Nutritional Effects on Fruit Quality for Apple Trees

Denise Neilsen and Gerry Neilsen

Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre

Summerland, BC, Canada

This paper was presented at the 2009 Cornell In-depth Fruit School on Mineral Nutrition.

> **"The major nutrients (N, P, K, and Ca) which can be precisely applied, either through foliar applications or fertigation have major effect on fruit quality. Our studies show that increased P applied through fertigation increased yield and decreased watercore and browning. Potassium fertilization increased fruit color and quality without increasing bitter pit. Calcium sprays reduced bitter pit while Nitrogen fertilization increased yield but reduced fruit color and quality."**

Fruit quality is a major determinant of grower returns and consequently has been studied widely. There are many components to fruit quality including surface and internal disorders, size, colour, firmness, soluble solids, and acidity. In addition there are many factors, which may influence fruit quality, some of which are outside of our control such as weather, site suitability and varietal genetic potential. There is increased interest in examining the interaction of varieties with environmental limitations and matching varieties to location, but these will not be discussed here. Similarly, there are many practices, which can influence fruit quality including crop load management, pruning for tree balance and light interception, maturity assessment for harvesting and nutrient and water management. This discussion will focus on nutritional effects on fruit quality.

Calcium (Ca)

Calcium is the mineral nutrient, which has been most highly implicated in the quality of fruit, particularly with respect to disorders, which affect storage. Common disorders include bitter pit and internal breakdown (Figure 1). Considerable effort has been expended on control of these disorders, mostly through the application of sprays to the fruit during the growing season or applications of Ca at harvest in the packinghouse. Most apple growing regions have recommendations for in season Ca applications similar to those for British Columbia, which include the use of $CaCl_2$ compounds, applied four – five times at 10 - day intervals starting mid-July with a concentration of 0.5% v/w applied at the rate of 8-12 kg/ha.

The timing of sprays relative to the timing of fruit Ca accumulation is shown in Figure 2. Note that Gala and Fuji appear to accumulate more Ca than Spartan. This difference is not wholly due to differences in fruit size. Consequently, few Ca-related disorders have been found in Gala grown in our region. Unlike some reports for more humid regions, where it has been considered that fruit Ca accumulation occurs mainly during cell division (Stage 1), fruit Ca continued to increase over the growing season (Figure 2). The occurrence of some losses in Ca concentration immediately before harvest, suggested that later sprays would be useful and a study was initiated looking at spray timing for a late-season variety, Braeburn. Calcium concentration in the fruit at harvest was increased above the 4.0 mg/100g fresh weight considered to be a threshold for disorders in 2001 and 2002 (Table 1). In 2003, a hot dry year, Ca

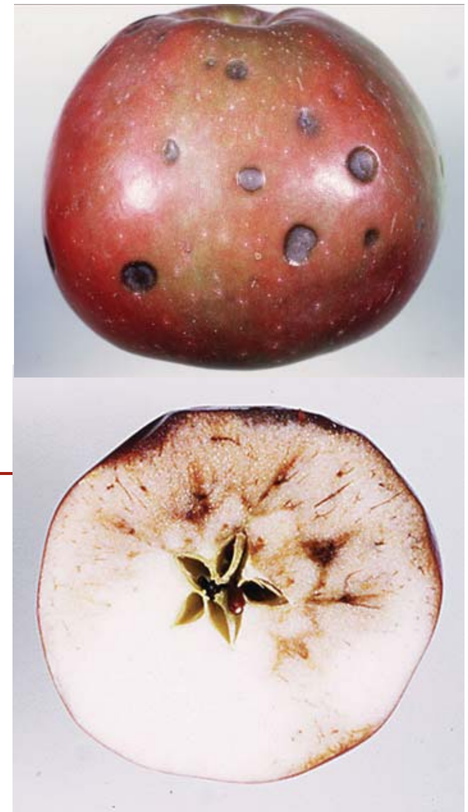

Figure 1. Common disorders of apple related to Ca. Top: bitter pit. Bottom: internal breakdown.

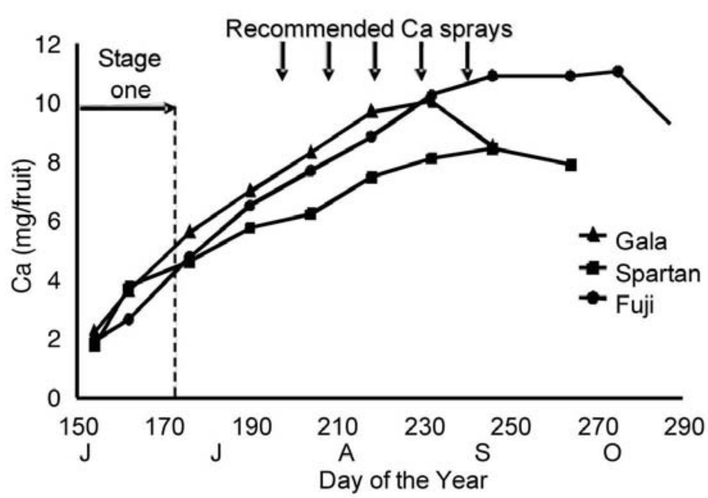

Figure 1. Ca accumulation over the growing season for different cultivars, grown in Summerland, BC.

Table 1. Fruit Ca concentration and incidence of bitter pit at harvest for Braeburn apple in response to timing of $CaCl_2$ sprays.

Treatment y	2001	2002	2003	2001	2002	2003
	Ca concentration (mg/100g F.W.)			Incidence of Bitter pit (%)		
Control	3.6b	3.4c	3.5	2	12a	36a
Early	3.3bc	3.7c	3.4	0	0b	6b
Mid	4.2a	4.9b	3.3	0	0b	9b
Late	4.4a	5.7a	3.8	3	2b	15b
	***	****	ns	ns	**	**

y Control – no sprays; Early – 5 weekly sprays starting first week June; Mid - 5 weekly sprays starting second week July; Late- 5 weekly sprays starting second week August

*,**, significantly different at p<0.05, 0.01, respectively.
Within columns different values followed by different letters are significantly different

Table 2. Effectiveness of different Ca sprays for increasing fruit Ca concentration in Braeburn/M.9

Treatment y	Year 1	Year 2	Year 3
	Ca concentration (mg/100g F.W.)		
Control	4.16c	3.29b	3.64b
$CaCl_2$	5.80a	4.49a	5.04a
Nutrical	4.71b	4.12a	-
Calcimax	4.08c	-	-
#sprays			

y Year 1 -recommended rate – cost equivalent per acre; Year 2 – Ca equivalent per acre. Within columns different values followed by different letters are significantly different

concentrations were not increased by Ca sprays, suggesting that plant water relations may have had an overwhelming control over fruit Ca inflow/outflow. The pattern of bitter pit incidence essentially followed that of fruit Ca content in 2001 and 2002. In 2003, Ca sprays reduced bitter pit, despite not increasing fruit Ca concentration. In humid climates, the five sprays of Ca would not be considered adequate, and a full program may consider up to 12 sprays throughout the whole season.

There are many Ca products available to growers that have been tested over the years, often with similar results. In one such experiment, two Ca formulations, Nutrical and Calcimax were compared with $CaCl_2$ and no Ca spray to determine their relative effectiveness in increasing fruit Ca concentrations. In year one, $CaCl_2$ and Nutrical increased fruit Ca concentrations above the control, but $CaCl_2$ was most effective (Table 2). In Year one, sprays were applied at the recommended rate and costs were roughly similar. However, Ca applied was lower for Nutrical and Calcimax than for $CaCl_2$ so in year two, Nutrical and $CaCl_2$ were applied at the same Ca rate and were similarly effective, but cost/acre was much lower for $CaCl_2$. In subsequent years, Ca was supplied as $CaCl_2$.

Potassium (K)

Potassium is often considered to be detrimental to fruit quality through interference with the uptake and utilization of Ca. However, over-emphasis on this issue can sometimes lead to K deficiency, particularly in high-density production systems on coarse-textured soils, or wherever soils are naturally low in K,

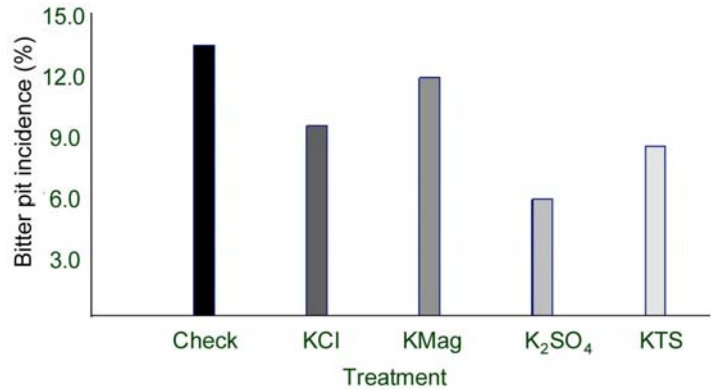

Figure 2. Incidence of bitter pit in Braeburn/M.9 in response to fertigated potassium 2001-2003.

due to parent material or the presence of K-fixing clay minerals. In an experiment with Braeburn/M.9, a variety that is susceptible to bitter pit, there were no detrimental effects on fruit quality from a range of K fertilizers (Figure 3). However, it should be noted that leaf K concentration in the control plots was around 1.3% - the deficiency threshold, and that leaf K concentrations in the treated trees were always below 2.0%.

Under deficient conditions, K applications may improve fruit quality. In a multi-year experiment where K was applied to four different apple cultivars, applications increased red colour (Table 3). However, fruit firmness was reduced slightly, although in all

Table 3. Effect of K fertigation on fruit quality under deficient conditions for 'Gala', 'Fuji', 'Fiesta' and 'Spartan' apples on M.9 rootstock

K application g/tree	Red colour (%)				Firmness (N)		
	Year 1	Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
	Gala	Fuji	All	All	All	Fiesta	All
0	72	73	80	68	85	92	84
15	77	76	84	72	85	85	81
Sign.	*	**	ns	ns	**	**	

*, **Paired means significantly different at P= 0.05, 0.01 respectively or not significantly (NS) different.

cases was still high. It should be stressed that trees receiving no K had showed deficiency symptoms on the leaves, which had less than 1% K concentration in some cases.

Phosphorus (P)

Like Ca, phosphorus is important in the creation and stability of cell walls in fruit. Because of difficulties associated with delivering P to tree fruit roots, there have been relatively few studies of the effects of P on fruit quality. However, fertigation of P improves transportation in the root zone. In a recent study, two fertigation treatments compared the presence (+P) or absence (-P) of phosphorus applied annually at 20g P/tree as ammonium polyphosphate, soon after full bloom to five apple cultivars: 'Ambrosia', 'Cameo', 'Fuji', 'Gala' and 'Silken' apples on dwarfing M.9 rootstock. Treatments were monitored for five years from the second to sixth growing seasons on trees receiving atmometer-scheduled drip irrigation, and annual fertigation of N, B and K.

Concentration of P in harvested fruit was nearly always increased by P-fertigation (Table 4). The single exception was fruit P values for 'Gala' apples in 2001, which, unlike the other five cultivars, were not significantly increased by P application.

Both cumulative fruit number and per tree yield for all five apple cultivars was increased by P-fertigation (Table 5). There was no overall effect on apple fruit size. The benefits of P-fertigation associated with increased per tree yield appear to result from an increase in fruit number rather than average fruit size.

The fruit disorder, watercore, was reduced by P-fertigation in two of three measurement years, 2001-2003 (Table 6). In 2001, both cultivars which had the disorder ('Fuji' and 'Silken') had reduced incidence associated with elevated fruit P concentration (Table 6). The same pattern was observed for P-fertigated fruit over all cultivars in 2002 but significant effects were not observed in 2003. Occurrence of water core is of less practical significance for 'Fuji' since water core virtually disappears after cold air storage of this cultivar. Reduction of water core in 'Silken' is more useful since this yellow-skinned cultivar shows the disorder more readily. Regardless, the results imply that P has beneficial effects on fruit membrane stability. P-fertigation also inhibited browning of cut apple slices after one week storage at 1ºC in modified atmosphere packages in 2001 and 2002, the years when water core was reduced by P-fertigation (Table 7). The P-treatment also decreased membrane leakage and increased antioxidant (water soluble and liposoluble) contents for Fuji after 90 days cold storage in 2002 (data not shown). This experiment suggests a more prominent role for P in fruit quality at harvest that previously realized.

Table 4. Harvest fruit P concentration (time B) for all apple cultivars ('Ambrosia', 'Cameo', 'Fuji', 'Gala' and 'Silken') as affected by presence (+P) or absence (-P) of P-fertigation near bloom, 1999-2003.

	Fruit P (mg/100g fw)								
Treatment	1999	2000	2001					2002	2003
Cultivar	All	All	A	C	F	G	Si	All	All
+P	15.8	12.8	11.0	12.9	14.5	10.7	12.9	10.2	13.1
-P	12.9	9.7	8.4	9.0	10.6	9.0	9.9	7.8	10.9
Significance	****	****	****	****	**	NS	**	****	**

,* Paired means significantly different at P=0.01, 0.001 respectively or not significantly (NS) different

Table 5. Cumulative number of fruit and yield per tree and average fruit size for all apple cultivars ('Ambrosia', 'Cameo', 'Fuji', 'Gala' and 'Silken') as affected by presence (+P) or absence (-P) of P-fertigation near bloom for the first five growing seasons (1999-2003).

Treatment	Fruit per tree	Yield per tree	Average fruit weight
	(n)	(kg/tree)	(g/fruit)
+P	239	47.2	199
-P	203	39.3	194
Significance	*	*	NS

* Paired means significantly different at P=0.05 or not significantly (NS) different

Table 6. Incidence of water core for apple cultivars 'Ambrosia', 'Cameo', 'Fuji', 'Gala' and 'Silken' as affected by presence (+P) or absence (-P) of P-fertigation near bloom (2001-2003).

	Proportion of apple fruit affected by water core			
Treatment	2001		2002	2003
Cultivar	F	Si	All	All
+P	0.62	0.00	0.22	0.27
-P	0.88	0.16	0.29	0.29
Significance	***	*	*	NS

*,*** Paired means significantly different at P=0.05 or P=.001 or not significantly (NS) different

Table 7. Browning of cut apple slices after 1 week at 1ºC in modified atmosphere packaging for apple cultivars 'Ambrosia', 'Cameo', 'Fuji', 'Gala' and 'Silken' as affected by presence (+P) or absence (-P) of P-fertigation (2001-2002 crop).

	Browning Scale (L-value)z								
Treatment	2001					2002			
Cultivar	A	C	F	G	Si	A	C	G	Si
+P	77.3	76.9	75.6	79.0	77.4	78.7	77.4	78.5	78.7
-P	76.6	76.1	73.8	78.2	76.4	77.5	76.2	77.4	76.0
Significance	*	*	*	*	*	*	*	*	*

*,*** Paired means significantly different at P=0.05 or P=.001 or not significantly (NS) different
z Higher values = lower surface browning

Nitrogen (N)

Precision management of N nutrition, especially with techniques such as fertigation, should allow a better control of N-affected fruit quality. Most of the N which is found in the fruit at harvest is accumulated after fruit cell division ends, during the period of fruit cell expansion. With this in mind, an experiment was initiated to examine the effect of applying N at 0-4, 4-8 or 8-12 weeks after bloom. The shift from cell division to cell expansion is expected to occur within the 4-8 week period after full bloom. A number of fruit quality parameters were measured (Figure 4). The most consistent effect was that late applications of N tended to result in lower fruit starch content, an indication that the fruit were further advanced in maturity. This was confirmed by the higher soluble solids content of fruit receiving later N applications, indicating that starch had been converted to sugars. However, fruit acidity remained higher in later N fruit, so the sugar:acid balance differed among the treatments. Red colour was unaffected by the timing of N applications. Other effects on yield, fruit size and return bloom were much less consistent.

The effect of high N rate on fruit performance was more consistent for five cultivars receiving either low or high N applications 0-8 weeks after bloom. With very few exceptions, fruit N content was increased in fruit receiving the high rate of N over five years (Figure 5). Except for the first year, fruit firmness was decreased by high N application rates. As in the experiment with N timing, fruit red colour responses to N rates were inconsistent, occurring only one year in five.

Summary

This brief overview of nutritional effects on fruit quality has focused on management of the major nutrients N, P, K, Ca which can be precisely applied, either through foliar applications or fertiga-

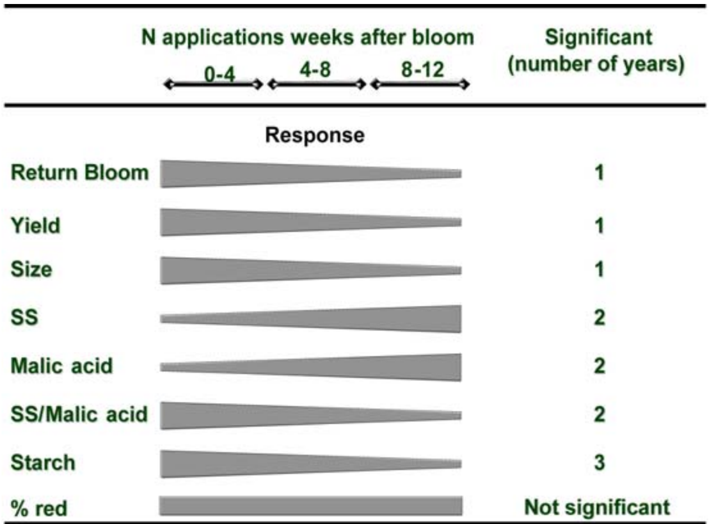

Figure 3. Fruit quality effects of th etiming of N applications to Gala/M.9. The thickness of the bar determines if the effect differed between application periods. The thinner the bar the lower the value.

tion. In general, results tend to differ from year to year, reflecting the importance of annual weather variation in determining fruit quality and tree performance. Some of these differences may be due to stresses from high temperatures within the growing season, water stress associated with high evaporative demand (despite irrigation) and carry-over effects from the previous year. Future work is required to quantify the magnitude of this inter-seasonal variation, which frequently exceeds any efforts at management, and to understand the relationships with climate variables.

Denise Neilsen is a research scientist with Ag Canada in British Columbia who specializes in soil nutrition, fertigation and climate change. Gerry Neilsen, her husband, is also a research scientist with Ag Canada who specializes in soil science.

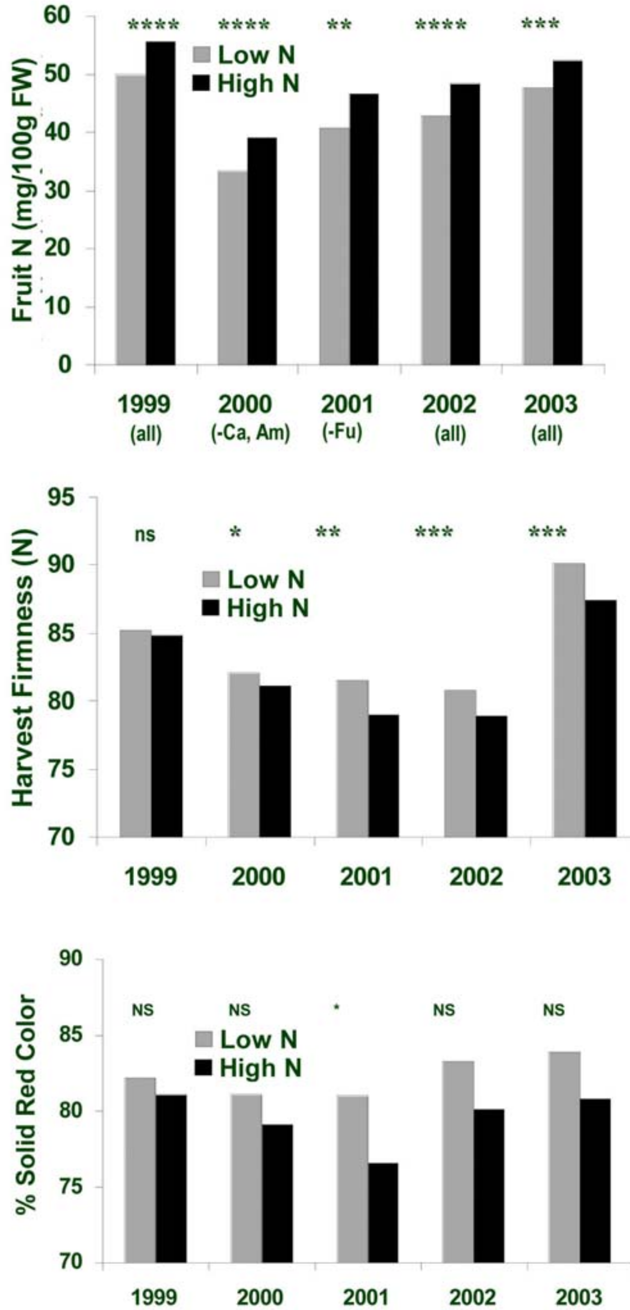

Figure 4. Fruit N content, firmness and red color at harvest averaged for 5 apple cultivars Cameo (Ca), Ambrosia (Am), Fuji (Fu), Gala (Ga) and Silken (Si) receiving either 28 mg/L or 168 mg/L N as $Ca(N)_3)_2$ fertifated daily.