab	29 c
0.45 (204)	1.60 a	2.21 a	4.91 b	9.22 b	12.88 ab	1.26 a	8.06 ab	8.66 b	3.18 b	2.97 ab	144.1 a	118.8 a	38 b
0.60 (272)	1.54 a	2.25 a	5.04 b	9.20 b	12.58 b	1.25 a	7.16 b	8.41 b	3.00 b	2.65 b	126.8 b	111.6 ab	50 a

[z]Mean separation within column by LSD at $P = 0.05$.
[y]Fruit color rating from 1 (green) progressively to 5 (pink-red).

treatments were 0.07, 0.15, 0.22, and 0.29 lb (34, 68, 102, and 136 g) per tree that were equivalent to 0.15, 0.30, 0.45, and 0.60 lb (68, 136, 204, and 272 g) actual N per tree per year, respectively.

Experimental design was a randomized complete-block split plot, with four rootstocks as main plots, four nitrogen treatments as subplots, and seven blocks. Within each block, a single tree was used for each rootstock–nitrogen combination.

Thirty leaves per tree were sampled randomly from the middle of the current-season's shoot in mid-August 1994, 1995, and 1996. Leaves were washed in a mild Liqui-nox detergent solution (Alconox Inc., New York, N.Y.), rinsed with distilled water, and dried in a forced-air oven at 149 °F (65 °C). Leaves were weighed before and after drying, and percent dry weight was calculated. Dried leaf tissue was ground to pass a 40-mesh screen, and analyzed for N by the micro-Kjeldahl method (Schuman et al., 1973) and for K, Ca, Mg, Fe, Zn, Mn, and Cu by dry ashing at 932 °F (500 °C), digestion, and atomic absorption spectrophotometry (Perkin-Elmer B1100, Norwalk, Conn.) as described by Chaplin and Dixon (1974) and Jones (1977).

Fruit were harvested twice each year based on their visual maturity (color). Number and weight of fruit were measured in each harvest, and yield per tree was recorded. Fruit color was rated visually at harvest and after storage on a scale of 1 = 20% pinkish-red progressively to 5 = 100% pinkish-red. Since larger fruit were always heavier, fruit weight and fruit size are used interchangeably throughout this manuscript.

Trunk cross-sectional area was calculated from trunk diameter measured 8 inches (20 cm) above the bud union in late February of each year.

During the 1998 growing season, severe natural incidence of fire blight was observed in the experimental area. Fire blight severity on each tree was visually rated as percent canopy blighted.

Analyses of variance were conducted using SAS (SAS Institute, Cary, N.C.), and means were compared by least significant difference (LSD) at 0.05.

Results and discussion

EFFECTS OF NITROGEN TREATMENTS. Trunk cross-sectional areas of trees from all nitrogen treatments were similar in 1992 and 1993 (Table 1). In 1994, 1995, and 1996 (2, 3, and 4 years after the beginning of nitrogen treatments, respectively), trees with 0.15 lb annual N had greater TCA than other treatments and the differences were often significant (Table 1). The exact reasons for this lack of response or reduced tree growth at higher levels of applied nitrogen, even under the sandy soil conditions of this experiment, are not clear but may be related to the dynamics of interaction of nitrogen with other nutrients adversely affecting tree growth. Trees that received the lowest amount of nitrogen

Table 2. Influence of soil applied nitrogen on leaf mineral nutrients (on dry weight basis) of 'Scarlet Gala' apple (1.0 ppm = 1.0 $mg \cdot kg^{-1}$).[z]

Actual N per tree per yr	Nutrient (%) N			K			Ca			Mg		
[lb (g)]	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
0.15 (68)	2.35 b	2.19 c	2.49 c	1.58 a	1.81 a	1.38 a	1.19 b	1.04 a	1.20 a	0.38 ab	0.28 c	0.36 c
0.30 (136)	2.37 b	2.33 b	2.59 b	1.51 a	1.76 a	1.42 a	1.19 b	1.07 a	1.18 a	0.36 b	0.32 b	0.37 bc
0.45 (204)	2.51a	2.40 ab	2.60 b	1.42 b	1.67 b	1.37 a	1.31 a	1.09 a	1.21 a	0.39 a	0.34 ab	0.40 a
0.60 (272)	2.59 a	2.48 a	2.67 a	1.38 b	1.61 b	1.37 a	1.32 a	1.08 a	1.14 a	0.40 a	0.35 a	0.34 ab

	Zn (ppm)			Cu (ppm)			Mn (ppm)		
	1994	1995	1996	1994	1995	1996	1994	1995	1996
0.15 (68)	16.4 a	11.9 a	13.9 b	5.3 a	11.9 a	7.1 a	241.9 b	175.1 b	198.5 c
0.30 (136)	20.3 a	16.4 a	15.0 ab	4.8 b	9.8 a	6.8 a	269.7 ab	282.3 a	352.1 b
0.45 (204)	15.7 a	13.2 ab	15.9 ab	4.7 b	8.7 a	6.3 b	300.2 a	290.2 a	410.0 a
0.60 (272)	18.0 a	15.4 ab	17.0 a	4.3 c	10.2 a	6.2 b	291.6 a	307.3 a	437.9 a

[z]Mean separation within column by LSD at $P = 0.05$.

Table 3. Effect of rootstock on tree growth, yield, fruit size and color, and fire blight severity of 'Scarlet Gala' apple (6.45 cm² = 1.0 inch²; 0.45 kg = 1.0 lb; 28.35 g = 1.0 oz).[z]

Rootstock	Trunk cross-sectional area (cm²) 1992	1993	1994	1995	1996	Total yield (kg/tree) 1995	1996	Cumulative yield (kg/tree) 1995–96	Color[y] (1–5) 1995	1996	Avg fruit wt (g) 1995	1996	Fire blight severity (% canopy blighted)
M.9	1.33 c	1.93 b	4.21 b	7.09 c	9.71 c	2.17 a	5.43 b	7.60 b	3.09 ab	1.96 c	148.0 a	116.2 a	44 a
M.26 EMLA	1.87 a	2.22 a	4.63 b	8.16 c	11.38 c	1.50 ab	7.32 b	8.82 b	3.15 ab	2.71 b	135.2 a	114.7 a	49 a
MM.106 EMLA	1.54 b	2.39 a	5.87 a	10.82 b	15.02 b	1.04 bc	12.01 a	13.12 a	3.69 a	3.56 a	137.3 a	106.5 a	27 b
MM.111 EMLA	1.46 bc	2.40 a	6.13 a	12.36 a	18.63 a	0.48 cd	12.82 a	12.79 a	2.93 b	3.39 a	132.6 a	112.9 a	23 b

[z]Mean separation within column by LSD at $P = 0.05$.
[y]Fruit color rating from 1 (green) progressively to 5 (pink-red).

also had higher yield, better fruit color, lower leaf N, and less fire blight than trees in other nitrogen treatments (Tables 1 and 2). Growth, yield and average fruit weight were statistically similar between trees with 0.15 lb N per tree and those with 0.30 lb N per tree (Table 1). However, the latter trees had significantly lower (more green) fruit color and higher leaf N than those of 0.15 lb per year in 1995 and 1996 (Tables 1 and 2). Application of N at or more than 0.30 lb per tree increased leaf Mn, and either worsened or did not improve fruit color. Application of more N than 0.30 lb per tree significantly increased the severity of fire blight (Table 1). Considering tree growth, yield, fruit color and fire blight severity, 0.15 lb N per tree per year seems to be the desirable level for 'Scarlet Gala' under these experimental conditions. Depending on crop load and tree age, the leaf N values for 0.15 lb N per tree were between 2.19% to 2.49% of dry matter (Table 2). Optimum leaf N may vary with tree age and crop load, having lower values in light cropping years (Fallahi, 1997). In 1996, trees had higher yield than in 1995. Trees with 0.15 lb N per tree had leaf N value of 2.49% in 1996 but 2.19% in 1995 (Table 2). Application of more than 0.30 lb N per tree decreased leaf K in 1994 and 1995, and leaf Cu in 1994 and 1996 as compared to the treatment with 0.15 N per tree (Table 2). A greater competition between NH_4^+ and these ions in the soil (Mengel and Kirby, 1979) could have resulted in a lower uptake of these elements in the higher N application. It should be noted that application of high N could decrease fruit firmness both at harvest and during storage, and increase fruit internal ethylene and respiration in apples (Fallahi, 1997, 2000). Nitrogen did not affect leaf Fe (data not shown).

Effects of rootstock. Trunk cross-sectional area of trees on MM.111 EMLA was the largest and that on M.9 was the smallest among the four rootstocks tested during 1993 through 1995, although differences were not always statistically significant (Table 3). Trees on M.9 were more precocious, followed by those on M.26 EMLA, producing more yield per tree in 1995 (Table 3). In 1996, trees on MM.106 EMLA and MM.111 EMLA had higher yield due to their larger size (TCA) (Table 3). Trees on MM.106 EMLA had the best fruit color in both 1995 and 1996. Fruit size was not affected by rootstock in either 1995 or 1996 (Table 3).

Trees on M.9 and M.26 EMLA had higher percentage of canopy damaged by fire blight than those on MM.106 EMLA and MM.111 EMLA rootstocks (Table 3). Such differential susceptibility of apple cultivars to fire blight depending on the rootstock was also reported by some researchers (Boyce, 1970; Mowry, 1969; Thompson, 1971; Keil and Van der Zwet, 1975). Of the four rootstocks studied, fire blight damage to the 'Scarlet Gala' trees was inversely related to the rootstock vigor, expressed as TCA (Table 3). In trees on less vigorous rootstocks, fire blight lesions can progress to involve a larger proportion of the canopy in a shorter time leading to more severe damage, as compared to trees on more vigorous rootstocks. On average, trees on M.9 and M.26 EMLA had about 63% less TCA than those on MM.106 EMLA and MM.111 EMLA in 1996 (Table 2). It should be noted that trees on less vigorous rootstocks might show a higher percentage of blighted canopy and yet have similar level of fire blight as those on more vigorous rootstocks. In another part of this study (data not reported), severity of fire blight in trees on Malling 7 (M.7 EMLA) was similar to those on MM.106 EMLA and MM.111 EMLA. In addition to increasing fire blight severity in the scion cultivar, as observed in this study, M.9 and M.26 as rootstocks are also known to be highly susceptible to fire blight, whereas

Table 4. Influence of rootstock on leaf mineral nutrients (on dry weight basis) of 'Scarlet Gala' apple (1.0 ppm = 1.0 mg·kg⁻¹).[z]

Rootstock	N (%) 1994	1995	1996	Ca (%) 1994	1995	1996	Mg (%) 1994	1995	1996	Zn (ppm) 1994	1995	1996	Cu (ppm) 1994	1995	1996
M.9	2.41 a	2.37 a	2.49 a	1.35 a	1.26 a	1.36 a	0.34 b	0.33 b	0.39 b	20.0 a	18.3 a	17.4 a	5.2 ab	10.9 ab	7.0 a
M.26 EMLA	2.49 a	2.40 a	2.65 a	1.32 a	1.13 ab	1.16 b	0.42 a	0.39 a	0.44 a	15.7 a	13.5 ab	14.8 ab	4.3 bc	8.9 ab	6.2 b
MM.106 EMLA	2.50 a	2.34 a	2.58 a	1.27 a	1.04 b	1.20 b	0.35 b	0.29 c	0.33 c	15.5 a	12.5 ab	14.4 b	5.4 a	12.2 a	6.9 ab
MM.111 EMLA	2.41 a	2.29 a	2.63 a	1.06 b	0.85 c	1.01 c	0.41 a	0.27 c	0.33 c	18.9 a	12.4 b	14.9 ab	4.2 c	8.5 b	6.3 ab

[z]Mean separation within column by LSD at $P = 0.05$.

MM.106 EMLA and MM.111 EMLA are among the least susceptible ones (Anthony and Clarke, 1946; Cummins and Aldwinckle, 1973; Rom and Slack, 1971; Van der Zwet and Beer, 1995). These results lead us to suggest that fire blight susceptibility in 'Scarlet Gala' will be greater when highly susceptible rootstocks and / or high levels of nitrogen fertilization are employed.

Leaf N and K were not affected by rootstock. However, trees on M. 9 had higher leaf Ca than those on MM.106 EMLA (except in 1994) and MM.111 EMLA rootstocks (Table 4). Trees on M.26 EMLA had higher leaf Mg than those on other rootstocks and the differences were statistically significant in 1995 and 1996 (Table 4), which is in agreement with earlier reports on 'Strakspur Golden Delicious' apple (Fallahi et al. 1984). Trees on MM.106 EMLA had lower leaf Mg than those on M. 9 and M.26 EMLA in 1995 and 1996 (Table 4).

Precocity, high yield efficiency, and smaller size of trees on M.9 rootstock is in agreement with previous reports on 'Fuji' (Tsuchiya et al., 1974) and on 'Rogers Red McIntosh' and 'Macspur' (Autio and Southwick, 1993). These desirable characteristics make M.9 a popular rootstock for high-density planting systems. However, trees on this rootstock are more prone to damage by fire blight, rodents and adverse environmental conditions. Also, trees on M.9 have less foliage, leading to significantly more sunburn on fruit, than those on other rootstocks. This situation was observed in 1994, when temperatures exceeded 100 °F (37.8 °C) during several days in summer (Data not shown).

Conclusions

Under conditions of this experiment, annual application of 0.15 lb actual N per tree was sufficient for optimum tree growth, yield, and fruit color. Increasing N supply to 0.30 lb or more per tree elevated tree N status, resulting in poor fruit color and increased fire blight damage. Application of high N can influence leaf concentrations of K, Ca, Cu, and Mn without additional applications of any of these minerals. Trees on M9 were more precocious and produced higher yield early. Three years after planting, trees on more vigorous rootstocks (MM.106 EMLA and MM.111 EMLA) had higher yield due to their larger size. Trees on M.26 EMLA always had higher leaf Mg than those on other rootstocks tested. Fire blight (percentage of canopy damage) was more severe in trees on M.9 and M.26 EMLA than those on MM.106 EMLA and MM.111 EMLA.

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