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'Honeycrisp' Apple Leaf and Fruit Nutrient Concentration is Affected by Rootstock During Establishment

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Abstract

A trial involving 31 dwarfing and semi-dwarfing apple [*Malus sylvestris* (L.) Mill var. *domestica* (Borkh.) Mansf.] rootstocks from Russia, USA and Germany, with 'Honeycrisp' as the scion, was established in 2010 in Summerland, B.C., Canada, as part of a larger experiment organized by the USDA NC-140 rootstock research group. Leaf and fruit nutrient concentrations were affected by rootstock during the critical, first three years of establishment under irrigated conditions. Trees exhibited a range of vigor and initial yield. Few problems were found in achieving adequate leaf N, B and Cu regardless of rootstock, whereas leaf Zn, P, Mg and fruit Ca often did not achieve sufficiency. Rootstocks were identified with superior and inferior abilities to accumulate individual nutrients, but only B.70-6-8 (P, Mn and K) and B.7-3-150 (P, K) were superior for more than a single nutrient. The ability to accumulate a range of key plant nutrients was not well-correlated with initial tree performance, with the exception of a close association between leaf P and initial tree vigor. There also was an apparent antagonism between P and fruit Ca concentration of the first crop.

Rootstocks have long been known to affect scion leaf nutrient concentration (Delap and Ford, 1958) with effects identified for many traditional apple cultivars (Kennedy et al., 1980; Poling and Oberly, 1979) and also newer cultivars such as 'Fuji' (Fallahi et al., 2002) and 'Gala' (Fallahi, 2012). 'Honeycrisp' is one such "new" apple cultivar that has increasingly been planted because of its high returns (Wood, 2001). In turn this has attracted increasing research interest, resulting in the establishment of rootstock and cultural trials (Privé et al., 2011). The cultivar is not without challenges to optimizing its growth, which have included a susceptibility to development of bitter pit (Rosenberger et al., 2004) and reports of relatively poor initial growth and establishment (Privé et al., 2011). It is not known the extent to which these problems might be ameliorated by selection of an appropriate rootstock including those that might improve absorption and translocation of key plant nutrients including Ca for fruit. A recent publication has advocated considering improved nutrient efficiency as a new criterion for selection and breeding of rootstocks (Fazio et al., 2013). This approach is of particular interest in the semi-arid apple growing region of the Pacific Northwest of North America where tree vigor has been compromised by micronutrient deficiencies, commonly of B and Zn (Neilsen et al., 2004) and poor tree establishment resulting from replant disorders and diseases often associated with inadequate P nutrition (Neilsen and Yorston, 1991). Furthermore fruit quality has been degraded, including for 'Honeycrisp', by disorders such as bitter pit associated with Ca deficiency (Peryea et al., 2007).

Thus, taking advantage of an opportunity provided by the establishment of an NC-140 apple rootstock trial with 'Honeycrisp' as the scion at the Pacific Agri-Food Research Centre in the Pacific Northwest fruit-growing

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region, the effect of rootstocks on nutrition of this cultivar was determined during the initial establishment years.

Materials and Methods

As part of an NC-140 co-operative trial on dwarfing apple rootstocks, an experimental planting was established in 2010 at the Pacific Agri-Food Research Centre in Summerland, southern interior British Columbia. Highly feathered nursery trees of 'Honeycrisp' on 31 different rootstocks (Willow Drive Nursery, Ephrata, WA), were planted in April 2010 in a randomized complete block design with four replications of one- to three-tree plots. The number of trees per plot varied because of a shortage of certain rootstocks. The rootstocks included 9 selections from the Budagovsky series bred in Russia, 13 selections from the Cornell-Geneva breeding program in New York, USA, and three from Pillnitz, Germany (Table 1). Three of the New York rootstocks were tested from both tissue-cultured (TC) and "normal" (N) field-propagated source material. Standard commercial rootstocks for comparison included

Table 1. Vigor (as indicated by trunk cross-sectional area, TCA), yield, yield efficiency (YE) and average fruit weight of 'Honeycrisp' apple in the third leaf (2012), as affected by rootstock. Standard commercial rootstocks used for comparison are shown in **bold** type. Rootstocks are sorted by TCA.

Rootstock	TCA (cm^2)	Yield (kg)	YE ($kg \cdot cm^{-2}$)	Avg. fruit wt. (g)
B.70-20-20	15.1 a[z]	11.7 abcd	0.77 l	343 ab
PiAu 9-90	8.6 b	7.4 efg	0.88 kl	358 a
G.202N	8.5 b	13.0 abc	1.55 defghi	328 abc
B.7-20-21	8.2 bc	10.3 bcdef	1.24 ij	261 bc
CG.4004	8.1 bc	15.1 a	1.78 bcdefg	289 abcde
G.5087	7.8 bc	13.7 ab	1.75 cdefgh	325 abcd
CG.3001	7.6 bc	14.7 a	1.90 abcde	293abcde
CG.4814	7.5 bc	13.6 ab	1.82 abcdef	287 abcde
B.67-5-32	7.3 bcd	9.0 def	1.25 ij	286 abcde
CG.5222	7.1 bcde	9.7 cdef	1.37 hij	294 abcde
G.935N	6.9 cdef	13.2 abc	1.88 abcde	289 abcde
B.70-6-8	6.1 defg	8.5 ef	1.37 hij	243 de
B.64-194	5.9 defgh	8.2 defg	1.42 ghij	260 bc
G.41N	5.8 efgh	10.6 bcde	1.81 abcdef	289 abcde
M.9 Pajam2	**5.7 efgh**	**9.1 def**	**1.57 defghi**	**253 cde**
G.202TC	5.5 fgh	7.3 efg	1.30 ij	229 e
B.7-3-150	5.4 gh	8.6 def	1.60 cdefghi	256 bcde
PiAu 51-11	5.4 gh	6.7 fg	1.24 ij	222 e
M.26 EMLA	**5.2 ghi**	**7.8 efg**	**1.48 fghij**	**256 bcde**
CG.4214	4.8 ghij	10.4 bcdef	2.15 ab	271 bcde
G.41TC	4.8 ghij	9.2 def	1.93 abcd	322 abcd
CG.4013	4.8 ghij	7.3 efg	1.53 efghij	251 cde
CG.2034	4.7 ghij	7.5 efg	1.55 defghi	276 bc
G.935TC	4.7 ghij	10.2 bcdef	2.19 a	267 bcde
B.10	4.6 ghij	8.0 efg	1.74 cdefgh	259 cde
Supporter 3	4.6 ghij	8.9 def	1.97 abc	283 abcde
G.11	4.5 hij	8.1 defg	1.77 cdefg	232 e
M.9 T337	**4.4 hij**	**7.7 efg**	**1.73 cdefgh**	**252 cde**
CG.4003	3.8 ij	6.9 efg	1.82 abcdef	252 cde
B.9	**3.6 j**	**4.8 g**	**1.29 ij**	**222 e**
B.71-7-22	1.4 k	1.6 h	1.15jk	279 abcde

[z] Means within a column followed by the same letter are not significantly different at p ≤ 0.05 according to Duncan's multiple range test.

Budagovsky 9, M.26, and two sub-clones of M.9. All rootstocks were expected to be in the semi-dwarfing to dwarfing vigor classes, and therefore suitable for modern high-density planting systems, such as tall spindle or super spindle.

The site was located on a Skaha gravelly sandy loam (Wittneben, 1986), a common soil series utilized for fruit growing through the southern Okanagan Valley, BC. No detailed soil sampling was undertaken at the site. However, these Orthic Brown soils generally drain rapidly, have low water-holding capacity, low organic matter, low N and P content, neutral pH and overlie coarse subsoils. The site had previously been planted with apples, and was fumigated with metam sodium at label rates in autumn 2009. At planting, 11.5 L of Hypnum black peat (Superior Peat, Inc.) was mixed with the soil in each 25 L planting hole. This peat was extracted locally from a high elevation site and in general has low nutrient content (2.3% N, 0.1% P and 0.1% K on a dry weight basis). Its primary effect was judged to be improving the moisture retention capacity of the soil and possibly the N nutrition of the trees. A 1.5 m wide herbicide strip was maintained via periodic applications of glyphosate (N-phosphono-methylglycine) at 1.0 kg a.i.$\cdot$ha^{-1} as required. The alleys were seeded with a mixture of 40% crested wheat grass (*Agropyron cristatum* (L.) Goertn. cv. 'Fairway'), 40% pubescent wheat grass (*Agropyron trichlophorum* Richt. cv. 'Greenleaf') and 20% perennial ryegrass (*Lolium perenne* L.).

Trees were trained and pruned as tall spindles (Robinson et al., 2011) and supported by a three-wire trellis system with posts 11-12 m apart in the row. Tree spacing was 1.2 m within the row and 4.0 m between rows. All trees were de-blossomed in 2011 to encourage tree growth. In 2012, the crop was thinned by hand in June to single-fruit clusters approximately 15-20 cm apart. Standard commercial production practices for the region were used to control insects and diseases, as required (British Columbia Ministry of Agriculture and Lands (BCMAL), 2010). Irrigation and fertilizers were applied via two 4 L$\cdot$h^{-1} drip emitters, spaced 0.3 m on both sides of each tree, twice daily to avoid the development of water stress. Overhead irrigation was used for hydro-cooling when air temperature exceeded 32°C (5 min. per hr from 11 a.m. to 5 p.m.) and to supplement the water supply for the alley vegetation, when needed. As required by the NC-140 trial protocol, calcium nitrate (15.5N-0P-0K) was applied; it was fertigated weekly from 16-May to 01-Aug in 2010 and from mid-June to early Aug. in 2011-2012 at rates sufficient to provide 20 g N/tree/yr. There was minimal application of other nutrients in the block with the exception of a foliar spray of Epsom salts in July 2010 and of 20-20-20 in June 2011. Applications were made at dilute concentrations as recommended in the local production guide (BCMAL, 2010) and were judged to have minimal effects on leaf nutrient concentration. Three food grade calcium chloride foliar sprays were made at recommended guide rates (4 g$\cdot$L^{-1} of Clorclear calcium chloride (34.5% Ca) sufficient to supply 6 to 9 kg ingredient/ha at each application) to the fruit crop on 10, 21 and 29 August in 2011.

Trunk diameter was measured annually in autumn (0.3 m above the bud union) and converted to trunk cross-sectional area (TCA) for analysis. Yield was recorded for the first harvest in 2011. Leaf samples were collected for each of the three years (2010 to 2012) from each rootstock plot and replicate. Samples comprised 20 (one tree plots) to 30 (two or three tree plots) leaves collected from the mid-third portion of extension shoots of the current year's growth during the standard midsummer sampling period (mid-July to mid August) from each plot. Leaf samples were oven dried at 65°C and ground in a stainless steel mill. Leaf N was determined using the LECO FP-528 (LECO Corporation, St. Joseph, MI) combustion analyzer. Leaf Ca, Mg, K, Mn, Zn, Fe, Cu and B were determined by inductively coupled argon plasma (ICP) emission spectrophotometry (Spectro

Modula, Spectro Analytical Instruments, Kleve, Germany) on ground 0.5 g samples, dry ashed and dissolved in 1.2 M HCl. In 2011 a random sample of 10 fruit from each rootstock plot and replicate was collected for mineral analysis. Samples were rinsed under distilled water and then air-dried. Chemical analyses were conducted on a composite of opposite, unpeeled quarters from each apple minus stem tissue and seeds. LECO N was determined on a 0.125 g sub-sample of freeze dried sectors and P, Ca, Mg and K on a 0.5 g freeze-dried sub-sample by ICP as described for leaf samples.

All plant tissue nutrient concentrations, yield and growth measurements were analyzed using a mixed model analysis of variance (ANOVA) in SAS (SAS Institute Inc., 2000). For leaf concentrations, year measurements were treated as repeated measures using the REPEATED statement in PROC MIXED. Year by rootstock interactions were generally significant so that means were compared within years using Duncan's multiple range test and subsequently presented in tables. PROC CORR in SAS was used to calculate correlation coefficients between tissue nutrient concentrations, yield, average fruit size and TCA in the third leaf.

Results and Discussion

Vigor and yield. Rootstocks significantly affected the initial vigor of 'Honeycrisp' as indicated by TCA in the third leaf and yield and yield efficiency of the first crop, which was harvested in 2012 (Table 1). In general larger trees had larger yields since crop load was adjusted in this study to commercial standards, thereby reducing crop on smaller trees. Nevertheless, notable differences in ranking between vigor and yield were observed for G.935TC (24th in vigor, 11th in yield) and PiAu 9-90 (2nd in vigor, 25th in yield). The four standard rootstocks exhibited low to medium vigor, yield and yield efficiency with few differences among rootstocks (Table 1). B.9 was significantly less vigorous than M.9 Pajam 2 or M.26 EMLA, but only M.9 Pajam 2 yielded significantly more than B.9. Yield efficiency of 'Honeycrisp' on M.9 T337 only exceeded that of B.9. Nine of the rootstocks classified as having highest vigor over the first three years of establishment in this study had TCA exceeding the four standard rootstocks, and five of these resulted in higher first crop yield (Table 1), all of them from the Cornell-Geneva program, implying effective selection for precocity and/or yield efficiency.

To our knowledge there have been few published studies on performance of 'Honeycrisp' as affected by rootstock. An earlier study by Privé et al. (2011) was restricted to 24 rootstocks, few of which were the same as rootstocks tested in this study. Noteworthy in our study was the relatively poor initial vigor and yield performance of B.9 and B.71-7-22. Similar small tree size and low yield were observed for irrigated 'Gala' apples grown in Idaho on B.9 rootstock (Fallahi, 2012), and at Summerland in two previous NC-140 trials (Autio et al., 2013; Marini et al., 2009).

Nutrition relative to standard values. The ability of 'Honeycrisp' to achieve locally recommended leaf nutrient concentrations on the rootstocks varied by nutrient and year (Table 2), with recommended values not achieved for more than half of the rootstock-years for leaf Zn, P, Mg and fruit Ca. Leaf Mn, K, Ca and Fe comprised a second grouping of nutrients which failed to achieve recommended values 20-40% of the tested occasions. In contrast, leaf N, B and Cu exhibited few (for N) to no inadequate values (B and Cu). The proportion of trees affected by low leaf concentrations varied by year so that low leaf Mg and Fe concentrations were pronounced in the second year, low leaf Mn in the second and third year, low leaf Ca in the first two years and low leaf K in the third year when the first crop was harvested. Fruit Ca was only measured in third leaf, and more than half the rootstocks had low fruit Ca concentrations despite the application of Ca sprays, as recommended for cultivars susceptible to Ca-deficiency, and calcium nitrate

Table 2. Number of rootstocks (31 total rootstocks), annually and cumulatively, with low leaf or fruit nutrient status according to recommended regional commercial values.

Nutrient	Unit[y]	Recommended value	Low rootstocks (n) Year 1	Year 2	Year 3	Cumulative	Percent
Leaf Zn	$mg\cdot kg^{-1}$	> 12	29	29	24	82	88%
Leaf P	$g\cdot kg^{-1}$	> 2.0	21	15	29	65	70%
Leaf Mg	$g\cdot kg^{-1}$	> 2.6	13	31	12	56	60%
Fruit Ca	$mg\cdot 100\ g^{-1}$	> 4			16	16	52%
Leaf Mn	$mg\cdot kg^{-1}$	> 25	0	18	18	36	39%
Leaf K	$g\cdot kg^{-1}$	> 13	0	1	29	30	32%
Leaf Ca	$g\cdot kg^{-1}$	> 10	11	15	0	26	28%
Leaf Fe	$mg\cdot kg^{-1}$	> 45	1	17	7	25	27%
Leaf N	$g\cdot kg^{-1}$	> 19	1	2	0	3	3%
Leaf B	$mg\cdot kg^{-1}$	> 20	0	0	0	0	0%
Leaf Cu	$mg\cdot kg^{-1}$	> 4	0	0	0	0	0%

[z] British Columbia Ministry of Agriculture and Lands (2010)
[y] Leaf nutrients expressed by dry weight; fruit Ca by fresh weight and measured only in year 3

fertigation.

Deficient leaf Zn concentrations are commonly reported in Pacific Northwest orchards despite applications of recommended annual sprays of dormant Zn (Neilsen, 1988) and these results suggest that annual maintenance Zn sprays will be required for ‘Honeycrisp’ regardless of rootstock. Recommended leaf P concentrations for young apple trees in British Columbia are to exceed 2.0 g $P\cdot kg^{-1}$, based on local research indicating superior performance of such apple trees when replanted in old orchard soils susceptible to replant disease (Neilsen et al., 2008). Achieving elevated leaf P concentrations may be less relevant for fruiting ‘Honeycrisp’ trees, particularly as there have been reports of a positive association between P nutrition and bitter pit occurrence (Robinson and Lopez, 2012). Mg and K deficiency have been occasionally reported in the region (BCMAL, 2010). Our data would suggest a strong effect of year on leaf Mg, Mn and K concentrations with decreased leaf K concentrations in the third year consistent with research indicating the potential for K-deficiency to be a problem as drip-irrigated apple trees grown on coarse-texture soils begin fruiting (Neilsen et al., 1998). The prevalence of low fruit Ca concentrations in the first ‘Honeycrisp’ crop regardless of rootstock is consistent with this cultivar’s susceptibility to developing bitter pit in initial fruit crops (Cline, 2005). The general persistence of low fruit Ca concentrations despite fertigation with calcium nitrate and application of three $CaCl_2$ sprays in August 2012 is consistent with recent research indicating foliar Ca sprays as early as June are more effective for augmenting Ca concentration of ‘Braeburn’ and ‘Honeycrisp’ apple at harvest (Peryea et al., 2007). The late season foliar Ca applications were insufficient to suffice for Ca reserves which were inadequate for the initial ‘Honeycrisp’ crop. Low leaf Ca and Fe concentrations are less of a concern since leaf Ca concentrations are rarely deficient and frequently inversely correlated to tree vegetative vigor. Leaf total Fe concentrations are poorly associated with Fe deficiency, which is more easily diagnosed by Fe chlorosis symptoms. The widespread adequacy of leaf N, B and Cu concentrations would suggest that the fertilization management employed in this study was sufficient for these nutrients regardless of rootstock.

Nutrition: differences among rootstocks. Leaf nutrient concentrations were affected by a significant interaction between year and rootstock with the exception of leaf Cu, which was significantly affected by the main effects of year and rootstock. The interactions were a result of differences being observed among rootstock ranking over the three study years as leaf nutrient concentrations often exhibited large annual fluctuations. Among major nutrients, leaf P, Mg, K and fruit Ca concentrations were frequently less than recommended values, but also were affected by rootstocks which had superior or inferior abilities to elevate leaf nutrient concentrations. This is apparent from data in Table 3, which lists for each year and these nutrients, the rootstocks that had concentrations within both the highest and lowest 10% of values. For leaf P, top rankings and highest P concentrations were consistently measured for trees growing on B.7-20-21 and B.70-6-8 rootstocks and in two of the three years for B.70-20-20 and B.7-3-150, implying these rootstocks might be selected to improve leaf P uptake and also avoid low tree vigor. In contrast, lowest leaf P was associ-

Table 3. Average 'Honeycrisp' leaf P, Mg and K and fruit Ca concentration as affected by rootstock ranked from most to least vigorous over the first three growing seasons. Values which fell between the top or bottom 10% of values are highlighted in bold.

	Leaf P[z]			Leaf Mg[z]			Leaf K[z]			Fruit Ca[y]
Rootstock	2010	2011	2012	2010	2011	2012	2010	2011	2012	2012
B.70-20-20	2.1cf	**2.5ab**	**2.1 a**	2.8ab	2.1ad	2.7ci	18.4bf	15.9bh	12.1a	3.53ce
G.5087	1.7gj	**1.7ij**	1.7ch	2.7dk	1.6gm	2.5ek	**14.2hi**	16.5bf	**13.1a**	3.62ce
PiAu 9-90	**1.6j**	**1.6 j**	**1.5 h**	2.7bj	1.5jm	2.1km	15.6ei	**13.7gi**	11.5af	3.75be
G.202N	1.8ej	1.8hj	1.8cf	3.0ac	1.6hm	2.5gl	17.6bg	15.7bh	**13.1a**	**3.36e**
B.7-20-21	**2.4ab**	**2.5ab**	**2.0 a**	2.5gm	1.8el	2.4hm	17.3bh	17.0bd	12.1ae	4.14be
CG.3001	1.9di	2.2bc	1.7cf	2.4gm	1.9ci	2.9cg	15.3fi	15.9bh	11.9ae	**3.44de**
CG.4814	1.9ej	2.1di	1.7ch	2.2kn	1.5kn	2.3im	14.5ai	16.1bg	12.2ad	3.91be
CG.4004	1.7gj	1.8fj	1.7cg	**3.2 a**	2.1ae	2.5fl	**14.2hi**	14.9ci	12.3ac	4.07be
B.67-5-32	2.0dg	2.1bh	1.8be	2.8ah	2.0ag	2.7cj	18.2bf	17.3bc	11.5af	3.91be
CG.5222	1.7gj	1.9dj	1.6eh	**3.2 a**	1.7fl	2.8bh	**13.8i**	14.2ei	11.5af	4.19be
G.935N	2.0dh	1.8fj	1.8bd	**2.1mn**	**1.4 ln**	**2.0mn**	16.5ai	14.9ci	**12.6ab**	4.10be
B.70-6-8	**2.5 a**	**2.8 a**	**1.9 ab**	2.4hm	**2.2 a**	3.1ac	**20.2a**	**17.4bc**	10.7bg	4.51bd
B.64-194	1.7fj	2.2bf	1.7eg	2.9aj	2.0af	2.4hm	18.6be	16.9bd	12.5ab	4.37be
G.41N	1.9dh	2.2bg	1.6eh	2.6ek	2.0bh	**3.3 a**	17.1ch	15.4ci	10.6bg	3.94be
M.9 Pajam2	1.8ej	2.3bd	1.6eh	2.7bi	2.1ae	2.7ci	17.1ch	14.1fi	**9.2gh**	4.08be
G.202TC	**1.6j**	**1.7ij**	**1.5 h**	3.0af	1.5jm	2.7cj	17.1ch	14.9ci	10.7bg	3.86be
B.7-3-150	**2.4ab**	**2.5 ab**	1.8bc	2.4gm	2.0af	3.0af	**19.5ab**	**18.3ab**	10.7bg	4.53bd
PiAu 51-11	1.8fj	2.1bi	1.7ch	2.4gm	1.8dk	2.7cj	16.7ci	15.6cg	10.6bg	4.25be
M.26 EMLA	1.7gj	1.8ej	1.7cg	3.1ad	**2.3 a**	2.9ag	16.6ci	14.7di	11.3af	4.24be
CG.4214	**1.6j**	**1.7ij**	1.6fh	2.5fm	**1.2 n**	**2.0mn**	**14.2hi**	**13.7gi**	11.4af	3.76be
G.41TC	2.0dh	1.9dj	1.7cf	2.5gm	1.7el	3.0ad	**21.8a**	16.8be	11.8ae	3.60ce
CG.4013	**1.6j**	1.8gj	1.6eh	**2.2 ln**	1.5kn	2.4hm	16.8ci	16.8be	12.1ae	3.66ce
CG.2034	1.8ej	1.9dj	1.7cg	2.7cj	1.5jm	2.7ci	16.1di	15.0ci	11.6af	3.77be
G.935TC	1.9dh	1.9ej	1.7cf	**1.8n**	**1.3.n**	**1.8n**	16.3ci	15.5ci	12.5ab	**3.35e**
B.10	2.3ac	2.2bf	1.7cg	**3.2 a**	**2.3 a**	**3.4a**	14.3hi	15.6ch	10.3cg	4.27be
Supporter 3	1.7gj	2.0di	1.6dh	2.6el	1.8dk	2.4hm	19.0ad	16.5bf	10.3dg	3.52ce
G.11	1.8ej	1.9dj	1.7ch	2.9ag	1.8dl	**3.3a**	15.6ei	**13.5hi**	**8.1h**	4.06be
M.9 T337	1.7gj	2.0dj	1.6ch	2.3im	1.8dk	2.6dg	17.4bh	14.9ci	10.0eg	**4.55bc**
CG.4003	1.8ej	1.9dj	1.6dh	2.9ag	1.7fl	3.0ae	16.0di	**12.9i**	**9.5fh**	3.90be
B.9	2.1be	2.1di	1.7cg	2.5fm	1.9ci	2.2jn	16.1di	15.9bh	11.3af	**5.51a**
B.71-7-22	2.2ad	2.1di	1.6ch	2.2jn	1.9cj	2.8bh	18.0bf	**20.2ab**	12.5ab	**4.77ab**

Average values followed by the same letter were not significantly different at $p < 0.05\%$ according to Duncan's multiple range test. Numerical values are rounded to reduced number of decimal points relative to letter ranking.

[z] in $g \cdot kg^{-1}$ dry weight

[y] in $mg \cdot 100\ g^{-1}$ fresh weight

Table 4. Average 'Honeycrisp' leaf Zn, Mn and B concentrations as affected by rootstock ranked from most to least vigorous over the first three growing seasons. Values which fell between the top and bottom 10 % of values are highlighted in bold.

	Leaf Zn (mg·kg⁻¹)[z]			Leaf Mn (mg·kg⁻¹)[z]			Leaf B (mg·kg⁻¹)[z]		
Rootstock	2010	2011	2012	2010	2011	2012	2010	2011	2012
B.70-20-20	10.5bc	**12.2a**	11.5bc	54.3ce	30.6eh	24.2ei	55.8dh	**29.3hi**	26.3ci
G.5087	9.2cd	9.4bf	12.6bc	44.6ej	19.7jk	24.0ei	63.5ag	35.8bh	28.9be
PiAu 9-90	9.0cd	**7.6ef**	**9.0c**	40.2ej	20.0jk	21.5fk	57.4dh	**46.1a**	**31.9a**
G.202N	9.3cd	8.5cf	11.5bc	44.7ej	23.6hk	25.0dh	59.5bh	36.0bh	**29.8ac**
B.7-20-21	9.8bd	9.3bf	**8.1c**	**75.9a**	38.9bd	27.4cf	49.1gh	32.4fi	25.1gj
CG.3001	8.8cd	9.7be	11.1c	**31.0j**	19.0jk	19.9gk	57.5dh	36.0bh	27.4cg
CG.4814	10.2bd	9.9be	12.4bc	36.7hj	17.9jk	**17.1ik**	49.6gh	33.9ci	25.6fj
CG.4004	10.4bd	9.8be	11.8bc	60.0bd	28.5fi	24.2ci	**76.5ab**	39.3af	28.3cf
B.67-5-32	**12.1ab**	**12.2a**	9.5c	40.8ej	24.6hk	22.6fj	57.3dh	33.1ei	27.1ch
CG.5222	9.0cd	8.7ef	9.9c	40.5ej	20.9jk	19.5gk	**77.8a**	41.8ad	29.6ad
G.935N	9.4bd	**7.7ef**	10.9c	37.5gj	**16.9k**	**16.0jk**	71.8ad	39.6af	**31.2ab**
B.70-6-8	10.5bc	8.9cf	10.1c	59.8bc	**47.4a**	**36.4ab**	64.6ag	**43.5ab**	27.2ch
B.64-194	10.2bd	**11.3ab**	10.4c	68.7ac	**42.1a**	26.2dg	50.6fh	33.3ei	**23.6ij**
G.41N	9.7bd	9.4bf	12.0bc	36.5ij	19.8jk	21.0fk	**77.4a**	39.0af	27.1ch
M.9 Pajam2	9.8bd	10.1bd	11.7bc	53.9cf	33.6dg	31.5bd	55.7dh	36.1bh	25.3gj
G.202TC	**7.9cd**	8.4cf	9.9c	43.4ej	17.8jk	21.9fk	64.7ag	**43.0ab**	25.3gi
B.7-3-150	9.2cd	9.4bf	11.9bc	52.5dh	36.7be	**35.4ab**	69.2ag	42.3ac	26.9dh
PiAu 51-11	9.3cd	9.1bf	9.8c	**33.9ij**	21.8jk	23.7ei	**42.2h**	**30.2gi**	**23.7ij**
M.26 EMLA	9.9bd	9.7be	10.0c	69.4ab	**42.8ab**	**39.9a**	64.1ag	40.1af	29.7ad
CG.4214	**8.0cd**	**7.2f**	**17.0ab**	53.0dg	22.1jk	22.1fk	75.2ac	36.7bh	25.5fj
G.41TC	**14.0a**	10.0bd	10.7c	36.5ij	**17.3jk**	18.6hk	72.1ad	34.0ci	28.6be
CG.4013	8.7cd	8.0df	10.4c	38.3fj	21.6jk	25.9dg	58.9ch	37.3bh	25.6fj
CG.2034	9.2cd	8.8ef	**13.9bc**	43.3ej	17.8jk	21.3fk	67.3af	38.5ag	27.4cg
G.935TC	10.0bd	8.3ef	11.1c	**34.5jk**	**16.5k**	**15.1k**	68.7ae	**43.0ab**	29.7ad
B.10	8.9cd	9.5bf	11.3bc	**78.1a**	34.2cf	33.9ac	59.9bg	34.9bh	26.7ch
Supporter 3	9.8bd	9.4bf	9.1c	36.5ij	22.2jk	19.6gk	49.2gh	41.4ae	28.6be
G.11	**10.6bc**	9.8be	11.1c	**71.2ab**	25.0hk	27.3cf	61.0ag	40.5af	26.2ei
M.9 T337	9.2cd	9.5be	10.3c	40.7ej	30.9dh	29.8be	51.5eh	35.7bh	25.7fj
CG.4003	10.4bd	9.5be	**8.8c**	68.7ac	25.8gi	26.1dg	72.6ad	**42.8ab**	29.5ad
B.9	9.4bd	9.9be	13.6bc	68.4ac	36.7be	33.2bc	**47.2gh**	33.6di	24.5hj
B.71-7-22	**7.7d**	10.5ac	**20.6a**	47.8de	22.7hk	19.9gk	**47.1gh**	**26.3i**	**23.1j**

Average values followed by the same letter were not significantly different at p< 0.05% according to Duncan's multiple range test. Numerical values are rounded to reduced number of decimal points relative to letter ranking.
[z] $mg \cdot kg^{-1}$ dry weight

ated with rootstocks PiAu 9-90 and G.202TC in all measurement years and with CG.4214 in two years. There was no direct association between low leaf P concentrations and low tree vigor. High leaf Mg was consistently observed on rootstock B.10, whereas trees grown on G.935, tissue cultured (TC) or not (N), or CG.4214 had low leaf Mg. For leaf K, no concentration pattern was consistent across all years, although rootstocks with high (B.70-6-8, B.7-3-150) or low (CG.4214, G.11, CG.4003) leaf K values were observed in two of three years. In the single year of measurement, fruit Ca concentrations were highest for fruit produced by trees on B.71-7-22, B.9 and G.11 rootstocks, all characterized by low vigor, whereas lowest fruit Ca concentration was measured on rootstocks G.935TC, CG.3001 and G.202N, the latter two rootstocks having a high vigor ranking.

With respect to minor nutrients, no rootstocks had consistently high or low leaf Zn and Mn concentrations for three consecutive years (Table 4). For two of three years, highest leaf Zn was achieved for trees growing on rootstock B.67-5-32, and highest leaf Mn on B.70-6-8 and M.26 EMLA, whereas lowest leaf Zn concentrations occurred on PiAu 9-90 and lowest Mn on G.935N and TC. Inconsistent year-to-year behavior was exhibited by rootstock CG.4214, which had amongst lowest Zn concentrations the first two years and amongst highest concentrations the third year when trees were fruiting. In this study leaf B concentrations were always acceptable regardless of rootstock, but for two of three years PiAu 9-90 and G.202N had highest leaf B whereas consistently low leaf B concentrations were measured on rootstocks PiAu 51-11 and B.71-7-22.

To our knowledge little has been reported concerning the effect of rootstock on 'Honeycrisp' leaf nutrition although it has long been recognized that rootstocks affect the mineral composition of scion apple leaves (Poling and Oberly, 1979; Kennedy et al., 1980). This study has identified several rootstocks with inferior abilities to acquire high or low concentrations of specific nutrients over initial establishment years of 'Honeycrisp' under Pacific Northwest growing conditions with a conservative fertilization regime typical of commercial orchards in the region. Significant effects were limited to a single nutrient for most of these rootstocks with the exception of B.70-6-8 which had amongst the highest leaf P, Mn and K and B.7-3-150 with high P and K. Rootstock PiAu 9-90 had high leaf B but amongst the lowest leaf P. Poor leaf nutrient accumulation was exhibited for Mg and Mn by G935N and TC while CG.4214 was particularly poorly performing with lowest leaf Zn, P, Mg and K. Since no measurements were made of root morphology or growth dynamics among rootstocks it was not possible to determine whether differences in leaf nutrient acquisition were related to variation in root characteristics such as density, length and size as reported by Psarras and Merwin (2000). This would be a topic worthy of further research. Fallahi et al. (2001) in a study of 'Fuji' apple on three rootstocks found highest leaf Ca and N and lowest leaf K on rootstock B.9 which also had lowest vigor. Our study of 31 rootstocks and two previous trials in Summerland (Autio et al., 2013; Marini et al., 2009) also found B.9 to have poor vigor, although the rootstock did not rank in the extremes of leaf nutrient concentration for 'Honeycrisp'.

Relationship between nutrition and tree performance. Significant correlations were observed between some third year leaf and fruit nutrient concentrations and cumulative tree growth when measurements were made across all rootstocks and replicates (Table 5). Tree vigor, as indicated by TCA, had highly significant positive associations ($r = 0.48$, $p \leq 0.0001$) with fruit size (AFW). Vigor (TCA) was also highly positively correlated with leaf P ($r = 0.54$, ****) and negatively with leaf Ca ($r = -0.43$, ****). Yield of the first crop was less strongly associated with nutrition, with highest correlation coefficients between yield and leaf P ($r = 0.39$, ****) and leaf Cu ($r = 0.36$, **) which were themselves highly correlated ($r = 0.50$, ****).

The association between larger trees and higher leaf P over the range of dwarfing rootstocks tested implies the importance of maximizing tree vigor in establishment years and also implies a role for improved P nutrition in tree establishment. It also supports the contention that 'Honeycrisp' should be grown on the more vigorous of dwarfing rootstocks (Privé et al., 2011). Vigor showed opposite relationships between P and Ca nutrition, with larger trees also associated more with lower fruit Ca ($r = -0.29$, **). These differences in behavior across rootstocks were also observed for fruit, with larger fruit associated with decreased fruit Ca concentration ($r = -0.29$, **) and increased fruit P concentration ($r = 0.37$, ****). Robinson and Lopez (2012) observed similar opposing behavior between Ca and P, such that bitter pit was associated with high fruit P concentration rather than low fruit Ca. It is noteworthy that

Table 5. Correlation coefficients between third-year plant measures of performance (trunk cross-sectional area (TCA), yield per tree, yield efficiency and average fruit weight (AFW)) and third year leaf and fruit nutrient concentrations across all rootstocks and replications (n = 119).

Tissue	Nutrient concentration	TCA (cm^2) [z]	Yield (kg) [z]	AFW (g) [z]	Fruit Ca[z]	Leaf P[z]
Fruit	Ca	-0.29 **	-0.29**	-0.29**		NS
	Mg	NS	NS	0.26**	0.25**	NS
	K	NS	-0.22*	0.25*	NS	NS
	P	0.32***	NS	0.37****	NS	0.37****
	B	NS	NS	0.35****	-0.19*	-0.21*
	N	NS	NS	NS	NS	NS
Leaf	Ca	-0.43****	NS	-0.19*	0.27**	NS
	Mg	NS	-0.21*	-0.19*	NS	NS
	K	0.29**	0.31***	0.41****	NS	0.29**
	P	O.54****	0.39****	NS	NS	
	B	0.23*	0.27**	0.29**	-0.37****	NS
	Zn	-0.20*	NS	NS	NS	NS
	Fe	NS	NS	NS	NS	NS
	Mn	NS	-0.19*	-0.28**	0.26**	NS
	Cu	0.22*	0.36****	NS	NS	0.50****
	N	NS	NS	-0.19*	NS	0.28**
Yield (kg)		0.65****				
AFW (g)		0.48****	0.33**			

[z]Correlation coefficient (r) indicated when statistically significant at p=0.05(*), 0.01(**), 0.001(***), 0.0001(****) or not significant (NS).

leaf N, TCA and yield were not positively correlated. This suggests growth in the block was not limited by N nutrition, which is consistent with benefits from application of peat in the planting hole and generally high and adequate leaf N concentrations across rootstocks (Table 2).

It would be useful to identify rootstocks which improve accumulation of fruit Ca as 'Honeycrisp' is known to be a cultivar susceptible to bitter pit, a Ca deficiency disorder (Rosenberger et al., 2004). The results from our study relate only to the first fruiting year, but suggest an inverse relationship between tree vigor and fruit Ca concentration, also exemplified by three very low vigor rootstocks (B.71-7-72, B.9 and G.11) having highest fruit Ca concentration. This lends support to a recent hypothesis that high vigor trees are antagonistic to fruit Ca accumulation due to high gibberellin production, which inhibits Ca translocation to fruit (Saure, 2005). It will be useful to continue to monitor this pattern since, from a production point of view, more vigorous rootstocks which are capable of carrying a larger initial crop and therefore entering a phase where crop load has a more dominant effect on fruit size and Ca concentration would be more desirable. This is also when 'Honeycrisp' is reported to be less susceptible to developing bitter pit (Robinson and Lopez, 2012).

Identification of rootstocks which are likely to improve the nutritional prospects of 'Honeycrisp' is not likely to be a simple task as illustrated by a summary of the number of years each assessed rootstock was able to achieve desirable concentrations according to local production standards for key nutrients (Table 6). For example, considering all nutrients, there was no relationship between tree vigor and the cumulative nutritional rating with the most vigorous stock B.70-20-20 having a lower rating than low vigor B.10. Similarly no rootstock was able to demonstrate consistent success (n = 3 for leaves, n = 1 for fruit) for all nutrients, with individual rootstocks being desirable for different nutri-

Table 6. Number of years that tissue nutrient concentrations of 'Honeycrisp' exceeded critical local nutrient concentrations as affected by rootstock ranked by vigor, 2010-2012.

	Number of years critical values of leaf or fruit nutrient exceeded						
Rootstock	Leaf P	Leaf Mg	Leaf K	Leaf Zn	Leaf Mn	Fruit Ca	Cumulative
B.70-20-20	3	2	2	1	2	0	10
PiAu 9-90	0	1	2	0	1	0	4
G.202N	0	1	3	0	2	0	6
B.7-20-21	3	0	2	0	3	1	9
CG.4004	0	1	2	0	2	0	5
G.5087	0	1	3	1	1	0	6
CG.3001	1	1	2	0	1	0	5
CG.4814	1	0	2	1	1	0	5
B.67-5-32	2	2	2	2	1	0	9
CG.5222	0	2	2	0	1	1	6
G.935N	0	0	2	0	1	1	4
B.70-6-8	2	1	2	0	3	1	9
B.64-194	1	1	2	0	3	1	9
G.41N	1	2	2	1	1	0	7
M.9 Pajam2	1	2	2	0	3	1	9
G.202TC	0	2	2	0	1	0	5
B.7-3-150	2	1	2	0	3	1	9
PiAu 51-11	1	1	2	0	1	1	6
M.26 EMLA	0	2	2	0	3	1	8
CG.4214	0	0	2	1	1	0	4
G.41TC	1	1	2	1	1	0	6
CG.4013	0	0	2	0	2	1	5
CG.2034	0	2	2	1	1	0	6
G.935TC	1	0	2	0	1	0	4
B.10	2	2	2	0	3	1	10
Supporter 3	1	2	2	0	1	0	6
G.11	0	2	2	0	3	1	8
M.9 T337	1	1	2	0	3	1	8
CG.4003	0	2	1	0	3	0	6
B.9	2	0	2	1	3	1	9
B.71-7-22	2	1	2	1	1	1	8

ents (e.g. B.70-20-20 for leaf P, G.10 for leaf Mg, etc.).

A recent study has indicated a high potential impact of breeding apple rootstocks with the ability to forage for essential mineral nutrients more efficiently and to translocate them to photosynthesizing tissues (Fazio et al., 2013). In the course of their experimentation, which attempted to understand the genetic inheritance of nutrient acquisition-related traits, rootstock G.935 stood out as conferring higher concentrations of Cu, K, P and Na when budded with 'Golden Delicious'. In our field study comparing a wide range of rootstocks budded with 'Honeycrisp', G.935 was not exceptional in its ability to achieve adequate concentrations of all essential nutrients (Table 6). This indicates the possibility of a significant scion x rootstock interaction, further complicating a process that was already acknowledged by the authors as being made complex by environment x genetic interactions resulting from the complex physical, chemical and biological environment in which roots operate.

Conclusions

Rootstock vigor varied in the first three years of this study. Rootstocks B.9 and B.71-7-22 particularly exhibited low vigor. Few problems were found in achieving adequate N, B and Cu concentrations regardless of rootstock with the fertilization regime used during the three-year orchard establishment period. In contrast, low tissue concentrations were measured on more than half the rootstock-years for leaf Zn, P, Mg and fruit Ca, suggesting these nutrients require careful attention when growing 'Honeycrisp' under irrigation in warm summer climates as occurs in the Pacific Northwest of America. The fertilization regime was the same for all rootstocks in this study. For N, the major applied fertilizer, this resulted in growth which was not limited by N, as indicated by generally adequate leaf N concentrations across rootstocks. It is unknown how rootstocks would have responded to reduced N applications designed to reduce vigor or to different N applications rates among rootstocks. It is also noteworthy that some of the nutrients which demonstrated low concentrations (leaf Zn, fruit Ca) have limited mobility to target sinks within the plant whereas leaf N and B, which had generally adequate values, are readily translocated within the plant. Rootstocks were identified which had superior and inferior abilities to accumulate and translocate these limiting nutrients to leaves. Thus it would be possible to select or avoid rootstocks on sites where similar nutrition problems are anticipated. However, it is likely that a rootstock's horticultural performance would be more important than any advantage in nutrient uptake as long as the trees respond to fertilization. Also, only rootstocks B.70-6-8 (P, Mn and K) and B.7-3-150 (P, K) resulted in elevated leaf concentrations of more than a single nutrient, implying it will not be an easy task to breed rootstocks with a superior ability to generally elevate leaf nutrient concentrations. Furthermore, across all rootstocks, the ability to achieve adequate concentrations of a range of key plant nutrients was not associated with improved initial growth. An exception was a positive correlation between vigor, and leaf P reaffirming previous research, which has indicated an important role for P in the establishment of apple trees. An apparent antagonism between high tree vigor vs. leaf P and fruit Ca requires additional assessment as cropping continues.

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Literature Cited

Autio, W., T. Robinson, D. Archbold, W. Cowgill, C. Hampson, R. Parra Quezada, and D. Wolfe. 2013. 'Gala' apple trees on Supporter 4, P.14, and different strains of B.9, M.9 and M.26 rootstocks: final 10-year report on the 2002 NC-140 apple rootstock trial. J. Amer. Pomol. Soc. 67(2):62-71.

British Columbia Ministry of Agriculture and Lands (BCMAL). 2010. Integrated fruit production guide for commercial fruit growers, Interior district. Victoria, BC, Canada.

Cline, J.A. 2005. Commercial production of 'Honeycrisp' apples in Ontario. OMAFRA Factsheet 05-047.

Delap, A.V. and E.M. Ford.1958. Studies in the nutrition of apple rootstocks.1.Effects of deficiencies of iron and magnesium on growth. Ann. Bot. 22:137-158.

Fallahi, E. 2012. Influence of rootstock and irrigation methods on water use, mineral nutrition, growth, fruit yield and quality in 'Gala' apple. HortTechnology 22:731-737.

Fallahi, E., I.J. Chun, G.H. Neilsen, and W.M. Colt. 2001. Effects of three rootstocks on photosynthesis, leaf mineral nutrition, and vegetative growth of 'BC.2 Fuji' apple trees. J. Plant Nutr. 24:827-834.

Fallahi, E., W.M. Colt, B. Fallahi, and I.J. Chun. 2002. The importance of apple rootstocks on tree growth, yield, fruit quality, leaf nutrition, and photosynthesis with an emphasis on 'Fuji'. HortTechnology 12:38-44.

Fazio, G., D. Kviklys, M.A. Grusak, and T. Robinson. 2013. Phenotypic diversity and QTL mapping of absorption and translocation of nutrients by apple rootstocks. Aspects Appl. Biol. 119:37-50.

Kennedy, A.J., R.W. Rowe, and T.J. Samuelson. 1980. The effects of apple rootstock genotypes on mineral content of scion leaves. Euphytica 29:477-482.

Marini, R.P., B. Black, R.M. Crassweller, P.A. Domoto, C. Hampson, S. Johnson, K. Kosola, S. McArtney, J. Masabni, R. Moran, R.P. Quezada, T. Robinson, and C. R. Rom. 2009. Performance of 'Golden Delicious' apple on 23 rootstocks: a five-year summary of the 2003 NC-140 dwarf rootstock trial. J. Amer. Pomol. Soc. 63(3):115-127.

Neilsen, G.H. 1988. Seasonal variation in leaf zinc concentration of apples receiving dormant Zn. HortScience 23:130-132.

Neilsen, G.H., D. Neilsen, E.J. Hogue, and L.C. Herbert. 2004. Zinc and boron nutrition management in fertigated high density apple orchards. Can. J. Plant Sci. 84:823-828.

Neilsen, G.H., D. Neilsen, P. Toivonen, and L. Herbert. 2008. Annual bloom-time phosphorus fertigation affects soil phosphorus, apple tree phosphorus nutrition, yield and fruit quality. HortScience 43:885-890.

Neilsen, G., P. Parchomchuk, M. Meheriuk, and D. Neilsen. 1998. Development and correction of K-deficiency in drip-irrigated apple. HortScience 33:258-261.

Neilsen, G.H. and J. Yorston. 1991. Soil disinfection and monoammonium phosphate fertilization increase precocity of apples on replant problem soils. J. Amer. Soc. Hort. Sci. 116:651-654.

Peryea, F.J., G.H. Neilsen, and D. Faubian. 2007. Start-timing for calcium chloride spray programs influences fruit calcium and bitter pit in 'Braeburn' and 'Honeycrisp' apples. J. Plant Nutr. 30:1213-1217.

Poling, E.B. and G.H. Oberly. 1979. Effect of rootstocks on mineral composition of apple leaves. J. Am. Soc. Hort. Sci. 104:799-801.

Psarras, G. and I. A. Merwin. 2000. Water stress affects rhizosphere respiration rates and root morphology of young 'Mutsu' apple trees on M.9 and MM.111 rootstocks. J. Amer. Soc. Hort. Sci. 125:588-595.

Privé, J.P., A. Leblanc, and C.G. Embree. 2011. Preliminary evaluation of supported and free standing 'Honeycrisp' trees on 24 apple rootstocks. Acta Hort. 903:335-340.

Robinson, T.L., S.A. Hoying, and G.H. Reginato. 2011. The tall spindle planting system: principles and performance. Acta Hort. 903:571-579.

Robinson, T. and S. Lopez. 2012. Crop load affects 'Honeycrisp' fruit quality more than nitrogen, potassium or irrigation. Acta Hort. 940:529-537.

Rosenberger, D.A., J.R. Schupp, S.A. Hoying, L. Cheng, and C.B. Watkins. 2004. Controlling bitter pit in 'Honeycrisp' apples. HortTechnology 14:342-349.

SAS Institute Inc. 2000. SAS/STAT user's guide, version 8.1. SAS Institute, Cary, N.C.

Saure, M.C. 2005. Calcium translocation to fleshy fruit: its mechanism and endogenous control. Scientia Hort. 105:65-69.

Wittneben, U. 1986. Soils of the Okanagan and Similkameen Valleys. Ministry of the Environment Technical Report 10. British Columbia Soil Survey, Report 52. Victoria, BC, Canada.

Wood, S. 2001. 'Honeycrisp'. Compact Fruit Tree 34:111-112.

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Influence of harvest date on fruit yield and return bloom in 'Marsh' grapefruit trees (*Citrus paradisi* Macf.) grown under a tropical climate

Abstract:

Grapefruit grown in tropical climates reach a suitable fruit size and juice content for fresh consumption during August – October in the northern hemisphere. However, some tropical plantations delay harvesting until November or December, with the fruit then being used for processing. In our experiments, delaying the harvest from October to December reduced the average mature fruit weight by 10% and increased abscission from 29 to 70 fruit per tree. Juice contents decreased slightly, from 44.5% (w/w) to 43.2% (w/w), while total soluble solids (TSS) contents barely changed, from 10.4 ºBrix to 10.2 ºBrix. Delaying the harvest date also reduced return flowering by 20% in the following Spring, and the number of fruit set by 20%. Mature fruit abscission and reduced flowering were not dependent on weather conditions. The former was spontaneous and due to senescence, while the latter was due to fruit remaining on the tree. Over a 4-year period, our results showed an average reduction of 30% in fruit yield per tree when harvest dates were delayed from October (153 kg tree^{-1}) to December (105 kg tree^{-1}). As juice content and TSS content values were suitable for processing in October, there was no reason to delay the harvest date.

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