

Performance of 'Golden Delicious' Apple on 23 Rootstocks at 12 Locations: A Five-Year Summary of the 2003 NC-140 Dwarf Rootstock Trial

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Abstract

In 2003, an orchard trial of apple [*Malus × sylvestris* (L.) var. *domestica* (Borkh.) Mansf.] dwarf rootstocks was established at 12 locations in Canada, Mexico, and the United States using 'Golden Delicious' as the scion cultivar. A core group of 11 rootstocks was planted at all locations. The four rootstocks included as industry standards were Malling 26 EMLA (M.26 EMLA), Budagovski 9 (B.9), M.9 Pajam2, and M.9 NAKBT337. The other seven rootstocks included selections from Russia (B), Cornell-Geneva (CG and G), Czech Republic (J-TE), and Germany (Pi Au); these included B.62396, CG.3041 [Geneva® 41], CG.5935 [Geneva®935], G.16, J-TE-H, and Pi Au56-83, and Pi Au51-4. Some locations also received two additional CG rootstocks, seven Japanese (JM) rootstocks, J-TE-G, or two Pi Au rootstocks. After five years, trees on J-TE-G were similar in size to B.9; trees on B.62396 and CG.3041 were similar in size to M.9 NAKBT337; trees on CG.5935, G.16, J-TE-H and M.9 Pajam2 were similar in size to M.26; and trees on Pi Au56-83, Pi Au51-4, Pi Au36-2 and JM.2 were larger than M.26 EMLA. For the first time in an NC-140 rootstock trial, several rootstocks have higher yield efficiency than M.26 EMLA and M.9 NAKBT337. Promising new rootstocks with very high yield efficiency included CG.5935, CG.3041, CG.5179 and J-TE-G.

Most new North American apple [*Malus × sylvestris* (L.) var. *domestica* (Borkh.) Mansf.] orchards planted in the past 15 years have been high density orchards. These orchards are more economical than lower density orchards because trees come into bearing at an early age, good light distribution favors high quality fruit, and labor costs for pruning and harvest are relatively low (9). Successful intensive orchards require appropriate dwarfing rootstocks. The two most widely used dwarf rootstocks are M.9 and M.26, but they each have weaknesses, especially in certain fruit producing regions. M.9 is difficult to propagate, is sensitive to fire blight [*Erwinia amylovora* (Burrill) Winslow et al.] and winter injury, and trees are poorly anchored, whereas M.26 is prone to burrknotting, often produces uneven scion growth in the orchard and is sensitive to fire blight and woolly apple aphid [*Eriosoma lanigerum* (Hausman)] (13). There is still a need for a series of high-yielding rootstocks, providing a range of tree vigor within the dwarfing category and able to survive a wide range of biotic and abiotic

stresses. Cooperators in the NC-140 regional project have evaluated a number of dwarfing rootstocks, and as new rootstocks become available from breeding programs around the world they are tested at many locations throughout North America.

The 2003 dwarf rootstock trial was established to evaluate new rootstocks from several rootstock breeding programs. Based on early reports and observations, all of these rootstocks were expected to fall into the dwarfing category. One new rootstock (Budagovski 62396) or B.62396 was included from the apple rootstock breeding program at Michurinsk College in Russia. Seven rootstocks (JM.1, JM.2, JM.4, JM.5, JM.7, JM.8, and JM.10) were included from the Apple Research Center in Morioka, Japan. The JM series of rootstocks resulted from crosses of *M. prunifolia* [(Willd.) Borkh.] x M.9 and were selected for ease of vegetative propagation by hardwood cuttings, and resistance to *Phytophthora* crown, root rot and woolly apple aphid (11), and they are reportedly more productive than M.9 and M.26 (12).

Preliminary reports indicate that JM. 1, JM.5 and JM.8 are in the M.27 size class, whereas JM.2 and JM.7 are in the M.9 size class (14). Four rootstocks (Pi Au36-2, Pi Au51-4, and Pi Au51-11, and Pi Au56-83) were included from the rootstock breeding program at the Institut für Obstforschung Dresden-Pillnitz, Germany. They were selected for ease of rooting in stool beds, provide a range of tree vigor (2), and reportedly have slightly higher yield efficiency than M.9 (4). Two rootstocks (J-TE-H and J-TE-G), from Techobuzice, Czech Republic were included. J-TE-G reportedly is similar in vigor to M.27, with very high yield efficiency; JT-E-H is similar in vigor to M.26, but may have poor yield efficiency (14). Five selections [CG.3041, CG.5935, CG.5179, CG.6210, and Geneva®16 (G.16)] were included from the Cornell-Geneva Apple Rootstock Breeding Program, located in Geneva, New York, USA. The objective of the Geneva program is to develop a series of rootstocks with a range of vigor, tolerance to cold temperatures, and resistance to several diseases and other pests, including fire blight and *Phytophthora* crown and root rot. Following the establishment of this trial, some of the rootstocks from the Cornell-Geneva program were released for commercial sale and are sold with different designations (CG.3041 = Geneva® 41 and CG.5935 = Geneva® 935). For the purposes of this report, rootstocks will be referred to by

their original designations. The purpose of this study was to evaluate the field performance of new dwarf apple rootstocks from several breeding programs across a range of climates and soils.

Materials and Methods

'Golden Delicious' (Gibson strain) trees on dwarfing rootstocks were planted at 12 locations (Table 1) in the spring of 2003 and were trained to the vertical axe system. Trees were propagated at Treco Nursery, Woodburn, OR. The experimental design was a generalized randomized complete block design (3) with four blocks at each location and two trees of each rootstock randomly assigned within each block to provide eight trees per rootstock at each location. Certain rootstocks had inadequate numbers of trees for this arrangement, so for some rootstocks only one tree was planted in some blocks and some locations. All locations except AR received a core of 11 rootstocks and an additional 12 rootstocks were planted at selected locations. Trunk circumference was measured each fall and trunk cross-sectional area (TCA) was calculated. In 2004 the trees were defruited and depending on tree size, trees were first allowed to fruit in 2005 or 2006. During harvest, all fruits were counted and weighed and average fruit weight (FW) was calculated by dividing yield by the number of fruit per tree. Cumulative yield

Table 1. Locations and cooperators participating in the 2003 dwarf rootstock trial.

Location	Cooperator	Planting Location
(AR) Arkansas	Curt R. Rom	Fayetteville
(BC) British Columbia	Cheryl Hampson	Summerland, Canada
(CA) California	Scott Johnson	Parlier
(CHIH) Chihuahua	Rafael Parra Quezada	Cuahtémoc, Chih., Mexico
(GA) Georgia	Steven McArtney	Blairsville
(IA) Iowa	Paul A. Domoto	Ames
(KY) Kentucky	Joseph Masabni	Princeton
(ME) Maine	Renae Moran	Monmouth
(NY) New York	Terence Robinson	Geneva
(PA) Pennsylvania	Robert Crassweller	Rock Springs
(UT) Utah	Brent Black	Kaysville
(WI) Wisconsin	Kevin Kosola	Sturgeon Bay

efficiency (YE) was calculated by dividing cumulative yield by TCA in 2007. Following harvest and before pruning in 2007, the height and spread of each tree was recorded. During the fall of 2007 the number of root suckers under each tree was recorded to provide an indication of root sucker production. The percentage of the circumference of the above-ground portion of the rootstock covered with burrknots was also recorded. Each winter the data were sent to the senior author for summarization and statistical analyses.

Statistical analyses were performed with SAS's Mixed Procedure (5), where block and trees within block were specified as random effects. For all response variables the Least squares means were compared with the *Simulate* method at an experiment-wise error rate of $P = 0.10$. The *cvadjust* option was included to request estimated experiment-wise error rates for some commonly used multiple comparisons. Depending on the response variable, the estimated error rates were 0.1 for the Simulate method, 0.0947 to 0.1002 for Tukey-Kramer, 0.0513 to 0.0561 for Bonferroni, and 1.00 for LSD (error rate = 100%).

Results and Discussion

Tree survival. Tree survival was influenced by location and rootstock and the interaction of the two factors was significant (Table 2). Results from SAS's *Slice* option indicate that tree survival was significantly affected by rootstock in only five of the 12 locations. Tree survival was lowest in AR and CA, and all trees survived in IA and WI (see Table 1 for abbreviations). In other trials, tree survival was also poor in AR and CHIH (1), but the co-operators gave no explanation for tree losses. Pooled over all locations, tree survival was highest for Pi Au56-83, J-TE-H and B.62396 and lowest for G.16, M.26 and M.9 Pajam2. M.9 Pajam2 survived poorly in CA and UT, and G.16 survived poorly in CHIH and KY. Of the rootstocks that were not part of the core group, those with high survival included Pi Au51-4, JM.2, and J-TE-G, but most of the tree mortality occurred in the western locations (CA, BC, and UT). Survival of JM.1

and JM.7 was poor in BC, possibly due to the fumigation of trees required before importing them into BC (personal correspondence with Cheryl Hampson). All trees survived in NY as they did in another trial (1). Tree survival in this trial was similar to, or higher than in previous multi-location rootstock trials (1, 6). Since more than five years is required to fully evaluate the influence of rootstock on tree survival (6), these results should be considered preliminary. In general trees on G.16, M.9 Pajam2, M.26 EMLA, JM.1, and JM.7 had poor survival.

TCA. Rootstock significantly affected TCA at all locations (Table 3), but generalizations are difficult to make because there was a significant location \times rootstock interaction. In general, trees in KY had the largest trunks and trees in NY, BC, IA, and ME had the smallest trunks. Factors that may have influenced tree vigor include fumigation of trees in BC and the fact that the IA site was a replant site (personal communication with Paul Domoto). Pooled over all locations, trees with the smallest trunks were on B.9 and trees with the largest trunks were on Pi Au56-83. Based on means pooled over all locations, and including rootstocks not in the core planting, the least vigorous rootstock in the trial was J-TE-G, which was similar to or slightly less vigorous than B.9 at most locations. Rootstocks providing tree vigor similar to M.26 EMLA included CG.5935, G.16, J-TE-H, and M.9 Pajam2. Rootstocks with vigor similar to M.9 NAKBT337 included B.62396 and CG.3041. Rootstocks considerably more vigorous than M.26 EMLA included Pi Au56-83, Pi Au51-4, Pi Au36-2 and JM.2. When compared to M.26 EMLA, several rootstocks were much more vigorous at CA than at the other locations. When averaged over all seven locations, the TCA of trees on M.26 EMLA were 99%, 77%, and 45% as large as trees on JM.1, CG.6210 and JM.2, respectively; but in CA, the TCA of trees on M.26 EMLA were only 70%, 52% and 32% as large as trees on JM.1, CG.6210 and JM.2, respectively. Trunks of trees on B.9 were also much smaller relative to M.26 EMLA in CA than in other locations. Of the noncore

Table 2. Survival (%) of 'Golden Delicious' trees on various rootstocks at 12 locations after five years.^z

Stock	AR	BC	CA	CHIH	GA	IA	KY	ME	NY	PA	UT	WI	Mean
B.62396	62	100	88b	100b	100	100	100b	100	100	100	75b	100	95
B.9	75	100	50b	100b	88	100	62ab	100	100	88	100b	100	89
CG.3041	88	88	62b	75ab	88	100	88b	100	100	100	75b	100	89
CG.5935	50	100	88b	75ab	100	100	62ab	100	100	100	88b	100	90
G.16	62	62	75b	62a	88	100	50a	88	88	100	100b	100	81
J-TE-H	75	100	100b	62a	100	100	100b	100	100	100	100b	100	95
M.26	62	100	12a	88ab	100	100	88b	100	100	100	50ab	100	83
M.9 Pajam2	75	100	12a	75b	100	100	100b	100	100	100	38a	100	83
PI Au 56-83	75	100	62b	100b	100	100	100b	100	100	100	100b	100	95
M.9T337	75	88	38ab	88ab	100	100	88b	100	100	100	88b	100	89
PI Au 51-4	--	100	100b	100b	100	100	100b	100	100	100	88b	100	--
CG.5179	--	--	88	--	--	88	--	--	88	--	--	--	--
CG.6210	--	88	71	--	--	88	--	100	100	100	88	--	--
JM.1	--	43	88	--	--	100	--	100	100	83	67	--	--
JM.10	--	--	75	--	--	100	--	--	100	--	--	--	--
JM.2	--	88	88	--	--	100	--	100	100	100	100	--	--
JM.4	--	--	88	--	--	100	--	--	100	--	--	--	--
JM.5	--	--	38	--	--	100	--	--	100	--	--	--	--
JM.7	--	71	71	--	--	100	--	88	100	88	71	--	--
JM.8	--	50	71	--	--	100	--	100	100	100	100	--	--
J-TE-G	--	88	86	--	--	100	--	100	100	100	100	--	--
PI Au 36-2	--	--	67	--	--	100	--	--	100	--	--	--	--
PI Au 51-11	--	100	75	--	--	100	--	100	100	100	43	--	--
Mean ^z	70	94	59	84	96	100	84	100	99	98	81	100	8.9
P-value ^y	.343	.148	.001	.002	.950	1.00	.003	.957	.998	.998	.001	1.00	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.

^y P-values were generated with the Slice option to test the hypothesis that all core rootstocks at a given location were equal.

Table 3. Trunk cross-sectional area (cm²) of 'Golden Delicious' trees on various rootstocks at 12 locations after five years.^z

Stock	AR	BC	CA	CHIH	GA	IA	KY	ME	NY	PA	UT	WI	Mean
B.62396	21.3b	20.1a	14.2ab	28.0ab	33.4b	24.5ab	43.7b	20.4ab	18.7a	24.2a	27.2ab	28.0a	25.3
B.9	10.5a	10.6a	5.7a	10.2a	14.8a	10.9a	11.9a	11.6a	9.3a	15.8a	13.2a	14.3a	11.5
CG.3041	25.6b	19.9a	25.1bc	28.8b	23.1ab	18.2a	39.1b	16.9a	15.8a	18.3a	24.2ab	21.6a	23.1
CG.5935	27.0bc	25.6a	42.2c	21.3ab	34.2b	28.1b	42.8b	26.4ab	18.6a	23.0a	33.2b	25.9a	29.0
G.16	33.6c	20.4a	42.4c	25.0ab	33.5b	20.6a	42.7b	18.3a	16.1a	23.1a	27.2ab	22.4a	27.2
J-TE-H	32.2c	26.5a	33.8c	37.9bc	30.5a	28.2b	49.6b	18.8a	23.8a	30.7a	37.7b	27.9a	31.5
M.26	32.5c	23.5a	40.6c	28.9b	31.1b	25.5ab	44.8b	17.7a	19.7a	29.6a	40.5b	35.1b	30.8
M.9 Pajam2	33.0c	18.4a	28.2b	20.5ab	24.5a	21.8a	53.4b	16.4a	21.0a	29.1a	32.6b	29.9a	27.4
PI Au 56-83	61.8d	62.5b	120.6d	68.5d	61.1c	47.8c	108.7c	34.0b	40.5b	58.8b	83.8c	56.6b	67.1
M.9T337	28.6bc	15.7a	22.1b	16.8ab	23.0ab	21.4a	42.6b	13.2a	15.4a	23.5a	29.3b	24.9a	22.9
PI Au 51-4	--	53.0b	126.0d	55.6cd	70.0c	48.6c	96.8c	23.4ab	41.3b	55.9b	79.8c	50.4b	--
CG.5179	--	--	28.4	--	--	24.1	--	--	19.9	--	--	--	--
CG.6210	--	26.7	75.9	--	--	32.1	--	26.3	30.1	33.8	39.8	--	--
JM.1	--	7.1	58.2	--	--	20.5	--	21.3	25.9	29.5	37.1	--	--
JM.10	--	--	98.7	--	--	22.9	--	--	22.1	--	--	--	--
JM.2	--	55.4	124.9	--	--	45.6	--	31.3	45.5	61.6	69.6	--	--
JM.4	--	--	87.4	--	--	30.6	--	--	29.8	--	--	--	--
JM.5	--	--	114.2	--	--	46.4	--	--	46.1	--	--	--	--
JM.7	--	23.9	58.6	--	--	24.8	--	22.6	20.1	29.2	38.6	--	--
JM.8	--	23.0	59.8	--	--	29.4	--	25.0	24.6	47.7	62.6	--	--
J-TE-G	--	6.4	6.0	--	--	10.7	--	7.2	5.6	12.8	12.7	--	--
PI Au 36-2	--	--	95.6	--	--	46.1	--	--	41.0	--	--	--	--
PI Au 51-11	--	24.2	44.7	--	--	29.1	--	16.3	29.4	32.6	70.3	--	--
Mean ^z	30.6	24.3	37.4	28.5	30.9	24.7	48.0	19.4	19.8	27.6	34.9	28.6	29.6
P-value ^y	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.
^y P-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

rootstocks, CG.5179, JM.1, JM.10, JM.7, and Pi Au51-11 were similar to M.26 EMLA; and Pi Au51-4, CG.6210, JM.2, JM.4, JM.5, JM.8 and Pi Au36-2 were more vigorous than M.26 EMLA. In another trial, where several JM rootstocks were planted in NY (1), JM.2 was 50% larger than M.26 EMLA, whereas JM.1 and JM.7 were about 30% larger than M.26 EMLA, and results were similar in the current trial except that JM.7 was similar in size to M.26 EMLA.

Canopy size. Tree height and spread were reported for only seven locations in 2007. These data must be evaluated cautiously because pruning can have a great impact on canopy size. In general, trees on B.9 had the smallest canopy and trees on Pi Au56-83 had

the largest canopy (Tables 4 and 5). Trees in NY had the smallest canopies and trees in KY had the largest canopies. Of the rootstocks not distributed to all locations, J-TE-G generally had canopies smaller than B.9, whereas Pi Au51-4 had canopies larger than Pi Au56-83. Trees on CG.6210 had canopies similar to or slightly larger than M.26 EMLA.

Root suckers. Rootstock influenced root sucker production at five of the eight locations reporting data (Table 6). Trees at UT produced the most root suckers, whereas trees at GA produced the fewest. Averaged over all locations, trees on B.62396, CG.3041, J-TE-H, M.26 EMLA, and Pi Au56-83 produced less than 1.0 sucker per tree, and CG.5935, M.9 Pajam2 and M.9 T337 averaged more than 3 root suckers

Table 4. Tree height (cm) of ‘Golden Delicious’ on various rootstocks after five years.^z

Stock	BC	GA	IA	KY	NY	PA	UT	Mean
B.62396	300ab	290c	329bc	308abc	254ab	299a	291b	296
B.9	260a	251a	252a	254a	209a	283a	230a	249
CG.3041	283ab	267ab	288ab	319bc	249ab	282a	277ab	281
CG.5935	311ab	304c	317b	306abc	265b	296ab	329b	304
G.16	302ab	283bc	280ab	280ab	224ab	282a	284ab	277
J-TE-H	302ab	292c	317b	344c	260ab	313ab	351b	312
M.26	316b	314d	324bc	335bc	266b	344bc	335b	320
M.9 Pajam2	294ab	270bc	308b	335bc	256ab	321ab	325b	301
Pi Au 56-83	413c	337d	391c	443d	331c	404c	485c	401
M.9T337	284ab	293c	293a	314abc	244ab	318ab	312b	294
Pi Au 51-4	408c	401e	382c	410d	331c	383bc	478c	--
CG.5179	--	--	300	--	292	--	--	--
CG.6210	314	--	353	--	300	322	306	--
JM.1	189	--	275	--	270	320	324	--
JM.10	--	--	313	--	278	--	--	--
JM.2	399	--	393	--	324	381	411	--
JM.4	--	--	327	--	291	--	--	--
JM.5	--	--	364	--	324	--	--	--
JM.7	302	--	289	--	252	327	295	--
JM.8	293	--	345	--	265	366	412	--
J-TE-G	184	--	240	--	174	244	240	--
Pi Au 36-2	--	--	392	--	327	--	--	--
Pi Au 51-11	299	--	314	--	294	321	454	--
Mean ^z	307	290	310	332	256	314	322	303
<i>P-value</i> ^y	.001	.001	.001	--	.001	.001	.001	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.

^y *P*-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

Table 5. Canopy spread (cm) of 'Golden Delicious' trees after five years at as influenced by rootstock and location.²

Stock	BC	GA	IA	KY	NY	PA	UT	Mean
B.62396	201ab	228a	221ab	258ab	99a	245ab	212a	209
B.9	158a	211a	186a	204a	91a	227ab	190a	181
CG.3041	217b	231a	202ab	259ab	98a	220a	234a	209
CG.5935	245bc	287b	255bc	280b	110a	251a	256ab	241
G.16	203 a	260ab	208ab	243ab	90a	247a	223a	211
J-TE-H	241b	271b	263c	295b	128b	258a	249ab	244
M.26	223bc	232a	230abc	263ab	110ab	258a	231a	221
M.9 Pajam2	191ab	225a	218ab	271ab	107a	261ab	227a	214
Pi Au 56-83	273c	290b	275c	306b	128b	320b	307c	271
M.9T337	189a	229a	213ab	257ab	107a	244a	227a	209
Pi Au 51-4	254bc	302b	262c	281b	121b	288b	289bc	--
CG.5179	--	--	230	--	117	--	--	--
CG.6210	229	--	257	--	125	267	252	--
JM.1	100	--	214	--	89	240	209	--
JM.10	--	--	191	--	97	--	--	--
JM.2	282	--	274	--	99	271	262	--
JM.4	--	--	208	--	98	--	--	--
JM.5	--	--	254	--	113	--	--	--
JM.7	214	--	231	--	112	259	234	--
JM.8	230	--	253	--	126	272	259	--
J-TE-G	122	--	169	--	63	208	181	--
Pi Au 36-2	--	--	299	--	134	--	--	--
Pi Au 51-11	196	--	225	--	109	241	279	--
Mean ²	214	246	227	264	107	253	235	221
<i>P-value</i> ³	.001	.001	.001	.001	.033	.001	.001	--

² Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.

³ *P*-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

per tree. Trees on GC.5935 produced 31.8 root suckers per tree at UT, and less than 4 root suckers per tree at other locations. The strong rootstock x location interaction observed in this trial was observed in previous rootstock trials. For example, in a previous trial, trees on Mark produced 65 root suckers per tree in IL, but only 6 root suckers per tree in BC, and trees on P.16 produced 64 root suckers per tree in PA at the Rock Springs site and only 5 root suckers per tree in PA at the Biglerville site (6). Apparently root sucker development is related to soil type, environmental conditions, or possibly orchard practices, and additional research is needed to determine the factors involved in root sucker development.

Cumulative yield. Lowest yields were reported for trees on B.9 and highest yields were reported for CG.5935 (Table 7). Low yields were reported at AR due to frost injury and IA had frost in 2005, but CA also had low yields due to light cropping in 2005 and 2006. Locations with high yields included BC, KY, PA, UT, and WI. Although CG.5935 and M.26 EMLA had similar vigor, CG.5935 had higher cumulative yield in 11 of the 12 locations; averaged over all locations, cumulative yield was about 40% greater for CG.5935 than for M.26 EMLA. Yield was inconsistent for trees on Pi Au56-83. The new rootstocks, B.62396 and CG.3041 were considered in the same size class as M.9 NAKBT337, but

Table 6. Number of root suckers per tree for ‘Golden Delicious’ trees in the fifth year as influenced by rootstock and location.^z

Stock	BC	CHIH	GA	IA	KY	NY	PA	UT	WI	Mean
B.62396	0.6ab	0.0a	0.0	0.1a	0.0	0.1	0.1a	0.0a	0.1a	0.1
B.9	2.1bc	0.2a	0.0	2.4ab	1.2	0.5	0.1a	5.1a	1.0a	1.4
CG.3041	0.1a	0.0a	0.0	0.0a	0.1	0.0	3.2b	1.5a	0.0a	0.6
CG.5935	0.9ab	2.3ab	1.5	1.1a	0.6	0.9	0.0a	31.8c	3.7b	4.3
G.16	2.8c	4.4b	0.0	0.4a	0.0	0.4	0.1a	2.8a	0.0a	1.3
J-TE-H	1.4abc	0.0a	0.0	0.2a	0.5	0.5	0.0a	0.5a	0.1a	0.4
M.26	0.9ab	0.0a	0.0	0.2a	0.0	1.0	0.2a	2.7a	0.4a	0.6
M.9 Pajam2	2.5c	0.1a	0.8	4.4b	1.4	0.4	0.6ab	19.5b	1.6ab	3.6
Pi Au 56-83	0.1a	0.2a	0.0	0.0a	0.2	0.1	0.5ab	2.6a	0.0a	0.4
M.9T337	2.6c	0.1a	0.0	3.6b	2.1	0.6	0.9ab	15.5b	1.0a	3.1
Pi Au 51-4	0.4	12.1	0.6	0.0	0.0	0.3	0.2	1.2a	0.0	1.8
CG.5179	--	--	--	1.3	--	2.5	--	--	--	--
CG.6210	0.5	--	--	1.8	--	0.7	0.0	14.5	--	--
JM.1	0.1	--	--	0.6	--	0.2	0.3	0.0	--	--
JM.10	--	--	--	0.0	--	0.0	--	--	--	--
JM.2	0.5	--	--	2.1	--	0.0	0.6	8.6	--	--
JM.4	--	--	--	0.2	--	0.0	--	--	--	--
JM.5	--	--	--	0.1	--	1.2	--	--	--	--
JM.7	0.4	--	--	0.0	--	0.1	0.0	1.3	--	--
JM.8	2.0	--	--	0.4	--	0.3	0.0	1.3	--	--
J-TE-G	0.0	--	--	0.0	--	0.0	0.0	0.0	--	--
Pi Au 36-2	--	--	--	0.0	--	0.0	--	--	--	--
Pi Au 51-11	4.3	--	--	16.1	--	0.9	0.0	2.2	--	--
Mean ^z	1.4	0.8	0.2	1.2	0.6	0.5	0.6	8.2	0.8	1.6
<i>P-value</i> ^y	0.054	0.002	0.863	0.001	0.486	0.993	0.044	0.001	0.008	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.

^y P-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

cumulative yield averaged over all locations was about 10% higher than cumulative yield for M9. NAKBT337. Of the rootstocks tested at only a few locations, only J-TE-G was in the B.9 vigor class and the two rootstocks had similar yields at most locations. Rootstocks in the M.26 vigor class included CG.5179, JM.1, JM.10, JM.7, and Pi Au51-11, but only JM.7 and CG.5179 had consistently higher yields than M.26 EMLA. Pi Au51-4, CG.6210, JM.2, JM.4, JM.5, JM.8 and Pi Au36-2 were more vigorous than M.26 EMLA and trees on JM.4 and JM.5 tended to have lower yields than M.26 EMLA. Trees on Pi Au51-4 and CG.6210 had higher yields than M.26 EMLA.

Trees on CG.6210 averaged nearly 50% more yield than trees on M.26 EMLA. In another trial after five years in NY (1), trees on JM.1, JM.2 and JM.7 all had yields at least twice as high as M.26 EMLA and in BC JM.2 and JM.7 had yields nearly 20% higher than trees on M.26 EMLA. Trees on Pi Au51-11, Pi Au51-4 and Pi Au56-83 in NY all had yields similar to those on M.26 EMLA (1). CA tended to be unique because many rootstocks with high yield in CA had relatively low yield in other locations and rootstocks with low yield in CA tended to have relatively high yield in other locations. However, CG.6210 out-yielded M.26 EMLA in all locations, possibly because

Table 7. Cumulative yield (kg) of surviving trees 'Golden Delicious' trees after five years as influenced by rootstock at 12 locations.^z

Stock	AR	BC	CA	CHIH	GA	IA	KY	ME	NY	PA	UT	WI	Mean
B.62396	5.7	49.6abc	7.0a	24.4ab	22.4ab	20.4a	48.2b	28.1ab	38.0ab	54.3b	50.8b	53.5ab	33.5
B.9	5.3	30.2a	1.7a	9.4a	9.2a	13.3a	12.6a	12.5a	26.4a	31.5a	24.0a	33.3a	17.4
CG.3041	7.2	52.9bc	11.1a	26.1b	14.6a	20.3a	40.8b	26.0ab	42.1b	45.3ab	58.9b	51.1ab	33.0
CG.5935	7.5	63.4c	12.8a	25.4a	32.2b	35.2b	59.5b	41.4b	40.8ab	55.8b	63.5b	64.5b	41.8
G.16	9.2	43.7ab	20.4ab	24.6ab	19.2a	24.2ab	38.7ab	26.2a	29.8ab	51.7b	50.1b	41.7a	31.7
J-TE-H	6.6	47.1abc	11.4a	19.3a	19.8a	24.9ab	57.6b	21.9a	43.5b	51.0b	70.0	44.2a	34.8
M.26	2.7	44.6ab	10.5a	25.9b	13.1a	20.0a	33.0a	21.8a	37.3ab	39.5a	57.7b	46.8ab	29.5
M.9 Pajam2	6.0	43.7ab	11.4a	17.8a	11.2a	22.1a	40.0ab	22.2a	39.9ab	51.3b	62.3b	46.5	31.2
PIAu 56-83	5.9	41.0ab	28.3b	12.5a	21.5ab	7.0a	63.3c	26.3ab	30.9b	62.2b	76.6	33.4a	36.6
M.9T337	5.6	40.6ab	12.1a	15.4a	13.5a	21.6a	39.4b	18.1a	32.2ab	45.0ab	62.4b	52.1ab	30.0
PIAu 51-4	--	50.8	28.2	10.3	19.8	18.3	51.8	19.9	42.1	72.2	96.1	41.7	--
CG.5179	--	--	14.5	--	--	21.1	--	--	37.9	--	--	--	--
CG.6210	--	57.4	19.6	--	--	29.6	--	35.0	62.7	70.6	69.6	--	--
JM.1	--	19.4	9.1	--	--	15.8	--	21.1	13.1	45.5	46.0	--	--
JM.10	--	--	15.4	--	--	9.4	--	--	22.1	--	--	--	--
JM.2	--	49.0	23.7	--	--	28.2	--	29.6	15.0	35.5	48.0	--	--
JM.4	--	--	13.7	--	--	8.7	--	--	19.3	--	--	--	--
JM.5	--	--	24.8	--	--	4.7	--	--	30.5	--	--	--	--
JM.7	--	42.8	8.5	--	--	15.1	--	21.6	43.5	58.7	73.0	--	--
JM.8	--	51.4	9.1	--	--	24.9	--	21.3	40.6	46.8	47.8	--	--
J-TE-G	--	22.6	3.1	--	--	14.0	--	15.5	15.8	33.0	29.4	--	--
PIAu 36-2	--	--	12.1	--	--	14.9	--	--	49.3	--	--	--	--
PIAu 51-11	--	38.8	9.3	--	--	19.2	--	17.4	33.3	40.0	77.1	--	--
Mean ^z	11.8	45.7	12.7	20.1	17.7	21.0	43.4	24.4	36.0	48.7	57.6	46.7	31.4
P-value ^y	.980	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.
^y P-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

Table 8. Cumulative yield efficiency (kg·cm⁻²) of surviving 'Golden Delicious' trees after five years at as influenced by rootstock at 12 locations.^z

Stock	AR	BC	CA	CHIH	GA	IA	KY	ME	NY	PA	UT	WI	Mean
B:62396	0.27	2.52bc	0.43	0.20	0.65ab	0.84a	1.11ab	1.37ab	2.02b	2.24cd	1.60b	1.97c	1.27
B:9	0.46	3.03c	0.34	0.11	0.63ab	1.24b	0.92ab	1.08ab	2.82d	2.06b	1.84b	2.33cd	1.41
CG:3041	0.27	2.64bc	0.44	0.24	0.61ab	1.13ab	0.89ab	1.53b	2.69d	2.50d	2.10c	2.37d	1.45
CG:5935	0.27	2.51b	0.31	0.26	0.90b	1.25b	1.18b	1.62b	2.22c	2.41d	1.96bc	2.49d	1.45
G:16	0.29	2.18b	0.48	0.20	0.57ab	1.20ab	0.84ab	1.37ab	1.88b	2.25cd	1.86bc	1.88b	1.25
J-TE-H	0.23	1.87b	0.35	0.12	0.65ab	0.91ab	1.17b	1.17ab	1.80b	1.68b	1.86bc	1.58b	1.12
M:26	0.06	1.94b	0.04	0.20	0.38a	0.80a	0.70ab	1.21ab	1.91b	1.35a	1.15a	1.33b	0.92
M:9 Pajam2	0.23	2.42b	0.12	0.16	0.45ab	1.01ab	0.73ab	1.37ab	1.96bc	1.77b	1.58b	1.54b	1.11
PIAu 56-83	0.11	0.69a	0.16	0.06	0.37a	1.01a	0.58a	0.76a	0.77a	1.05a	0.92a	0.57a	--
M:9T337	0.42	2.35b	0.25	0.16	0.52ab	1.05ab	0.81ab	1.38ab	2.14c	1.94bc	2.06bc	2.18c	1.27
PIAu 51-4	--	0.94	0.22	0.06	0.29	0.37	0.55	0.85	1.03	1.29	1.30	0.82	--
CG:5179	--	--	0.53	--	--	0.88	--	--	1.77	--	--	--	--
CG:6210	--	2.21	0.27	--	--	0.94	--	1.32	2.10	2.14	1.65	--	--
JM:1	--	1.80	0.29	--	--	0.78	--	1.15	0.67	1.72	1.40	--	--
JM:10	--	--	0.15	--	--	0.40	--	--	1.02	--	--	--	--
JM:2	--	0.77	0.19	--	--	0.62	--	0.78	0.33	0.58	0.73	--	--
JM:4	--	--	0.15	--	--	0.29	--	--	0.99	--	--	--	--
JM:5	--	--	0.28	--	--	0.11	--	--	0.68	--	--	--	--
JM:7	--	1.81	0.19	--	--	0.61	--	1.02	2.16	2.01	1.73	--	--
JM:8	--	1.41	0.32	--	--	0.86	--	0.89	1.97	1.14	1.00	--	--
J-TE-G	--	3.60	0.38	--	--	1.34	--	1.87	2.85	2.60	1.40	--	--
PIAu 36-2	--	--	0.13	--	--	0.34	--	--	1.23	--	--	--	--
PIAu 51-11	--	1.67	0.18	--	--	0.67	--	1.07	1.16	1.23	0.90	--	--
Mean ^z	0.28	2.2	0.3	0.2	0.57	0.96	0.89	1.29	2.02	1.93	1.69	1.83	1.25
<i>P-value</i> ^y	0.489	0.001	0.136	0.982	0.034	0.001	0.001	0.001	0.001	0.001	0.001	0.001	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.
^y P-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

the trees were relatively large.

Cumulative yield efficiency. Cumulative yield efficiency (YE) was significantly affected by rootstock in nine locations, but not in AR, CA, and CHIH and all three of those locations reported low YEs (less than $0.4 \text{ kg}\cdot\text{cm}^{-2}$ TCA) (Table 8). YE exceeded $2.0 \text{ kg}\cdot\text{cm}^{-2}$ TCA in BC and NY. When averaged over all locations, trees on M.26 EMLA had the lowest YE (0.92) and B.9, CG.3041, and CG.5935 had $\text{YE} > 1.4$. Compared to M.9 NAKBT337, trees on B.62396 had similar YE, and in all locations trees on CG.3041 had higher YE than trees on M.9 NAKBT337. Of the core group of rootstocks, Pi Au56-83 was the most vigorous and had the lowest YE at half of the locations. Of the rootstocks not included in all locations, those generally inducing lower YE than M.26 EMLA included Pi Au51-4, JM.10, JM.2, JM.4, JM.5, Pi Au36-2, and Pi Au51-1; only CG.6210 induced higher YE than M.26 EMLA in most locations. Trees on J-TE-G had higher YE than B.9 at most locations. In another trial, YE in NY, but not BC, was higher for JM.1, JM.2, and JM.7 than for M.26 EMLA, but YE was slightly lower for Pi Au51-11, Pi Au56-83 and Pi Au56-83 (1).

Burrknots. Only six locations reported burrknot data (BC, GA, IA, KY, PA, and UT), and at only three of those locations (BC, IA, and UT) did rootstock significantly affect burrknot development (data not shown). In general, burrknot development was low. About 5 to 10% of the rootstock circumference was covered with burrknots at BC, IA, and UT, whereas no burrknots were reported for GA, KY, and PA. Rootstocks with the greatest incidence of burrknots included B.9, B.62396, and M.26 EMLA, whereas rootstocks with little burrknotting included CG.3041, CG.5935, Pi Au56-83, and Pi Au51-4. In an earlier NC-140 trial, the severity of burrknotting depended on the combination of rootstock and location (8, 10). Of the core rootstocks, Pi Au51-11 had a very high incidence of burrknots at IA and at BC, but a low incidence at PA and UT.

Fruit size. Fruit weight (FW) was significantly affected by the interaction of rootstock and location (Table 9). In previous trials, FW

was influenced by the interaction of crop density, rootstock and location (8, 9) and variances for locations were also unequal. Therefore, to properly adjust FW for crop density will likely require fitting a factorial model with unequal variances and unequal slopes. Such an analysis is beyond the scope of this paper, and the influence of rootstock on FW in this trial will be addressed in a separate paper when the trial is terminated after the 2012 season. Nonadjusted FW values are presented in Table 9 to provide an indication of how FW was affected by location and rootstock. Rootstock did not significantly affect FW in BC, IA, PA, and WI. In general, FW was low in AR, CA, CHIH, IA, ME, and NY, whereas FW was high in BC and UT. Rootstocks with low FW included G.16 and B.9, whereas trees on J-TE-H and Pi Au56-83 produced fruit with the highest FW, and results were fairly consistent across locations. High FW for Pi Au56-83 might be expected because these trees also had relatively low YE. However, CG.3041 and CG.5935 had high YE and still produced moderate FW. Another factor that may have influenced FW is how and when crop load was managed at the different locations because cooperators were instructed to follow local tree management recommendations.

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Table 9. Fruit weight (g), averaged over all cropping years (2005, 2006, and 2007) for surviving 'Golden Delicious' trees after five years as influenced by rootstock at 12 locations.^z

Stock	AR	BC	CA	CHIH	GA	IA	KY	ME	NY	PA	UT	WI	Mean
B.62396	90b	254	144ac	146ab	151ab	153	200b	159ab	154ab	167	222ab	185	169
B.9	80abc	240	121a	134a	161ab	152	163a	175b	147ab	165	198a	190	161
CG.3041	112c	256	140ac	153b	159ab	148	197ab	139a	151ab	164	226ab	181	169
CG.5935	108c	241	149ac	146ab	149ab	151	180ab	135a	133a	162	219ab	183	163
G.16	97bc	250	143ac	142ab	155ab	136	167a	139a	133a	159	210ab	181	159
J-TE-H	100c	242	150ac	135ab	164b	153	185ab	168ab	157b	177	236b	185	171
M.26	73a	238	151ac	143ab	140a	147	173ab	163ab	143ab	164	230ab	179	162
M.9 Pajam2	99b	247	176b	130ab	150ab	152	182ab	155ab	151ab	167	225ab	186	168
PI Au 56-83	96b	235	186bc	157b	161ab	151	201b	163ab	148ab	163	242b	186	174
M.9T337	116c	247	150a	122a	138a	151	174ab	163ab	148ab	168	234b	184	166
PI Au 51-4	--	251	187bc	118a	155ab	146	196ab	170ab	149ab	165	241b	184	--
CG.5179	--	--	147	--	--	148	--	--	123	--	--	--	--
CG.6210	--	250	160	--	--	157	--	133	141	168	221	--	--
JM.1	--	233	174	--	--	145	--	155	131	161	227	--	--
JM.10	--	--	174	--	--	136	--	--	144	--	--	--	--
JM.2	--	258	176	--	--	150	--	158	145	157	226	--	--
JM.4	--	--	164	--	--	131	--	--	154	--	--	--	--
JM.5	--	--	172	--	--	132	--	--	150	--	--	--	--
JM.7	--	257	157	--	--	148	--	133	160	168	232	--	--
JM.8	--	246	157	--	--	153	--	162	162	160	224	--	--
J-TE-G	--	254	135	--	--	155	--	179	153	168	234	--	--
PI Au 36-2	--	--	196	--	--	146	--	--	170	--	--	--	--
PI Au 51-11	--	242	140	--	--	157	--	173	154	167	230	--	--
Mean	97	245	151	141	153	149	182	156	147	166	224	184	166
P-value ^y	.001	.243	.001	.001	.055	.243	.001	.001	.001	.949	.001	.989	--

^z Least squares means within columns for the core group of 11 rootstocks were compared with the Simulate method at the 10% level of significance.

^y P-values were generated with the Slice option to test the hypothesis that all rootstocks at a given location were equal.

Literature Cited

1. Autio, W., T. Robinson, W. Cowgill, C. Hampson, M. Kushad, J. Masabni, R. Quezada, R. Perry and C. Rom. 2008. Performance of 'Gala' apple on Supporter 4, P.14, and different strains of B.9, M.9, and M.26 rootstocks: a five-year report on the 2002 NC-140 apple rootstock trial. *J. Amer. Pomol. Soc.* 62:119-128.
2. Fischer, M. 1997. The Pillnitz apple rootstock breeding program and selection results. *Acta Hort.* 451:89-97.
3. Hinkelmann, K. and O. Kempthorne. 2008. Design and analysis of experiments. Vol. I. Introduction to experimental design. 2nd Ed. John Wiley and Sons, New York.
4. Kosina, J. 2002. Evaluation of some dwarf apple rootstocks. *Hort Sci. (Prague)*. 29:23-25.
5. Littell, R.C., G.A. Milliken, W.W. Stroup, R.D. Wolfinger, and O. Schabenberger. 2006. SAS for mixed models, second edition. SAS Institute, Cary, NC.
6. Marini, R.P., J.L. Anderson, W.R. Autio, B.H. Barritt, J. Cline, W.P. Cowgill, Jr., R.C. Crassweller, R.M. Garner, A. Gauss, R. Godin, G.M. Greene, C. Hampson, P. Hirst, M.M. Kushad, J. Masabni, E. Mielke, R. Moran, C.A. Mullins, M. Parker, R.L. Perry, J.P. Privé, G.L. Reighard, T. Robinson, C.R. Rom, T. Roper, J.R. Schupp, E. Stover, and R. Unrath. 2006. Performance of 'Gala' apple trees on 18 dwarfing rootstocks: ten-year summary of the 1994 NC-140 rootstock trial. *J. Amer. Pomol. Soc.* 60:69-83.
7. Marini, R.P., J.A. Barden, J. Cline, R.L. Perry and T. Robinson. 2002. Effect of apple rootstocks on average fruit weight at four locations after adjusting for crop load. *J. Amer. Soc. Hort. Sci.* 127:749-753.
8. Marini, R.P., M.L. Parker, J.A. Barden, and C.R. Unrath. 2003. The effect of eight dwarf rootstocks on burrknot development on 'Gala' apple trees at two locations. *J. Amer. Pom. Soc.* 57:93-96.
9. Marini, R.P. and J.A. Barden. 2004. Yield, fruit size, red color, and a partial economic analysis for 'Delicious' and 'Empire' in the NC-140 1994 systems trial in Virginia. *J. Amer. Pomol. Soc.* 58: 4-11.
10. Marini, R.P., R. Moran, C. Hampson, M. Kushad, J. Masabni, R. Parra Quesada, R. Perry and C. Rom. 2008. Effect of dwarfing apple rootstocks on average 'Gala' fruit weight at six locations over three seasons. *J. Amer. Pomol. Soc.* 62:129-136.
11. Soejima, J., H. Bessho, S. Komori and S. Tsuchiya. 1998. New apple rootstocks ARM1, ARM7 and ARM8. *Acta Hort.* 484:217-220.
12. Soejima, J., K. Abe, N. Kotoda and H. Kato. 2000. Recent progress of apple breeding at the apple research center in Morioka. *Acta Hort.* 538:211-213.
13. Webster, A.D. 1997. A review of fruit tree rootstock research and development. *Acta Hort.* 451:53-74.
14. Webster, A.D. and S.J. Wertheim. 2002. Apple rootstocks. Pp. 91 -124. In: D.C. Ferree and I.J. Warrington (eds.) *Apple: botany, production, and uses*. CABI Publishing, Cambridge, Mass.



The Role of Pistil Quality in Fruit Set

Researchers in Spain are studying the role of pistil features in fruit set of apricot. Under the same pollination conditions, the flowers that ultimately set a fruit had larger stigmatic area, more pollen grains, and more pollen tubes growing along the style and xylem vessels surrounding the transmitting tissue than flowers that abscised before fruit set. In addition, starch was present in the transmitting tissue of the style in all the flowers that developed into fruits, but only in half of the flowers that abscised. They suggest that the capacity of a flower to become a fruit could be preconditioned at anthesis. See Rodrigo et al. 2009. *Annals of Applied Biology* 154(3):365-375.