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Performance of Sweet Cherry Rootstocks in the 1998 NC-140 Regional Trial in Western North America

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Abstract

A regional trial evaluating the performance of rootstocks for sweet cherries in western North America was planted in the spring of 1998 at six locations in the states of Washington, Oregon, Colorado, and Utah, and in the province of British Columbia, Canada. The rootstocks included: Mazzard seedling (*Prunus avium*), *P. mahaleb* seedling, Gisela® (G) 3, G5, G6, G7, Giessen (Gi) 195/20, Gi 318/17, Gi 473/10, Tabel® Edabriz, Weiroot (W) 10, W13, W72, W53, W154, and W158. The scion cultivar was 'Bing'. Rootstocks significantly affected tree size, yield and fruit quality, and these effects were not consistent across all locations. However, Mazzard and Mahaleb consistently produced among the largest trees and W72, G3 and W53 among the smallest. Root suckers tended to be most numerous for Tabel® Edabriz and the Weiroot series. Mazzard and Mahaleb usually had the lowest yield and yield efficiency. G3, G5, G7, W53 and W72 were fivefold or more as yield-efficient as Mazzard.

Producers of sweet cherry (*Prunus avium* L.) in western North America have predominantly used the vigorous rootstocks Mazzard (*P. avium*) or Mahaleb (*P. mahaleb*). Both Mazzard and Mahaleb produce large trees that are slow to come into production. Mazzard has good graft compatibility with sweet cherries, appears to have wide soil adaptability, and can be propagated easily from seeds. Some sweet cherry cultivars are not compatible on some Mahaleb genotypes, causing tree decline and eventual death. Mahaleb is sensitive to wet soils, performing better on light-textured soils with very good drainage (Webster and Schmidt, 1996). Mahaleb is also more drought tolerant than Mazzard. Seed propagation is fairly simple with Mahaleb rootstocks though some genotypes are clonally propagated.

The search for reliable, size-controlling rootstocks for sweet cherries has expanded over the past two decades. In addition to scion dwarfing, the desired characteristics include precocity, improved productivity, improved fruit quality, and adaptability to a range of soil conditions (Webster and Schmidt, 1996). Various breeding programs around the world have released a number of new rootstocks. Some have resulted from interspecific hybrids (Gruppe, 1985; Tréfois, 1980) and others are selections within a species (Edin, 1989; Schimmelpfeng and Liebster, 1979; Tréfois, 1980). Many of these rootstocks are presently being tested around the world. A range of dwarfing rootstocks with all the desired beneficial characteristics would help in the intensification of sweet cherry orchards, the development of pedestrian orchards, and the improvement of sweet cherry production economics.

A previous coordinated cherry rootstock evaluation trial in North America was planted in 1987/88 with 'Montmorency' as the scion cultivar for sour cherries and 'Heldelfingen' and 'Bing' for eastern and western North America, respectively (Perry et

[1] See Table 1 for author addresses

al., 1998). A second coordinated trial was established in North America in 1998 to test additional rootstocks. These included three commercially available rootstocks from the Giessen program: Gisela® 5 (G5), G6, and G7. Four experimental rootstocks from the Giessen program were also tested: Giessen (Gi) 195/20, Gi 209/1 (eventually released as G3), Gi 318/17, and Gi 473/10 (eventually released as G4 but later withdrawn). There were also seven *P. cerasus* rootstocks; Tabel® Edabriz, Weiroot (W) 10, W13, W53, W71, W154, and W158. The standard rootstocks were Mazzard seedling and Mahaleb seedling. This report provides the final results for the sweet cherry trial with 'Bing' as the scion in western North America.

Materials and Methods

Trees were propagated by Meadowlake Nursery (McMinnville, Oregon), using virus-free 'Bing' sweet cherry budwood. Cooperating sites were located in Summerland, British Columbia, Canada; Hotchkiss, Colorado; Corvallis and Hood River, Oregon; Logan, Utah; and Prosser, Washington (Table 1). Rootstocks tested included: Mazzard seedling, *P. mahaleb* seedling, G3, G5, G6, G7, Gi 195/20, Gi 318/17, Gi 473/10, Tabel® Edabriz, W10, W13, W72, W154, and W158 (Table 2).

Table 1. Locations of plantings of the 1998 NC-140 regional sweet cherry rootstock trial in western North America, with names and affiliations of cooperators.

Location	Cooperator	Affiliation
British Columbia	Frank Kappel[z]	Agriculture and Agri-Food Canada
Colorado	Ron Godin	Colorado State University
	Al Gaus	
	Ramesh Pokharel	
Corvallis, Oregon	Anita Azarenko	Oregon State University
Hood River, Oregon	Roberto Nuñez-Elisea[y]	Oregon State University
	Tim Facteau[y]	
Utah	Thor Lindstrom	Utah State University
Washington	Matt Whiting	Washington State University
	Greg Lang[x]	

[z] retired [y] deceased [x] present location: Michigan State University

Table 2. Species of the cherry rootstocks used in the 1998 NC-140 cooperative sweet cherry trial.

Rootstock	Alternate name	Species
Mazzard		*Prunus avium*
Mahaleb		*P. mahaleb*
Gisela 3	Giessen 209/1	*P. cerasus x P. canescens*
Gisela 5	Giessen 148/2	*P. cerasus* × *P. canescens*
Gisela 6	Giessen 148/1	*P. cerasus* × *P. canescens*
Gisela 7	Giessen 148/8	*P. cerasus* × *P. canescens*
Gi 195/20	Giessen 195/20	*P. canescens* × *P. cerasus*
Gi 318/17	Giessen 318/17	*P. canescens* × *P. avium*
Gi 473/10	Giessen 473/10	*P. avium* × *P. fruticosa*
Tabel® Edabriz		*P. cerasus*
W10	Weiroot 10	*P. cerasus*
W13	Weiroot 13	*P. cerasus*
W53	Weiroot 53	*P. cerasus*
W72	Weiroot 72	*P. cerasus*
W154	Weiroot 154	*P. cerasus*
W158	Weiroot 158	*P. cerasus*

Table 3. Tree spacing used at each location in the trial.

Location	Between-row spacing (m)	Within row spacing (m)
Summerland, B.C., Canada	6.0	6.0
Hotchkiss, Colorado, USA	6.0	5.5
Corvallis, Oregon, USA	4.9	3.7
Hood River, Oregon, USA	n/a[1]	n/a
Kaysville, Utah, USA	5.0	4.0
Prosser, Washington, USA	5.5	5.5

[1] no information available

Unbranched trees (whips) were planted in the spring of 1998 at different row and tree spacings among locations, as shown in Table 3. Trees were trained to a modified central leader system with irrigation, rates and choice of herbicides, other pesticides, and fertilizer applied according to local recommendations. Each experimental orchard was established using a randomized complete block design with eight blocks of single-tree replicates for all sites except Colorado, which had seven blocks. Data are only being presented for the trials in British Columbia, Colorado, Oregon, and Washington, because they had the most complete data sets. The planting in Utah suffered severe tree loss due to winter freezes. The planting at Colorado did not have the rootstocks Gi 318/17, Gi 473/10, and W154 due to inadequate tree numbers at the beginning of the trial. The trial ran through 2005 at all sites except for Hood River, Oregon, which stopped collecting data at the end of 2004.

Trunk diameter or circumference was measured at 20 cm above the soil surface at the end of each season and trunk cross-sectional area (TCA) was calculated. All fruit from each tree were harvested at commercial maturity. A sub-sample of fruit ($n \geq 100$) was used to calculate average fruit weight. Survival of trees was also recorded for most of the sites annually throughout the trial. Some sites collected blossom data and data on the amount of root suckering.

Data were analyzed by analysis of variance using SAS GLM (SAS Institute, Cary, NC), and least squares means were compared with the probability of the difference (Pdiff) test at $P = 0.05$ (SAS Institute, Cary, NC). When a significant interaction was found between location and rootstock, the data were analyzed separately for each location.

Results

Location and rootstock interacted significantly to influence all the response variables, and therefore the results are presented separately for the different locations.

Summerland, British Columbia

In British Columbia, trees on Mazzard had the lowest survival rate of all the rootstocks (Table 4). Most of the tree deaths occurred during the first year of the trial due to dehydration during shipping from the nursery in Oregon to British Columbia. Trees on Mazzard had mainly a large tap root with very little branching.

'Bing' trees on Mahaleb and Mazzard rootstock had the largest trunk cross-sectional area (TCA) at the end of 2005, whereas Gi 473/10 produced the smallest trees (about one-third the size of trees on Mahaleb) (Table 4). The rootstocks could be divided into five broad vigor groups. The most vigorous group included Mahaleb and Mazzard; the second group, at about 85% of the most vigorous, included Gi 318/17, G6, and W13; a third group at about 70% of standard included W158, W10, Gi 195/20, and G7. A fourth group at about 50% of standard included W72, G5 and W154. The smallest trees, at 30 to 40% the size of standard, included Tabel® Edabriz, G3, W53, and Gi 473/10.

Root suckers were predominantly a problem of *P. cerasus* rootstocks, with W154 having the

Table 4. Eight-year performance of 'Bing' sweet cherry on 16 rootstocks at Summerland, British Columbia.

Rootstock	Survival (%) 2005	Final trunk cross-sectional area (cm^2) 2005	Number of root suckers 2003	Number of root suckers 2004	Cumulative yield (kg) 2000 – 2005	Cumulative yield efficiency ($kg \cdot cm^{-2}$) 2005	Average fruit weight (g) 2003	Average fruit weight (g) 2004	Average fruit weight (g) 2005
Mazzard	62.5 b[z]	271.9 ab	4.1 fg	5.6 e	23.3 g	0.090 j	9.9 abc	10.3 abc	11.1 a-e
Mahaleb	87.5 a	310.2 a	1.0 g	0.0 e	46.2 ef	0.159 hij	10.6 a	10.8 a	11.7 abc
G3	100.0 a	124.1 hi	0.4 g	0.0 e	62.6 d	0.518 ab	9.9 abc	9.4 cd	11.1 a-e
G5	100.0 a	152.2 gh	0.0 g	0.0 e	81.7 ab	0.540 a	9.1 c	10.2 abc	11.8 a
G6	100.0 a	243.9 bc	0.0 g	0.0 e	70.9 bc	0.309 efgh	10.1 ab	10.5 ab	11.7 ab
G7	100.0 a	192.2 efg	5.8 fg	0.0 e	88.9 a	0.469 abc	9.5 bc	10.1 abc	11.6 abc
Gi 195/20	100.0 a	192.3 efg	0.0 g	0.0 e	84.8 ab	0.500 ab	9.1 c	10.1 abc	11.4 a-e
Gi 318/17	100.0 a	255.4 bc	0.0 g	0.0 e	59.8 de	0.273 fgh	9.9 abc	10.3 abc	11.3 a-e
Gi 473/10	87.5 a	95.7 j	16.9 def	12.6 de	53.5 de	0.530 ab	7.7 d	8.7 dc	9.8 f
Tabel®Edabriz	100.0 a	143.3 hi	8.4 fg	12.5 de	57.7 cde	0.411 bcde	9.9 abc	10.0 abc	11.0 b-e
W10	100.0 a	197.7 def	40.8 bc	55.6 bc	59.1 cde	0.333 defg	9.8 abc	9.6 bcd	11.2 a-e
W13	100.0 a	241.0 bcd	45.6 ab	64.0 b	33.6 fg	0.141 ij	10.2 ab	10.4 ab	11.6 a-d
W53	100.0 a	101.2 i	11.8 efg	5.9 e	44.9 de	0.526 ab	7.9 d	8.2 e	10.6 ef
W72	100.0 a	157.6 fgh	31.4 cd	33.8 cd	63.4 cd	0.422 abcd	9.9 abc	9.9 abc	10.8 de
W154	100.0 a	146.0 h	55.0 a	83.0 a	48.3 def	0.373 cdef	10.2 ab	10.1 abc	11.9 cde
W158	87.5 a	217.4 cde	26.0 de	29.3 d	49.8 de	0.231 ghi	9.7 abc	10.0 abc	11.5 a-e

[z] Means within columns followed by the same letter are not significantly different at $P < 0.05$

most, followed by W13, W10, W72, and W158 (Table 4). The other rootstocks had sucker numbers similar to Mazzard and Mahaleb.

Trees on G7, Gi 195/20, G5, G6, W72, and G3 had significantly higher cumulative yields than trees on Mahaleb (Table 4). All trees on rootstocks other than W13 had cumulative yields greater than trees on Mazzard. Trees on G5, Gi 473/10, W53, G3, Gi 195/20, G7, W72, Tabel® Edabriz, W154, and W10 had yield efficiencies significantly better than Mahaleb. All the previously noted rootstocks plus G6, Gi 318/17, and W158 had yield efficiencies higher than Mazzard. Fruit from trees on Gi 473/10 and W53 consistently were the smallest over the three years (2003 to 2005) whereas fruit from trees on Mahaleb, G6, and W13 tended to be the largest.

In 2007, after the trial was completed, the trees had an extremely high infestation of black cherry aphid (*Myzus cerasi* [F.]), as every tree had high populations. These high aphid populations caused a decline and possibly the death of a number of the trees on several *P. cerasus* rootstocks. About 39% of the trees on the *P. cerasus* rootstocks were affected. All trees on Tabel® Edabriz were affected, whereas none of the trees on W72 and W158 appeared to be (data not shown).

Hotchkiss, Colorado

Tree losses occurred in Colorado, but there were no significant differences among the rootstocks (Table 5). Mahaleb, W13, and G6 produced the largest trees, whereas G5 and G3 produced the smallest trees (Table 5). The smallest trees were less than half the size of the largest trees. The *P. cerasus* rootstocks tended to have the highest number of root suckers (i.e., trees on W10, W13, W53, W158, and Tabel® Edabriz) while G7 also produced a large number.

Trees on W13, W158, G6, and G5 had the highest cumulative yields, whereas yields on Gi 195/20, W72, G3, and Mazzard were lowest (Table 5). Highest yielding trees produced about twice as much fruit as the lower yielding trees. No differences in yield efficiencies or fruit size were found.

Table 5. Eight-year performance of 'Bing' sweet cherry on 13 rootstocks at Hotchkiss, Colorado.

Rootstock	Survival (%) 1998-2005	Final trunk cross-sectional area (cm^2) 2005	Number of root suckers 2004	Number of root suckers 2005	Cumulative yield (kg) 2000 - 2005	Cumulative yield efficiency ($kg{\cdot}cm^{-2}$) 2005	Average fruit weight (g) 2003	Average fruit weight (g) 2004	Average fruit weight (g) 2005
Mazzard	57.1 a[z]	121.2 ab	1.2 d	17.3 cd	1.52 d	0.016 a	7.3 a	.	6.4 a
Mahaleb	85.7 a	142.9 a	3.0 d	1.9 d	5.51 bc	0.047 a	7.2 a	6.9 a	6.6 a
G3	57.1 a	59.4 d	4.3 d	0.0 d	2.94 cd	0.059 a	7.6 a	7.0 a	7.2 a
G5	100.0 a	68.1 d	0.4 d	1.3 d	6.38 ab	0.097 a	7.8 a	6.5 a	7.1 a
G6	85.7 a	136.5 a	0.0 d	2.7 d	6.46 ab	0.052 a	8.6 a	6.6 a	7.2 a
G7	85.7 a	90.9 cd	27.2 cd	26.9 c	4.92 bc	0.065 a	7.0 a	6.7 a	7.2 a
Gi 195/20	71.4 a	124.9 ab	0.5 d	3.4 d	4.64 bcd	0.048 a	7.4 a	6.9a	7.2 a
Tabel®Edabriz	100.0 a	89.4 cd	27.0 d	33.0 c	5.46 bc	0.061 a	7.4 a	7.3 a	6.8 a
W10	100.0 a	132.1 ab	65.6 a	58.4 a	5.32 bc	0.044 a	9.3 a	7.1 a	6.5 a
W13	100.0 a	141.1 a	56.9 ab	54.3 ab	9.24 a	0.068 a	7.2 a	6.0 a	7.2 a
W53	85.7 a	83.3 cd	56.7 abc	35.4 bc	4.90 bc	0.062 a	6.8 a	6.3 a	7.1 a
W72	71.4 a	84.4 cd	10.0 d	28.5 c	4.27 bcd	0.061 a	7.3 a	6.4 a	6.9 a
W158	85.7 a	108.2 bc	28.0 bcd	27.3 c	6.64 ab	0.064 a	6.8 a	6.8 a	6.9 a

[z] Means within columns followed by the same letter are not significantly different at P <0.05

Table 6. Eight-year performance of 'Bing' sweet cherry on 16 rootstocks at Corvallis, Oregon.

Rootstock	Survival (%) 1998 - 2005	Final trunk cross-sectional area (cm^2) 2005	Rating[z] of number of suckers 2001	Rating[z] of number of suckers 2002	Cumulative yield (kg) 2000 - 2005	Cumulative yield efficiency ($kg{\cdot}cm^{-2}$) 2005	Average fruit weight (g) 2003	Average fruit weight (g) 2004
Mazzard	100.0 a[y]	246.1 a	1.5 ef	0.9 de	21.3 e	0.086 h	9.0 a	7.9 a
Mahaleb	100.0 a	175.3 cde	1.6 def	0.9 de	23.6 e	0.143 gh	9.4 a	7.7 a
G3	100.0 a	103.3 h	1.2 ef	0.0 f	41.3 bcd	0.390 ab	9.8 a	6.4 b
G5	87.5 a	131.6 fgh	1.1 ef	0.0 f	41.3 bcd	0.314 bcd	9.5 a	6.7 b
G6	100.0 a	190.3 bcd	1.1 ef	0.0 f	57.8 a	0.308 cde	9.6 a	6.2 b
G7	87.5 a	118.4 gh	3.1 ab	3.0 a	39.0 bcd	0.336 bc	9.7 a	6.5 b
Gi 195/20	100.0 a	165.2 def	1.0 f	0.2 ef	37.7 cd	0.232 ef	9.9 a	6.7 b
Gi 318/17	100.0 a	164.3 def	1.8 def	0.0 f	41.2 bcd	0.257 cdef	9.6 a	6.6 b
Gi 473/10	12.5 b	96.6 h	3.4 a	2.8 ab	.	.	10.9 a	7.4 ab
Tabel®Edabriz	100.0 a	150.8 efg	1.4 ef	0.6 de	35.3 d	0.237 def	10.0 a	6.1 b
W10	87.5 a	217.1 ab	2.5 bc	1.6 bc	50.5 ab	0.233 ef	9.5 a	7.4 ab
W13	87.5 a	213.1 abc	2.9 ab	2.3 bc	46.2 abcd	0.225 f	9.1 a	7.3 ab
W53	75.0 a	104.5 h	1.9 cde	0.9 de	48.8 abc	0.457 a	9.5 a	6.2 b
W72	87.5 a	133.5 fgh	1.8 def	1.2 cd	41.6 bcd	0.345 bc	9.2 a	6.6 b
W154	87.5 a	183.5 bcde	2.8 ab	2.6 abc	45.4 abcd	0.201 fg	10.5 a	7.9 a
W158	100.0 a	177.6 cde	2.4 bcd	0.8 de	42.5 bcd	0.239 def	.	6.9 b

[z] Number of suckers were rated using the following rating scheme: 1 = 0 suckers; 2 = 1 to 10 suckers; and 3 = 11 to 20 suckers
[y] Means within columns followed by the same letter are not significantly different at P <0.05

Corvallis, Oregon

In Corvallis, tree losses on Gi 473/10 were higher than for any of the other rootstocks (Table 6). There were no significant differences in tree survival for any of the other rootstocks. The largest trees were on Mazzard, W10, and W13, whereas the smallest trees were on W72, G5, G7, W53, G3, and Gi 473/10. The largest trees were about twice the size of the smallest, as measured by TCA. The amount of root suckering was rated rather than counted, with Gi 473/10, G7, and W13 rated as having the most root suckers, more than double the ratings of Mazzard and Mahaleb.

The yields of trees on Gi 473/10 were not included in the analysis because of the significant tree mortality. 'Bing' trees on G6, W10, W53, W13, and W154 had the highest cumulative yields, more than double the yield of trees on Mahaleb and Mazzard (Table 6). Trees on these standard rootstocks had significantly lower yields than all the others. With the larger tree size and lower yields, trees on Mazzard and Mahaleb had the lowest cumulative yield efficiencies. W53 and G3 had the highest yield efficiencies. Fruit size showed very few differences among trees on the different rootstocks.

Hood River, Oregon

No data were collected from the planting in Hood River in 2005, and therefore cumulative yield through 2004 and the 2004 TCA were used to calculate cumulative yield efficiency. Tree survival was good except in the case of trees on Mazzard where 75% of the trees died (Table 7). The largest trees were on Mazzard. The smallest trees, about 30% of Mazzard, were on W72, Gi 473/10, W53, and G3. The rest of the trees could be grouped into rootstocks that produced trees 65 to 75% of standard, which included W13, Mahaleb, W10, G6, Gi 318/17, W154, and W158, and rootstocks that produced trees about 45% of standard, which included Gi 195/20, G5, G7, and Tabel® Edabriz. W154 had significantly more root

Table 7. Seven-year performance of 'Bing' sweet cherry on 16 rootstocks at Hood River, Oregon.

Rootstock	Survival (%)	Final trunk cross-sectional area (cm^2)	Number of suckers	Cumulative yield (kg)	Cumulative yield efficiency ($kg \cdot cm^{-2}$)[z]	Average fruit weight (g)	
	1998 - 2004	2004	2001	2000 - 2004	2004	2003	2004
Mazzard	25.0 b[y]	324.0 a	1.8 de	.	.	.	.
Mahaleb	100.0 a	244.4 bc	5.4 cd	134.8 abc	0.525 ef	10.3 a	9.9 a
G3	100.0 a	90.4 i	0.0 e	80.8 g	0.975 ab	10.0 a	7.3 d
G5	100.0 a	138.9 fg	0.0 e	124.5 bcd	0.863 bc	10.0 a	8.2 c
G6	100.0 a	227.4 bcd	0.2 e	155.7 a	0.693 cde	10.2 a	9.2 ab
G7	100.0 a	138.3 fg	6.5 bcd	117.8 bcde	0.878 bc	10.5 a	7.9 cd
Gi 195/20	100.0 a	164.8 ef	0.0 e	139.2 ab	0.888 b	10.5 a	7.8 cd
Gi 318/17	100.0 a	214.2 cd	0.1 e	112.8 cdef	0.513 ef	10.2 a	8.9 bc
Gi 473/10	100.0 a	98.4 hi	9.5 b	103.7 defg	1.136 a	9.4 a	7.4 d
Tabel®Edabriz	100.0 a	125.6 gh	0.1 e	90.2 fg	0.815 bcd	10.1 a	8.4 bc
W10	100.0 a	237.6 bcd	4.6 cd	118.1 bcde	0.497 f	9.8 a	10.0 a
W13	100.0 a	259.7 b	6.8 bc	126.4 bcd	0.455 f	10.0 a	9.9 a
W53	100.0 a	92.0 hi	0.9 e	97.6 efg	0.910 b	9.9 a	7.7 cd
W72	100.0 a	108.9 ghi	1.0 e	91.2 fg	0.863 bc	10.1 a	8.3 c
W154	100.0 a	209.9 cd	16.0 a	121.6 bcde	0.534 ef	9.8 a	10.3 a
W158	100.0 a	204.1 de	2.8 de	123.0 bcde	0.618 def	10.3 a	8.6 bc

[z] Trunk cross-sectional area for 2004 was used to calculate yield efficiency
[y] Means within columns followed by the same letter are not significantly different at $P < 0.05$

Table 8. Eight-year performance of 'Bing' sweet cherry on 16 rootstocks at Prosser, Washington.

Rootstock	Survival (%) 1998 - 2005	Final trunk cross-sectional area (cm^2) 2005	Number of root suckers 2003	Number of root suckers 2005	Cumulative yield (kg) 2000 - 2005	Cumulative yield efficiency ($kg \cdot cm^{-2}$) 2005	Average fruit weight (g) 2003	Average fruit weight (g) 2004	Average fruit weight (g) 2005
Mazzard	37.5 c[z]	414.8 a	0.9 bcd	0.9 c	36.0 i	0.065 e	7.9 abc	8.0 a	10.6 a
Mahaleb	100.0 a	298.6 cd	0.0 d	0.3 c	93.3 efg	0.248 d	7.2 bcd	7.8 a	10.3 a
G3	100.0 a	185.8 hi	0.5 cd	0.0 c	121.5 cd	0.548 ab	7.1 cd	5.7 c	9.8 a
G5	100.0 a	270.0 def	0.4 d	1.0 c	143.6 bc	0.479 bc	7.2 bcd	7.5 a	10.1 a
G6	100.0 a	328.8 c	0.1 d	0.0 c	163.5 ab	0.402 c	7.4 bcd	7.6 a	10.4 a
G7	100.0 a	233.5 efg	2.8 bcd	0.8 c	175.7 a	0.628 a	7.1 cd	7.2 ab	10.3 a
Gi 195/20	100.0 a	227.3 fgh	0.0 d	0.1 c	145.8 bc	0.540 ab	7.3 bcd	6.7 ab	10.2 a
Gi 318/17	100.0 a	358.1 b	0.2 d	0.0 c	117.9 de	0.292 d	7.8 abc	7.1 ab	10.7 a
Gi 473/10	100.0 a	153.3 i	4.0 b	1.4 c	108.8 def	0.614 a	7.6 abc	6.7 ab	9.6 a
Tabel®Edabriz	100.0 a	195.2 ghi	1.1 bcd	0.5 c	101.0 defg	0.424 c	7.4 bcd	6.6 b	10.2 a
W10	100.0 a	343.0 c	3.4 bc	5.0 bc	101.1 defg	0.245 d	8.1 a	7.7 a	10.4 a
W13	87.5 ab	319.9 cd	8.2 a	8.4 b	81.8 gh	0.214 d	7.9 abc	7.0 ab	10.0 a
W53	75.0 b	93.0 j	0.8 cd	0.6 c	55.4 hi	0.546 ab	6.8 d	7.3 ab	10.7 a
W72	87.5 ab	155.5 i	2.9 bcd	2.0 c	110.5 def	0.558 ab	7.7 abc	7.2 ab	10.2 a
W154	100.0 a	178.2 i	9.1 a	17.8 a	50.9 i	0.280 d	7.4 bcd	7.1 ab	10.2 a
W158	75.0 b	277.6 de	2.6 bcd	1.7 c	89.7 fg	0.267 d	7.9 ab	7.3 ab	9.8 a

[z] Means within columns followed by the same letter are not significantly different at $P < 0.05$

suckers than all other rootstocks. The rootstocks with the fewest root suckers included W72, W53, G6, Gi 318/17, Tabel® Edabriz, Gi 195/20, G3, and G5.

Mazzard yield data were not included in the statistical analysis because of the high mortality of trees. The highest yielding trees were on G6, Gi 195/20, and Mahaleb (Table 7). The lowest yielding trees (W53, W72, Tabel® Edabriz, and G3) produced about two-thirds the yield of the highest. Gi 473/10 had the highest yield efficiency and W10 and W13 had the lowest. Mahaleb was not significantly different from the least efficient rootstocks. The largest fruit in 2004 were from trees on W154, W10, Mahaleb, W13, and G6 while the smallest fruit were from trees on G7, Gi 195/20, W53, Gi 473/10, and G3.

Prosser, Washington

Tree mortality at Prosser was high on Mazzard and some tree losses occurred on W158 and W72 (Table 8). There were no differences in mortality among the other rootstocks. Trees on Mazzard were largest, followed by those on Gi 318/17, W10, and G6 at about 80 to 85% of Mazzard. The smallest trees were on W53, at about 20% the size of trees on Mazzard. The next smallest group consisted of trees on Gi 473/10, W72, and W154, which were about 40% the size of trees on Mazzard. G3 and Tabel® Edabriz were about 45% and G5 was about 65% of Mazzard. W154 and W13 had the most root suckers.

Trees on G7 and G6 had the highest yields, about four-times the cumulative yield of trees on W154 or Mazzard, which had the lowest yield (Table 8). All trees except W53 and W154 had yields significantly higher than Mazzard. Trees on G7 and Gi 473/10 had the highest yield efficiencies, followed by W72, G3, W53, Gi 195/20, and G5. All trees had significantly higher yield efficiencies than those on Mazzard. The largest fruit in 2003 were from trees on Mazzard, Mahaleb, W10, G6, and G5 while the smallest fruit were from trees on G3. In 2004, the largest and smallest fruit were from trees on W10 and

W53, respectively. There were no significant differences in fruit size in 2005.

Discussion

Tree survival. Tree mortality is an important consideration when choosing rootstocks for new orchards. Across all sites most rootstocks had good survival, except for Mazzard (56%) and Gi 473/10 (75%). The poor survival of trees on Mazzard was likely due to poor tree condition upon arrival from the nursery. First-year mortality of trees on Mazzard was noted mainly in British Columbia, Hood River and Washington. These results with Mazzard are not consistent with widespread experience by commercial cherry growers in numerous locations, and thus should be discounted.

Lang et al. (1998) and Lang and Howell (2001) reported that several of the rootstocks in the 1998 NC140 trial (namely, Gi 195/20, Gi 473/10, W53, W154) subsequently proved to be sensitive or hypersensitive to Prune Dwarf Virus (PDV) and/or Prunus Necrotic Ringspot Virus (PNRSV), which are spread via infected pollen. Virus sensitivity may be a source of some of the later mortality that occurred in the trial for trees on these four rootstocks. Other rootstock trials from different countries have reported variable mortality levels. A trial in Vignola, Italy, had mortality levels of 0 to 69% (Lugli and Sansavini, 2008). The highest mortality was with Tabel® Edabriz and Gisela 4 (Gi 473/10). 'Lapins' trees had mortality values ranging from 0 to 74% in two locations in Italy (Trento and Cosenza), which was largely attributed to inadequate irrigation (De Salvador et al., 2008). In another trial in Italy (Apulia, a hot dry climate where irrigation apparently was not used), mortality of 'Lapins' trees ranged from 85% on Gisela 5 to no trees dead for trees on the rootstocks Avima® Argot and CAB11E (Godini et al., 2008). Balmer (2008) had very low mortality with 'Regina' trees in Germany on various rootstocks. Also in Germany, Hilsendegen (2005) reported that mortality was influenced by location, cultivar and rootstock, with no tree mortality at two locations (Weinsberg and Oppenheim), higher mortality with 'Hedelfinger' compared to 'Regina', and at the highest mortality location (Bavendorf), three of the five highest mortality rootstocks were the virus-sensitive Gi 473/10, Gi 195/20, and W154.

Tree size. The trial in Washington produced the largest trees overall, whereas the smallest trees were in the Colorado trial (Table 9). Tree vigor for the rootstocks, averaged across multiple sites, is shown in Table 10, sorted in descending order of TCA. The rootstocks do not fall into discrete categories, but certainly trees on Mazzard were consistently vigorous (standard sized), and W72, G3 and W53 consistently produced among the smallest trees. Mahaleb, W13, G6 and W10 appear to be less vigorous than Mazzard on this listing, but at specific sites (BC and CO), Mahaleb actually produced trees similar to or larger than Mazzard (Tables 4 and 5). On average, the commercially avail-

Table 9. Location effects across all rootstocks (excluding Gi 473/10, Gi 318/17, and W154) on tree vigor (trunk cross-sectional area), cumulative yield and average fruit weight.

Location	Trunk cross-sectional area in 2005 (cm^2)	Cumulative yield 2000-2005 (kg)	Average fruit weight for 2003 and 2004 (g)
British Columbia	195.8	59.0	9.8
Colorado	106.3	5.2	7.1
Corvallis, Oregon	163.6	40.5	7.8
Hood River, Oregon	-[z]	-[z]	9.4
Washington	257.2	97.8	7.3

[z] Hood River location only collected data to the end of 2004. At that time the means for trunk cross-sectional area and cumulative yield were 181.2 cm^2 and 116.6 kg, respectively.

Table 10. Trunk cross-sectional area, cumulative yield, average fruit weight and cumulative yield efficiency of rootstocks averaged across locations for data from Summerland (BC), Prosser (WA), Corvallis (OR) and Hotchkiss (CO). Rootstocks Gi 473/10, Gi 318/17, and W154 were not present in Colorado and have been excluded from this table.

Rootstock	Trunk cross-sectional area in 2005 (cm^2)	Cumulative yield froom 2000-2005 (kg)	Cumulative yield efficiency in 2005 ($kg.cm^{-2}$)	Average fruit weight in 2003 and 2004 (g)
Mazzard	263.5	20.5	0.078	8.6
Mahaleb	231.8	42.2	0.182	8.5
W13	228.8	42.7	0.187	8.1
G6	224.9	74.7	0.332	8.3
W10	222.5	54.0	0.243	8.6
W158	195.2	47.2	0.242	6.9
Gi 195/20	177.4	68.2	0.385	8.0
G7	158.8	77.1	0.486	8.0
G5	155.5	68.2	0.439	8.1
Tabel®Edabriz	144.7	49.9	0.345	8.1
W72	132.8	54.9	0.414	8.0
G3	118.2	57.1	0.483	7.9
W53	95.5	38.5	0.403	7.4

able rootstocks G3, G5 and G6 produced trees 45%, 59% and 85%, respectively, of the size of those on Mazzard (Table 10). The rootstock × location interaction means that caution is required when looking at trends in Table 10. It is especially unwise to make any assumption about performance at locations where the rootstocks were not tested.

In a trial in Poland, the largest trees were on Mazzard F12/1 and Maxma 14, whereas the smallest were on Tabel® Edabriz and P-HL C (Grzyb et al., 2008). A trial in Slovenia had results similar to the Polish trial, with trees on Mazzard F12/1 and Maxma 14 being the largest and the trees on Tabel® Edabriz and W72 the smallest (Usenik et al., 2008). The differences in tree size when comparing all of the various rootstock trials that have been carried out could be due to different soils, climates, and management factors like irrigation, as well as different scion cultivars.

Root suckers. Root suckers tended to be highest for the *P. cerasus* rootstocks, i.e., Tabel® Edabriz and the Weiroot series. De Salvador et al. (2008) found a similar trend, but they also observed suckering of Avima® Argot rootstock (an open-pollinated selection of SL 64 [*P. mahaleb*]) to be similar to the *P. cerasus* rootstocks. In contrast, Charlot et al. (2005) reported low levels of suckering with Tabel® Edabriz rootstock in various trials in France.

Yield. Previous studies have shown that ranking of rootstocks for yield can be dependent on location and scion cultivar (De Salvador et al., 2008; Godini et al., 2008; Lugli and Sansavini, 2008; Usenik et al., 2008). In the present study, scion cultivar was constant at all sites so the differences in yield are largely due to location. The Hood River, Oregon, location had the highest cumulative yield of all the trials even though yield data for 2005 were not recorded (Table 9, footnote). The lowest yielding location was Colorado. Across all locations, trees on G6 and G7 yielded the most, followed by trees on G5 and Gi 195/20 (Table 10). The lowest yielding trees were on Mazzard. It should be noted that yield records for Mazzard were based on relatively few replicate trees at some locations, due to the high tree mortality in the first growing season, as previously mentioned.

Cumulative yield efficiency averaged across all sites (Table 10) was lowest for Mazzard, and this was consistent for every reporting location except Hood River. The next lowest group of rootstocks included the other industry standard, Mahaleb, as well as W13. The highest yield efficiency was with G7 and G3, followed by G5, W72 and W53, all of which were about twice or more as yield-efficient as Mahaleb, and five-times or more as efficient as Mazzard. Both Gi 195/20 and W53 are unlikely to be commercially viable due to virus sensitivity (Lang and Howell, 2001), leaving G3, G5 and G7 and W72 as highly yield-efficient rootstocks that provide a useful range of vigor levels.

Fruit size. Among locations, the largest fruit in 2003 and 2004 were at British Columbia and Hood River, while the smallest fruit were at Colorado and Washington. Averaged over all locations, the trees producing the largest fruit were on Mazzard and W10 whereas the smallest fruit were produced on trees on the rootstocks W158, W53 and G3.

Conclusions

This study showed that several new rootstocks are more productive and precocious than the standard cherry rootstocks Mazzard and Mahaleb, while providing a range of reduced vigor levels. Such rootstocks are worthy of larger scale grower trials, but management practices will need to be modified from those used for the traditional rootstocks (Lang, 2005). The more dwarfing the rootstock, the more intensive the management may need to be. When managed conventionally, trees on these dwarfing, productive rootstocks can lose vigor, resulting in stunting and poor fruit quality. Production practices that may require modification for growing cherries on less vigorous rootstocks include attention to early training, pruning, optimum fertility and irrigation, and crop load management.

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