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Performance of 'Montmorency' Sour Cherry (*Prunus cerasus* L.) on Size-Controlling Rootstocks at Six NC-140 Trial Locations in North America

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Abstract

'Montmorency' sour (aka tart) cherry (*Prunus cerasus* L.) was budded to 11 potentially size-controlling clonal rootstocks plus the standard Mahaleb seedling rootstock at a commercial nursery, grown for one year, then planted in 1998 at six locations in North America under the auspices of the NC-140 Regional Research project. Eight replicate trees on each rootstock were planted at each site (Michigan, New York, Ontario, Pennsylvania, Utah, and Wisconsin). The planting in Pennsylvania was terminated in 2002. The remaining sites continued to collect data through 2007. Significant differences between rootstocks were found for their effects on tree mortality, tree size, root suckering, cumulative yield, cumulative yield efficiency and fruit size within and among the various trial sites. Trees on *P. cerasus* rootstock genotypes varied in scion vigor, ranging from some of the smallest (Edabriz, W.53) to some of the largest (W.10, W.13). Trees on interspecific hybrid rootstocks ranged from dwarfing (Gi.3) to semi-vigorous (Gi.195/20, Gi.6). No rootstock genotype conferred the best performance across all measured characteristics and all locations. Overall, the highest cumulative yields were on Mahaleb, W.10 and Gi.6. The highest mortality was on W.53, followed by Gi.195/20 and G.7, all of which have been found to be sensitive to pollen-borne viruses such as Prune Dwarf and Prunus Necrotic Ringspot. This high mortality should eliminate further commercial consideration of these rootstocks. Extensive root suckering was noted with W.13, W.10 and G.7 at several sites, suggesting that their potential for commercial production should be considered carefully in those sites, especially if mechanized harvest will be with newer over-the-row equipment rather than traditional trunk-shaking machinery.

The success of size-controlling apple rootstocks for induction of greater yield efficiencies and higher yields (Lordan et al., 2018 a, b) has created interest in finding similar rootstock-influenced benefits for other tree fruit crops (Lang, 2000). For hand-harvested sweet cherries (*Prunus avium* L.), smaller trees make harvest safer and more efficient by avoiding the need for ladders. Sour or tart cherries (*Prunus cerasus* L.) are harvested mechanically with tree trunk shakers and catch frames; therefore, reduced tree size has not been a primary objective in the past. However, trunk shaking equipment requires relatively large trees for efficient harvest and minimal trunk damage, so growers typically don't begin to harvest until the sixth or seventh leaf, resulting in three or four years of unharvested small crops and delayed income. Accumulated trunk damage also shortens the life of trees (Papenfuss, 2010). Studies of over-the-row (OTR) harvesting equipment for tart cherries have found the best results with short statured trees < 4 m in height (Black, personal communication). This new approach to harvesting has renewed tart cherry grower interest in smaller trees and the potential for dwarfing rootstocks to reduce tree size.

Research on size-controlling rootstocks for tart cherries has been minimal in the U.S. as well as elsewhere in the world. The

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NC-140 Regional Research project is an association of tree fruit scientists across North America that was established several decades ago to coordinate rootstock trials across diverse growing regions for apple, peach, plum, pear, and cherry (e.g., Perry et al., 1998; Anderson et al., 1996; Johnson et al., 2011; Reighard et al., 2011a; Robinson et al., 2010). Under the auspices of NC-140, coordinated tart cherry rootstock trials were planted in the late 1980s, the results of which were subsequently published (Perry et al., 1996). A similar independent trial was coordinated across European sites about the same time (Wertheim et al., 1998). The preliminary outcomes of both of these coordinated rootstock trials were reported at the 1997 International Cherry Symposium. There have been no additional reports of new tart cherry rootstock evaluations since that time.

In 1998, a "next generation" NC-140 coordinated rootstock trial series was established at multiple sites across North America to evaluate the performance of either tart or sweet cherry trees on a range of size-controlling rootstocks of various species or species hybrids. The results of these sweet cherry trials in western North America locations were published previously (Kappel et al., 2005; Kappel et al., 2008). The objectives of the associated tart cherry trials were to evaluate the compatibility and performance of new size-controlling rootstocks with the industry standard scion cultivar, 'Montmorency', and to determine rootstock adaptability to the important and diverse tart cherry-producing regions of the U.S. and Canada.

Materials and Methods

In 1998 a tart cherry rootstock performance trial using 'Montmorency' as the scion cultivar was planted at six locations in North America (Table 1). The trial evaluated 12 rootstocks, including *P. mahaleb* seedling (as the industry standard), five clonal Weiroot selections of *Prunus cerasus* (W.10, W.13, W.158, W.53, W.72) from Weihenstephan, Germany, five clonal interspecific hybrid rootstocks (four released selections Gisela® [Gi.3, Gi.5, Gi.6, Gi.7] and one un-released selection Gi.195/20) from Giessen, Germany, and a clonal selection of *Prunus cerasus* from France, Tabel® Edabriz (Table 2). All trees were propagated by Meadowlake Nursery (McMinnville, OR) using certified virus-free bud wood. At each location, trees were arranged as a randomized complete block experimental design with 8 single tree replications per rootstock. Trees were planted with graft union height at 7.5-10 cm above the soil and at a spacing of 5 x 6 m. Trees were trained to a modified central leader canopy architecture (Kesner and Nugent, 1984). Each trial followed local

Table 1. Cooperators and sites participating in the 1998 NC-140 tart cherry rootstock trial.

Location, State/Province	Trial Cooperators and Affiliation
Geneva, New York	Robert Andersen, Terence Robinson, J. Freer New York Agricultural Experiment Station
Traverse City, Michigan	Ronald Perry, Greg Lang Michigan State University
Vineland, Ontario	Bill Lay, John Cline Horticultural Research Institute
Biglerville, Pennsylvania	George Greene Penn State University
Kaysville, Utah	Lamar Anderson, Brent Black Utah State University
Sturgeon Bay, Wisconsin	Teryl Roper and Matt Stasiak University of Wisconsin-Madison

Table 2. Description of rootstocks tested in the 1998 NC-140 regional tart cherry trial.

Rootstock	**Country of Origin**	**Species or Hybrid**
Mahaleb	Mediterranean basin	*P. mahaleb* seedling
Gisela 3® (Gi.209/1)	Germany	*P. canescens* x *P. cerasus*
Gisela 5® (Gi 148/2)	Germany	*P. cerasus* x *P. canescens*
Gisela 6® (Gi 148/1)	Germany	*P. cerasus* x *P. canescens*
Gisela 7® (Gi 148/8)	Germany	*P. cerasus* x *P. canescens*
Tabel® Edabriz	France	*P. cerasus*
Gi.195/20	Germany	*P. canescens* x *P. cerasus*
W.10	Germany	*P. cerasus*
W.13	Germany	*P. cerasus*
W.158	Germany	*P. cerasus*
W.53	Germany	*P. cerasus*
W.72	Germany	*P. cerasus*

recommendations for site-specific pest management, fertilization, and irrigation. Although trees eventually varied in size due to rootstock genotype, water and nutrients were applied uniformly across individual locations. Trial design and implementation were organized by consensus of the NC140 tart cherry subcommittee members.

Annual data collection included tree survival, root suckers and trunk circumference (cm) measurements taken in the fall at 30 cm above the soil. Circumference measurements were converted to trunk cross-sectional area (cm^2, TCA) for tree size comparison. In 2000 and 2001, at some sites, branch blossom density (flowers per cm^2 branch cross-sectional area) was calculated from flower counts and circumference measurements taken on three randomly-selected branches per tree. Starting in 2000, fruit were hand-harvested and yield (kg/tree) was determined. Yield efficiency ($kg \cdot cm^{-2}$ TCA) was calculated and average fruit weight was estimated from a random 50-fruit sample per tree. Pennsylvania terminated the trial in 2002. The remaining sites continued recording data through 2007.

Statistical analyses. Data were analyzed as a randomized complete block design at each site with 8 blocks. Proc Mixed (SAS Institute, Cary, NC) was used to perform analyses of variance for each response variable at each site. Block and the block × rootstock interaction were specified as random effects and degrees of freedom were adjusted with the Satterthwaite approximation. Rootstock LSmeans were compared with the Simulate adjustment at the 5% level of significance. This adjustment holds the experiment-wise error rate at 5%. Since the data were analyzed by state, the results are presented by state.

Results

New York tree mortality was greatest on W.53 (62%), followed by Gi.195/20 (37%), W.10 (38%), and Mahaleb (25%) (Table 3). Trunk cross-sectional area is a convenient approximation for tree canopy size in apple (Westwood and Roberts, 1970) as well as tart cherry (Brym, 2016). Trees with the largest TCA in 2007 were on W.13, W.10, and Gi.6. Trees with the smallest TCA were on W.53, Gi.3 Edabriz, Gi.5 and W.72. Most of the Weiroot rootstocks, including W.13, W1.58, W.72 and W.53 along with Gi.7, produced an overabundance of root suckers whereas Gi.195/20, Gi.3, Gi.5, Gi.6 and Mahaleb seedling produced the fewest. Cumulative

Table 3. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), root suckers, cumulative yield (CY), mean fruit weight (FW) and cumulative yield efficiency (CYE) on 12 rootstocks in Geneva, New York.

	Tree Survival (%)		TCA (cm^2)		Cum. Root Suckers (no./tree)		CY (kg/tree)		Avg. FW (g/fruit)	CYE ($kg.cm^2$)	
Rootstock	2002	2007	2002	2007	2002 (suckers/tree)	2007 rating	2002	2007	2001-2007	2002	2007
Edabriz	100	100a	62.6c	144.0 c	3.5 bcde	3.6 cd	18.4 ab	233.1 ab	4.8 ab	0.29 bc	1.67 a
Gi.195/20	88	63ab	72.6abc	181.6 bc	1.3 de	1.4 e	18.2 ab	259.8 ab	5.0 a	0.26 bc	1.45 abc
Gi.3	100	100a	48.5c	111.8 c	1.5 de	1.2 e	10.1 c	180.5 c	4.9 ab	0.22 c	1.61 a
Gi.5	100	100a	61.9c	133.7 c	1.0 e	1.0 e	15.8 bc	226.5 ab	5.0 a	0.27 bc	1.72 a
Gi.6	100	100a	84.6ab	215.0 ab	2.0 cde	1.4 e	22.2 ab	283.2 a	5.0 a	0.29 bc	1.37 bc
Gi.7	100	88ab	67.2bc	136.7 c	6.6 a	6.1 ab	18.1 ab	214.9 bc	5.0 a	0.28 bc	1.62 a
Mahaleb	100	75ab	88.5ab	210.2 b	2.2 cde	1.6 de	17.4 abc	266.4 ab	4.7 ab	0.23 c	1.28 bc
W.10	100	62b	90.3ab	227.0 a	6.2 ab	4.5 bc	25.3 a	273.6 ab	4.6 ab	0.30 bc	1.24 c
W.13	100	100a	98.5a	244.4 a	4.9 abc	7.4 a	21.1 ab	279.3 a	4.8 ab	0.21 c	1.16 c
W.158	100	100a	75.6ab	196.7 b	4.5 abcd	6.2 ab	19.3 ab	242.4 ab	5.0 a	0.27 bc	1.23 c
W.53	100	38b	51.5c	110.5 c	5.2 abc	5.4 abc	22.7 ab	202.1 bc	4.5 b	0.45 a	1.80 a
W.72	100	100a	56.0c	134.3 c	4.6 abc	6.3 ab	21.9 ab	215.4 b	4.9 ab	0.40 ab	1.68 a
P-value	0.4656	0.0003	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0053	0.0001	0.0001

[Z] LSmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

yield (CY) per tree reflected TCA, with the larger trees tending to have the highest CY, and the lowest cumulative yield efficiency (CYE). Trees on W.53 had the highest CYE, which was statistically similar to that for trees on Gi.5, W.72, Edabriz, and Gi.7. Fruit on W.53 were the smallest. All other rootstocks produced fruit of a similar size.

Ontario tree mortality was only significant on W.53 (62%) (Table 4). Rootstocks that produced trees with smaller TCA in year 5 (2003) remained small through year 11 (2008). Trees on Mahaleb, W.10 and W.13 had the largest TCA, whereas trees on Gi.3, Edabriz, W.53, Gi.5 and Gi.7 had the smallest TCA. W.13 produced the most root suckers, followed by W.10. All the other rootstocks, including W.10, had a similar amount of root suckers by year 10. Mahaleb, Gi.6, W.10, and W.13 had the highest CY. Fruit size was

Table 4. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), precocious branch blossom density, root suckers, cumulative yield (CY), mean fruit weight (FW) and cumulative yield efficiency (CYE) on 12 rootstocks in Vineland, Ontario, Canada.

	Tree Survival (%)		TCA (cm^2)		Cum. Root Suckers (no./tree)	CY (kg/tree)	FW	CYE (kg/cm^2)
Rootstock	2003	2008	2002	2008	2002-2008	2000-2007	(g/fruit	2000-2007
Edabriz	100	88 a[z]	16.5e	36.2d	10.8 b	6.6 cd [z]	4.0 b	1.35 a
Gi.195/20	88	88 a	42.0cd	88.5cd	2.6 b	12.3 bc	5.3 a	1.04 ab
Gi.3	100	100 a	17.0e	33.7d	4.2 b	6.2 cd	4.1 b	1.42 a
Gi.5	100	88 a	28.0de	57.3d	0.5 b	10.5 cd	4.5 b	1.27 ab
Gi.6	100	100 a	53.0bc	137.9bc	1.5 b	18.0 ac	4.5 b	0.99 ab
Gi.7	100	100 a	39.7cd	67.2d	5.5 b	10.5 cd	4.3 b	1.14 ab
Mahaleb	100	100 a	76.3a	245.1a	2.4 b	20.6 a	4.8 a	0.62 b
W.10	100	100 a	65.4ab	186.2b	27.4 ab	18.8 ab	4.9 ab	0.86 ab
W.13	88	88 a	55.4bc	185.4b	46.7 a	15.3 abc	4.5 b	0.67 b
W.158	100	100 a	39.9cd	135.1bc	3.6 b	13.8 bc	4.6 b	0.79 b
W.53	88	38 b	16.0e	42.4d	0.9 b	4.5 d	4.7 b	1.34 ab
W.72	100	100 a	28.7de	93.5c	5.6 b	13.5 b	4.6 b	1.07 ab
P-value	0.5792	0.0001	0.0001	0.0001	0.0001	0.0001	0.001	0.3285

[Z] LSmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

Table 5. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), root suckers, blossom density and rating, cumulative yield (CY), cumulative yield efficiency (CYE) and average fruit weight (FW) on 12 rootstocks in Traverse City, Michigan.

	Tree survival (%)		TCA (cm^2)		Cum. Root suckers (no. tree)	Blossom Density (no./tree)	Blossom Density (no./cm^2 BCSA[W])		Bloom rating[X]	CY[Y] (kg/tree)	FW (g/fruit)	CYE[Y] (kg/cm^2)
Rootstock	2002	2007	2002	2006	2000-2002	2000	2001	2002	2003	2000-2007	2000-2006	2000-2007
Edabriz	100 a	100 a[Z]	13.7 c	22.7 c	0.5 b	14.0 bc	3.1 a	5.8 a	3.9 ab	53.3 c	3.3	1.90 b
Gi.195/20	100 a	0 b	36.4 b	68.5 b	0.3 b	34.6 ab	2.3 abc	5.4 ab	3.0 ab	- - -	3.6	- - -
Gi.3	100 a	75 a	9.7 c	20.3 c	0.0 b	46.9 a	2.3 abc	4.0 ab	3.6 ab	54.7 c	3.4	2.45 ab
Gi.5	100 a	100 a	18.8 bc	35.3 c	0.4 b	26.0 abc	2.7 ab	5.6 a	2.6 b	94.8 bc	3.6	2.73 ab
Gi.6	100 a	100 a	28.6 bc	57.0 bc	0.0 b	31.8 abc	2.6 ab	6.0 a	3.2 ab	183.9 bc	3.9	3.08 ab
Gi.7	100 a	0 b	29.0 bc	49.9 bc	17.5 a	25.2 abc	2.6 ab	5.2 ab	3.9 ab	130.7 abc	3.5	2.35 ab
Mahaleb	100 a	100 a	55.2 a	131.7 a	0.0 b	14.9 bc	1.2 c	3.1 b	2.9 ab	376.8 a	3.6	2.85 ab
W.10	100 a	100 a	38.8 b	75.8 b	4.6 ab	26.4 abc	1.7 bc	3.6 b	3.6 ab	249.2 ab	3.6	3.17 ab
W.13	100 a	88 a	46.6 ab	83.9 b	4.8 ab	19.6 bc	1.7 bc	3.9 a	3.8 ab	309.0 a	3.5	3.65 ab
W.158	100 a	100 a	32.4 b	77.6 b	4.0 ab	7.8 c	2.0 abc	4.1 ab	2.8 ab	234.5 abc	3.4	3.01 ab
W.53	50 b	25 bc	23.1 bc	44.6 bc	7.0 ab	20.9 bc	2.7 ab	6.4 a	4.0 a	117.1 bc	3.5	2.23 ab
W.72	100 a	100 a	32.1 b	61.2 bc	6.6 ab	10.1 bc	1.9 abc	4.2 ab	3.2 ab	271.6 ab	3.5	4.27 a
P-value	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0029	0.0001	0.1621	0.0001

[W] Branch cross-sectional area
[X] Rated on a scale of 0 to 5, where 0 = no bloom and 5 = heavy bloom.
[Y] The entire crop was lost to frost in 2002, therefore, CY and CYE data are lower than might otherwise be expected.
[Z] Lsmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

largest on Gi195/20, Mahaleb, and W.10. Trees on Edabriz and Gi.3 had the highest CYE and trees on Mahaleb and W.13 had the lowest CYE.

Michigan tree mortality was most severe on Gi.195/20 and Gi.7 (both 100%), followed by W.53 (75%); nearly all of the other rootstocks had 100% survival (Table 5).Trees on Mahaleb were the largest, followed by those on W.13. Trees on Gi.3, Gi.5, and Edabriz were the smallest. Gi.7 produced the most root suckers per tree, followed by all of the Weiroot series. The most precocious bloom was on the Gisela® series and W.53. The highest CY was on Mahaleb, followed by W.13, which also were the largest trees. Trees on Edabriz and Gi.3 produced the lowest CY and were the smallest trees. However, CYE did not follow tree size; W.72 had the highest CYE and was midsize, while Edabriz was the smallest tree and had the lowest CYE.

Utah tree mortality was 100% on W.53 and very severe on Gi.195/20 (75%) (Table 6). Only trees on Mahaleb and W.13 had 100% survival. The trees with the largest TCA also were tallest and had the greatest spread. Trees on Gi.6, Mahaleb, W.10, W.13, and W.158 were largest, and trees on Gi.3, Gi.5, Gi.195/20, Edabriz and Gi.7 were the most compact. Gi.3 was the most precocious in 2000, and Gi.5 had the highest bloom density in 2001, followed by the other Gi stocks and Edabriz. W.13 and W.72 had the most root suckers per tree, followed by Gi.195/20. As with many of the other sites, the larger trees (i.e., Mahaleb, W.13, W.10) had the highest CY. However, the trees with the highest CYE tended to be the smaller trees (Gi.5, Edabriz, Gi.3, Gi.195/20, and W.72.) Fruit size was largest from trees on W.10, W.13, and W.158.

Wisconsin tree mortality was only significant on W.53 (88%) (Table 7). Trees on Edabriz, Gi.3, W.53, and W.72 were smallest, and trees on W.10, Mahaleb, W.13 and Gi.6 had the largest TCA. W.13 produced the most root suckers, followed by W.10, W.158, and Gi.7. Trees on Gi.6 and W.10 had the highest

Table 6. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), height and spread, precocious branch blossom density, root suckers, cumulative yield (CY), mean fruit weight (FW) and cumulative yield efficiency (CYE) on 12 rootstocks in Kaysville, Utah.

Rootstock	Tree Survival (%) 2002	Tree Survival (%) 2007	TCA (cm^2) 2002	TCA (cm^2) 2007	Height (cm)	Spread (cm)	Blossom Density (no./branch cross-sectional area) 2000	Blossom Density (no./branch cross-sectional area) 2001	Cum. Root Suckers (no./tree) 2000 -2007	CY (kg/tree) 2002	CY (kg/tree) 2007	FW (g/fruit)	CYE (kg/cm^2)
Edabriz	100	88 a [z]	52.9 bc	91.8 b	402 bc	392 cd	6.6	53.4 abc	100 b	15.9 bc	142 bc	4.0 b	1.54 ab
Gi.195/20	100	25 bc	50.9 bc	80.7 b	376 bc	261 d	11.6	48.8 abc	218 ab	16.6 bc	126 bc	3.9 b	1.49 abc
Gi.3	88	88 a	39.9 c	70.4 b	348 c	351 cd	15.7	66.5 ab	158 b	10.5 c	102 c	3.9 b	1.49 abc
Gi.5	100	88 a	43.0 c	73.2 b	350 c	388 c	10.1	71.1 a	30 b	12.8 c	128 c	4.0 b	1.73 ab
Gi.6	100	88 a	61.7 b	128.2 ab	446 ab	439 bc	6.8	56.1 ab	72 b	15.9 bc	172 bc	4.2 ab	1.35 bc
Gi.7	100	62 a	50.8 c	84.9 b	375 c	374 cd	5.2	62.1 ab	102 b	14.9 bc	135 c	4.0 b	1.70 ab
Mahaleb	100	100 a	89.9 a	220.2 a	487 a	480 ab	11.6	35.0 c	164 b	23.6 a	223 a	4.0 b	1.26 bc
W.10	100	88 a	83.1 a	187.6 ab	488 a	501 a	5.3	38.7 c	166 b	16.0 bc	209 a	4.3 a	1.12 c
W.13	100	100 a	81.5 a	212.8 a	487 a	488 a	13.2	24.9 c	433 a	19.7 ab	193 ab	4.2 a	1.17 c
W.158	100	75 a	60.6 b	151.6 ab	448 ab	440 abc	11.0	38.9 c	89 b	15.0 bc	149 bc	4.2 a	1.01 c
W.53	86	0 c	47.6 bc	- - -	- - -	- - -	18.3	41.4 bc	- - -	10.2 c	- - -	- - -	- - -
W.72	100	88 a	47.6 bc	89.2 b	404 bc	399 bc	10.3	42.8 bc	422 a	14.3 bc	146 bc	4.1 b	1.68 ab
P-value	0.4681	0.0001	0.0001	0.0001	0.0001	0.0001	0.3483	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001

[z] LSmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

CY, followed by W.13, W.158 and Mahaleb, although as large trees, these all tended to have lower CYE values. The highest CYE was on W.72, followed by Edabriz. Fruit size was largest on Gi.5 and Gi.7 and trees on Mahaleb produced the smallest fruit.

Pennsylvania tree mortality through the initial 5 years of the trial was highest on W.158 (38%), followed by Gi.5 (25%) (Table 8). The largest trees were on W.13, Mahaleb, and W.10 and the smallest were on Gi.3 and Gi.5, followed by W.53 and W.72. Root suckering was relatively low, with the most on W.13, followed by Gi.7. Although bloom in 2000 was most precocious on several of the Gisela rootstocks, with only 3 years of yield data, CY was highest on W.13 and Gi.6, suggesting better sustained precocity. At such an early stage of continued orchard development, the CYE values varied somewhat but not for practical comparisons. The largest fruit were produced on W.53.

Table 7. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), root suckers, cumulative yield (CY), mean fruit weight (FW) and cumulative yield efficiency (CYE) on 12 rootstocks in Sturgeon Bay, Wisconsin.

Rootstock	Tree Survival (%) 2002	Tree Survival (%) 2007	TCA (cm^2) 1998-2002	TCA (cm^2) 1998-2007	Cum. Root Suckers (no./tree) 2007	CY (kg/tree) 2002	CY (kg/tree) 2007	FW (g/fruit)	CYE (kg/cm^2) 2002-2007
Edabriz	100 a [z]	100 a	42.9 c	99.0 d	5.1 b	2.8 b	153.6 bc	4.4 b	1.54 ab
Gi.195/20	100 a	75 a	66.3 ab	163.3 bcd	3.8 b	3.7 ab	183.5 bc	4.6 ab	1.12 bc
Gi.3	100 a	100 a	37.5 c	95.6 d	0.2 b	3.5 ab	126.6 c	4.6 ab	1.35 bc
Gi.5	100 a	100 a	49.5 c	130.9 cd	3.4 b	3.3 ab	188.2 bc	4.8 a	1.43 b
Gi.6	100 a	100 a	77.0 a	203.5 ab	23.0 b	4.6 ab	257.7 a	4.5 b	1.28 bc
Gi.7	100 a	75 a	60.2 bc	144.7 cd	61.2 ab	5.1 a	191.2 bc	4.8 a	1.33 bc
Mahaleb	75 b	62 a	67.9 ab	204.7 ab	7.2 b	4.5 ab	208.5 abc	4.2 b	1.02 c
W.10	100 a	100 a	66.2 ab	201.0 abc	74.0 ab	3.0 ab	261.5 a	4.4 b	1.30 bc
W.13	100 a	88 a	71.6 a	205.9 a	85.9 a	4.9 ab	247.2 ab	4.3 b	1.21 c
W.158	100 a	100 a	61.5 bc	191.6 abc	69.1 ab	2.8 b	213.0 ab	4.6 ab	1.12 c
W.53	100 a	12 b	48.2 c	87.0 d	4 .5 b	3.7 ab	120.5 c	4.5 ab	1.48 b
W.72	100 a	100 a	45.1 c	102.1 d	21.7 b	4.5 ab	175.0 c	4.6 ab	1.72 a
P-value	0.017	0.001	0.0001	0.0001	0.001	0.006	0.001	0.001	0.001

[z] LSmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

Table 8. 'Montmorency' tart cherry tree survival, trunk cross-sectional area (TCA), precocious branch blossom density, root suckers, cumulative yield (CY), mean fruit weight (FW) and cumulative yield efficiency (CYE) on 12 rootstocks in Biglerville, Pennsylvania.

Rootstock	Tree Survival (%) 2002	TCA (cm^2) 2002	Blossom Density (no./branch cross-sectional area) 2000	2001	Cum. Root Suckers (no./tree) 2002	CY (kg/tree) 2000-2002	FW (g/fruit) 2002	CYE (kg/cm² 2000-20
Edabriz	100 a [z]	40.1 c	29.3 ab	17.2 ab	0.5 b	4.8 b	4.3 b	0.13 a
Gi.195/20	100 a	42.0 c	31.2 a	18.2 ab	0.0 b	4.1 b	3.9 b	0.09 ab
Gi.3	100 a	22.6 d	39.5 a	24.0 a	0.0 b	1.9 c	4.3 b	0.08 b
Gi.5	75 b	22.6 d	39.4 a	21.5 a	0.0 b	1.5 c	4.2 b	0.06 b
Gi.6	100 a	47.3 c	33.0 a	17.6 ab	0.0 b	5.1 ab	4.2 b	0.11 ab
Gi.7	88 ab	38.9 c	26.2 b	20.4 a	7.5 a	2.4 c	4.1 b	0.06 b
Mahaleb	100 a	53.1 bc	19.4 b	10.1 b	0.0 b	4.6 b	3.9 b	0.09 b
W.10	100 a	51.8 abc	20.1 b	10.3 b	4.8 b	4.9 b	4.0 b	0.09 b
W.13	88 ab	56.1 a	22.7 b	15.2 b	12.0 a	6.7 a	3.9 b	0.11 ab
W.158	62 b	44.5 bc	16.6 b	16.4 ab	0.0 b	3.6 b	4.4 ab	0.08 b
W.53	100 a	28.2 d	31.4 a	15.4 b	4.6 b	3.6 b	4.6 a	0.13 a
W.72	100 a	29.0 d	30.3 ab	12.6 b	1.0 b	4.1 b	4.4 ab	0.14 a
P-value	0.030	0.001	0.005	0.006	0.004	0.001	0.001	0.001

[z] LSmeans within columns followed by common letters do not differ at the 5% level of significance by the simulate adjustment.

Discussion

Due to personnel changes at some sites, the summarization of these data was delayed longer than desired. However, rootstock information for tart cherry is lacking because most cherry rootstock trials are limited to sweet cherry scions. Therefore, the information from this trial for tart cherry is unique and relevant. The data were not analyzed across sites because some locations discontinued the planting prior to the planned 10-year duration of the trial, while other sites continued to completion. Nearly all NC-140 multi-state trials result in large rootstock x location interactions, thus the strongest conclusions about rootstock performance are site specific. Since the data were not analyzed across sites, it is not possible to draw many overarching conclusions about performance across locations. However, there were some similarities across locations.

Tree survival on W.53 was extremely poor across all locations that had 10 years of data, and very poor on Gi.195/20. The next worst rootstock was Gi.7, which had relatively poor survival at half of the sites. These results are not surprising, given the previously reported sensitivity of all three rootstocks to the pollen-borne viruses Prune Dwarf (PDV) and Prunus Necrotic Ringspot (PNRSV) (Lang and Howell, 2001), which could cause increasing probabilities of infection and tree decline with each additional year of spring bloom (Oliver et al., 2009). Although virus infection was not tested (and therefore not confirmed) as the causal agent for the decline of the trial trees on these rootstock genotypes, their widespread poor performance across multiple locations and their known virus sensitivity suggest that they should not be recommended for commercial adoption.

Tree vigor and relative tree size varied across locations, with the greatest tree vigor reported in Utah, New York and Wisconsin. In the majority of the trials, the rootstock producing the smallest trees was Gi.3, followed by a group of slightly less dwarfing rootstocks that included W.53, Gi.5, and Edabriz. The rootstocks that consistently produced large trees included Mahaleb, W.13, W.10, W.158 and Gi.6. These results are consistent with previous sweet cherry rootstock trials. In Bulgaria, 'Bigarreau Burlat' sweet cherry was grown on seven of the rootstocks tested in our trial (Lichev and Papachatzis, 2011). In that study, the crown volume of 11-year-old trees on W.10 and W.13 were 86% and 93% as large as for trees on Mahaleb. Trees on W.53, W.72 and W.158 had crown volumes 34% as large as on Mahaleb, and trees on G.5 had crown volume only 19% of that on Mahaleb. In the NC-140 sweet cherry rootstock trial planted at the same time as this trial, trees on Gi.3 were the smallest, followed by trees on Gi.5, and then W.53 and W.72; trees on Mahaleb, W.10, W.13 and Gi.6 were the largest (Kappel et al., 2008).

Root suckering was inconsistent across the locations. Trees grown in Utah, Wisconsin and New York had significant suckering, whereas those in Ontario, Pennsylvania, and Michigan had fewer suckers overall. The rootstocks with the highest relative number of suckers across a majority of sites were W.13 and Gi.7, followed by W.10. In the Bulgarian sweet cherry trial, W.10 and W.13 had the most root suckers, whereas trees on Mahaleb and Gi.5 produced no suckers (Lichey and Papachatzis, 2011). All of the trees in Utah had prolific root suckers compared to the other states, and this has been observed in other tree fruit species in NC-140 trials (Marini et al., 2014; Reighard et al., 2011b). Root suckering is an orchard management annoyance for trees harvested by trunk shaker, since they do not impede the shaker or collection equipment, and there is plenty of clearance around the trunk for periodic removal of suckers. However, root suckering can be much more problematic for orchards harvested by over-the-row machinery, since they may impede the collection equipment catch plates that capture harvested fruit in the middle of the tree row below the tree canopy. Furthermore, the low development of the bushy canopy that is critical to increasing its yield potential (given the height limitations of OTR harvesters) would make sucker removal or suppression difficult, possibly leading to the competition of non-fruiting rootstock shoots that grow into the fruiting scion canopy.

When compared across sites that measured precocious bloom density in 2000 and 2001 (Years 3 and 4 after planting), Edabriz and the Gi rootstocks tended to produce more flowers on young trees than other rootstocks. Average fruit size (fresh weight) was not consistent across locations or rootstocks, which is not surprising since fruit size is strongly influenced by annual variations in crop load and leaf-to-fruit ratios. Across most sites, the highest cumulative yields tended to be on the largest trees (Gi.6, Mahaleb and W.10), but when yield efficiency differences were significant, smaller (Gi.5, W.72) and intermediate-sized (Gi.6, W.158) trees tended to be more yield efficient than larger trees. This is consistent with other fruit crops such as apple (Marini et al., 2006). Our results generally are comparable to those for the Bulgarian sweet cherry trial, where ranking for yield efficiency was Gi.5 > W.72 > W.53 = W.10 > W.158 > W.13 > Mahaleb (Lichey and Papachatzis, 2011). For the concomitant NC-140 sweet cherry rootstock trial, Mahaleb, W.13, and W.158 had low yield efficiency at most sites (Kappel et al., 2008).

P. cerasus exhibits great diversity when used as a rootstock. In this trial, some of the smallest (Edabriz) and some of the largest (W.10) trees were on *P. cerasus* rootstocks. Trees on the interspecific hybrid rootstocks tended to be smaller, but not always since Gi.6 was among the larger trees. The standard rootstock for the North American tart cherry industry, Mahaleb, was always among the highest yielding rootstocks, but it is not precocious, not yield efficient, and not vigor-limiting, which are three critical traits for OTR harvesting systems.

These results are based on small research trials of 'Montmorency' tart cherry to compare selected tree and fruiting traits on a common group of experimental rootstock genotypes, repeated across climatically and geographically diverse locations. Certainly, commercial tart cherry producers would optimize the management of their trees relative to the anticipated traits of the rootstock genotype judged to most meet their production and site needs, including desired training system, fertilization, irrigation, and harvest technique. From this trial, it is clear that three of the rootstocks (W.53, Gi195/20 and Gi.7) should be discarded from further consideration by the North American tart cherry growers for poor survival, and in certain cases or sites, two others (W.13 and W.10) should be avoided due to excessive suckering. For traditional trunk-shaker harvest, which requires relatively vigorous trees, none of the new rootstocks consistently and markedly surpassed the industry standard, Mahaleb. However, for OTR harvest, which requires semi-dwarfing to possibly semi-vigorous trees, several of the remaining cherry rootstocks may have good potential due to their higher yield efficiencies that accompany their smaller sizes. Further rootstock research with this range of rootstocks, planted at the higher densities necessary for OTR harvest, is warranted for production regions where growers are considering potential OTR production of 'Montmorency' tart cherries.

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