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

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Abstract

Dwarf apple (*Malus spp.*) rootstocks with 'Golden Delicious' as the scion cultivar were evaluated at eight locations in North America for 10 years. A core of 11 rootstocks was evaluated at all locations. Core rootstocks included four industry standards (B.9, M.9 NAKBT337, M.26 EMLA, and M.9 Pajam 2), along with B.10 (formerly called B.62396) from Russia, G.16, G.41, and G.935 from Cornell-Geneva, J-TE-H from the Czech Republic, and PiAu 51-4 and PiAu 56-83 from Germany. Some locations also received CG.5179 and G.210 (Cornell-Geneva), JM. 1, 2, 4, 5, 7, 8, and 10 (Japan-Morioka), J-TE-G (Czech), and PiAu 36-2 or PiAu 51-11 (Germany). B.9 was less vigorous than M.9 NAKBT337 and J-TE-G was less vigorous than B.9. J-TE-G was too dwarfing for most commercial situations. Rootstocks in the M.9 size class included G.16, G.41, G.935, CG.5179, G.210 (formerly known as CG.6210), JM.1 and B.10. All rootstocks in this size class had high yield efficiency (YE), and G.41 and G.935 may be candidates to replace M.9 because trees survived well and had high YE. Rootstocks in the M.26 size class included J-TE-H, G.210, JM.7, JM.8 and PiAu 51-11. J-TE-H was the only rootstock with 100% tree survival at all locations. Cumulative YE was similar for M.26 EMLA and JM.7, it was slightly higher for J-TE-H and it was highest for G.210. Due to exceptional tree survival and high YE, both J-TE-H and G.210 deserve further evaluation as potential replacements for M.26. Rootstocks more vigorous than M.26 included PiAu 51-4, PiAu 56-83, PiAu 36-2, JM.2, JM.4, JM.5, and JM.10. All of these vigorous rootstocks had lower YE than M.26 EMLA and are probably too vigorous for modern commercial apple orchards. Biennial bearing increased with increasing trunk cross-sectional area at three of the eight locations, so factors other than rootstock vigor also influenced annual cropping.

Rootstock is an important component of an apple orchard system because rootstock influences tree size, precocity, resistance to biotic and abiotic stresses (Webster and Wertheim, 2003), and fruit size (Marini et al., 2012). In recent years, the vertical axe system (or variations of it) has become the dominant training system in North America and M.9 is the most widely planted rootstock. There are at least 25 clones of M.9 and NAKBT337, from The Netherlands, is the most commonly planted. M.9 Pajam 1 and Pajam 2, from France, are sometimes preferred when a slightly more vigorous rootstock is desired. Although M.9 has many favorable characteristics, it has some problems, such as poor anchorage in the soil, propagation difficulty, winter injury, brittle roots, and susceptibility to fireblight [*Erwinia amylovora* (Burrill) Winslow et al.] and crown gall [*Agrobacterium tumefaciens* (E.F. Smith and Townsend)]. Therefore new dwarfing rootstocks without the shortcomings of M.9 are desirable.

Rootstocks from a number of rootstock breeding programs have been evaluated in the NC-140 project. The 2003 dwarf apple rootstock trial was established to evaluate new rootstocks from five programs. Budagovsky 10 (B.10) is from the breeding program at Michurinski College in Russia. Rootstocks in the Budagovsky program were selected

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for resistance to low temperature stress. Seven rootstocks in the JM series (JM.1, JM.2, JM. 4, JM. 5, JM.7, JM.8, and JM.10) from the Apple Research Center in Morioka, Japan 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* root and crown rot and woolly apple aphid [*Eriosoma lanigerum* (Hausmann)] (Soejima et al., 2000). Four rootstocks (PiAu 51-4, PiAu 56-83, PiAu 36-2 and PiAu 51-11) from the Pillnitz program at the Institut für Obstforschung Dresden-Pillnitz, Germany (Fischer, 1997) were open-pollinated selections and were selected for ease of rooting and were reported to have relatively high yield efficiency (Fischer, 1994, 1997). Two rootstocks (J-TE-H and J-TE-G) from Techobuzice, Czech Republic resulted from crosses of M.9 x 'Croncels' and M.9 x 'Anyzove', respectively (Kosina, 2004). Four new rootstocks (G.41, G.935, CG.5179 and G.210) from the Cornell-Geneva breeding program located in Geneva, NY, USA were selected for horticultural characteristics and resistance to fire blight. In field trials in New York, G.935 and G.41 were similar in size to M.9 but with higher yield efficiency and superior fire blight resistance (Russo et al. 2007).

Rootstock can alter gene expression patterns in apple scions (Jensen et al., 2003). Although Jensen et al. (2010) later reported that relatively few genes in the scion are regulated by rootstock, it is possible that rootstock may influence biennial bearing in apple. Rootstock influenced biennial bearing of 'Valencia' orange (El-Zeftawi and Thornton, 1975) and 'Clementine' mandarin (Georgiou, 2002) but not of 'Ellendale' mandarin (Smith et al., 2004). Hoblyn et al. (1936) developed the biennial bearing index (BI) to quantify biennial bearing. The index can have values from 0.0 (no alternate bearing) to 1.0 (complete alternate bearing; where BI = (year 1 yield – year 2 yield) / (year 1 yield + year 2 yield). Barritt et al. (1997) combined data from two apple rootstock trials with three cultivars in Washington to determine the relationship between trunk size and BI. For 'Golden Delicious' and 'Granny Smith', the incidence of biennial bearing increased as rootstock vigor increased, but for 'Redchief Delicious' biennial bearing declined as rootstock vigor increased. Forshey and Elfving (1989) and Jonkers (1979) reviewed the literature and concluded that, in general, there was a negative relationship between vegetative and reproductive growth in apple. The vigor range is relatively small in the present trial because only rootstocks that were thought to be dwarfing were included, but some of the CG selections have high yield efficiency (Marini et al., 2009) and biennial bearing is another important rootstock characteristic to evaluate for these new rootstocks.

After the first five years of the current trial, promising new rootstocks with very high yield efficiency included G.935, G.41, CG.5179, from the Cornell-Geneva program, and J-TE-G, from the Czech Republic (Marini et al., 2009). This report describes the performance of these rootstocks after 10 years.

Materials and Methods

'Golden Delicious' (Gibson strain) trees on dwarfing rootstocks were planted at 8 locations (Table 1) in the spring of 2003 and were trained to the vertical axis system. Trees were propagated at Treco Nursery, Woodburn, OR. The experimental design was a generalized randomized complete block design (Hinkelmann and Kempthorne, 2008) 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. For some rootstocks there were inadequate numbers of trees to plant two trees per rootstock in all blocks, so only one tree was planted in some blocks. Eleven rootstocks were tested at all locations and are referred to as the "core" group. An additional 7 or 12 rootstocks were planted at selected locations. Trees at all locations were fastened to a tree stake,

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

Location	Cooperator	Planting location	Irrigation	Site history
(BC) British Columbia	Cheryl Hampson	Summerland, Canada	Yes	Vacant several years after apples; fumigated
(IA) Iowa	Paul A. Domoto	Ames	Yes	Preceded by apples; not fumigated
(KY) Kentucky	Dwight Wolfe	Princeton	Yes	Preceded by fruit trees other than apple; not fumigated
(ME) Maine	Renae Moran	Monmouth	No	Vacant several years after apples; not fumigated
(NY) New York	Terence Robinson	Geneva	After 2006	Preceded by apples; fumigated
(PA) Pennsylvania	Robert Crassweller	Rock Springs	No	Preceded by apples, then 2 yrs cover crops, not fumigated
(UT) Utah	Brent Black	Kaysville	Yes	Virgin soil, never been planted in trees
(WI) Wisconsin	Matt Stasiak	Sturgeon Bay	No	Preceded by apples, then 1 yr in potatoes & 1 yr in Sudan grass

usually a 3.0 m-long conduit 5.85 to 19.05 mm in diameter, attached to two wires at heights of 2.7 and 1.2 m above ground.

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. Each fruiting year, excess cropping was minimized by hand-removal of fruit within six weeks after bloom to a maximum crop density of about 7 fruit·cm^{-2} TCA. 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 efficiency (YE) was calculated by dividing cumulative yield by TCA in 2012. Following harvest in 2012, the height and spread of each tree were recorded. During the fall of 2012 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. Yield data from the final five years of the trial were used to calculate biennial bearing index for the 2008-2009, 2009-2010, 2010-2011, and 2011-2012 seasons and averages were calculated.

Each winter the data were sent to the senior author for summarization and statistical analyses. Statistical analyses were performed with SAS's GLIMMIX Procedure (Littell et al., 2006), where block and trees within block were specified as random effects. The location x rootstock interaction was significant for all response variables, so the rootstock least squares means were compared at the 5% level of significance within each location using the "slicediff" option in the lsmeans statement.

Results

General. Most response variables were greatly influenced by both rootstock and location and the interaction was always highly significant. We have observed a strong rootstock x location interaction in all multi-location rootstock trials (Autio et al., 2013; Marini et al., 2006; Marini et al., 2009; Marini et al., 2012). The source of the interactions is not known, but may be due to differences in crop load, time of fruit thinning, soil moisture, soil type, or environmental factors. When averaged over all 11 rootstocks, TCA ranged from 58 cm^2 in BC to 124 cm^2 in KY (Table 2). When averaged over the eight locations, TCA ranged from 31 cm^2 for B.9 to 193 cm^2 for Pi Au 56-83. However, since the location by rootstock interaction was highly significant, it is difficult to make general statements about rootstock performance. For example, M.9 NAKBT337 and M.26 EMLA represent the range of vigor generally desired for most orchard situations and are usually considered to be in different size classes; M.26 EMLA had significantly greater TCA at all locations except at BC. When averaged over all eight locations, M.26 was 42% larger than M.9 NAKBT337 (Table 2). However, M.26 EMLA was 18% and 100% larger than M.9 NAKBT337 in NY and ME, respectively, so it was sometimes difficult to place some rootstocks into a size class, especially for non-core rootstocks that were grown at only two locations. Based on TCA, the rootstocks can be broadly classified into four vigor categories: those that were less vigorous than M.9 NAKBT337, those that were similar to M.9 NAKBT337, those that were similar to M.26 EMLA, and those that were more vigorous than M.26 EMLA. The results for other response variables will be presented by size classification for trees that survived for the duration of the trial.

Table 2. Trunk cross-sectional area (cm^2) of surviving 10-year-old 'Golden Delicious' trees on various rootstocks at eight locations.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Trunk cross-sectional area (cm^2)								
B.9	21.4 a	31.9 a	22.3 a	35.0 a	21.1 a	56.7 a	56.7 a	37.3 a	31.3
G.41	45.3 bc	65.7 c	92.1 bcd	48.1 abcd	44.8 bc	66.7 ab	66.7 b	51.0 ab	59.2
G.16	40.7 abc	63.3 b	104.2 de	51.6 abcd	34.2 ab	76.6 b	76.6 b	58.1 bcd	61.1
M.9 T337	33.4 ab	83.4 cd	92.6 bcd	34.1 a	45.6 b	92.4 cd	92.4 bc	72.7 c	67.7
B.10	35.7 ab	93.4 cd	86.9 bc	56.7 cde	45.4 bc	78.8 bc	65.9 b	74.2 d	67.2
G.935	50.4 bc	94.0 de	73.4 b	66.4 de	43.6 bc	77.7 bc	77.7 bc	65.4 cd	68.3
M.9 Pajam 2	38.4 abc	83.8 cde	126.9 f	41.3 abc	53.5 c	105.4 de	105.4 c	69.5 cd	78.0
J-TE-H	55.6 c	91.6 c	102.7 cde	62.1 de	63.6 d	112.9 ef	112.9 d	83.8 d	85.5
M.26	54.3 bc	99.9 e	117.2 e	69.9 e	53.9 c	125.4 f	125.4 d	112.7 e	96.1
PiAu51-4	128.5 d	206.7 f	252.4 g	91.7 f	143.8 e	189.6 g	189.6 e	154.1 f	176.9
PiAu 56-83	134.8 d	208.8 f	296.0 h	119.4 g	133.0 e	205.2 g	205.2 e	181.3 g	192.9
Mean	58.0	102.1	124.3	61.5	62.0	107.9	112.6	87.3	
	Non-core rootstocks								
CG.5179	---	84.2	---	---	50.6	---	---	---	
G.210	55.0	109.8	---	75.0	74.3	109.7	89.1	---	
JM.1	11.8	60.1	---	64.4	125.6	99.8	94.1	---	
JM.2	133.6	169.0	---	97.4	172.1	231.0	223.8	---	
JM.4	---	136.2	---	---	107.3	---	---	---	
JM.5	---	190.7	---	---	160.7	---	---	---	
JM.7	48.0	82.4	---	71.7	53.2	87.7	94.7	---	
JM.8	39.1	105.3	---	77.8	69.0	154.2	207.8	---	
JM.10	- --	114.2	---	---	84.5	---	- --	---	
J-TE-G	15.5	33.8	---	19.1	12.1	39.8	24.8	---	
PiAu36-2	---	183.3	---	---	134.3	---	---	---	
PiAu 51-11	50.3	95.0	---	58.4	70.4	129.2	238.8	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 3. Survival (%) of 'Golden Delicious' trees on various rootstocks at 12 locations after 10 years.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Survival (%)								
B.9	100 a	100	50 b	100	100	88	100 a	100	92
G.41	88 a	100	88 a	100	100	100	75 ab	100	98
G.16	62 b	100	50 b	88	88	88	88 a	100	88
M.9 T337	88 a	100	75 a	100	100	100	50 b	100	91
B.10	88 a	100	100 a	100	100	100	62 b	100	97
G.935	100 a	100	25 c	100	100	100	88 a	100	94
M.9 Pajam 2	100 a	100	88 a	100	100	100	12 c	100	91
J-TE-H	100 a	100	100 a	100	100	100	100 a	100	100
M.26	100 a	100	75 a	100	100	100	25 c	100	88
PiAu 51-4	100 a	100	100 a	100	100	100	88 a	100	99
PiAu 56-83	88 a	100	100 a	100	100	100	100 a	100	99
Mean	92	100	78	100	99	99	71	100	
	Non-core rootstocks								
CG.5179	---	100	---	---	88	---	---	---	
G.210	86	100	---	100	100	100	86	---	
JM.1	43	100	---	100	100	83	67	---	
JM.2	88	100	---	100	100	100	100	---	
JM.4	---	100	---	---	100	---	---	---	
JM.5	---	100	---	---	100	---	---	---	
JM.7	71	100	---	86	100	86	72	---	
JM.8	40	100	---	100	83	100	67	---	
JM.10	---	100	---	---	100	- --	- --	---	
J-TE-G	86	100	---	100	100	100	12	---	
PiAu 36-2	---	100	---	---	100	---	---	---	
PiAu 51-11	86	88	---	100	100	100	43	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 4. Tree height (cm) of 10-year-old 'Golden Delicious' trees on various rootstocks.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Tree height (cm)								
B.9	271 a	281 a	243 a	340 a	245 a	322 a	246 a	297 a	280
G.41	321 ab	338 b	355 b	381 abc	291 b	337 ab	338 b	362 bc	338
G.16	304 a	318 a	328 bc	333 a	248 a	322 a	321 b	308 ab	310
M.9 T337	285 ab	357 bc	334 bc	328 a	295 b	376 b	353 bc	368 c	337
B.10	302 ab	390 c	321 b	366 ab	296 b	356 ab	349 b	374 cd	344
G.935	331 b	375 c	309 b	423 bc	309 b	347 ab	375 bc	366 bc	353
M.9 Pajam 2	297 ab	363 bc	367 c	315 a	296 b	365 bc	361 b	360 b	340
J-TE-H	317 b	381 c	352 b	394 abc	313 b	382 b	416 c	390 c	367
M.26	324 b	396 c	366 c	398 bc	310 b	402 c	399 c	430 de	378
PiAu 51-4	405 c	475 d	459 d	435 cd	392 c	442 cd	508 d	448 e	446
PiAu 56-83	383 c	491 d	479 d	482 d	388 c	464 d	513 d	459 e	459
Mean	319	379	356	381	308	374	380	378	
	Non-core rootstocks								
CG.5179	---	370	---	---	335	---	---	---	
G.210	336	403	---	418	350	385	355	---	
JM.1	201	294	---	367	354	353	360	---	
JM.2	383	460	---	423	404	455	---	---	
JM.4	---	426	---	---	360	---	---	---	
JM.5	---	465	---	---	407	---	---	---	
JM.7	309	364	---	391	307	373	---	---	
JM.8	267	398	---	411	308	422	447	---	
JM.10	---	390	---	---	342	---	---	---	
J-TE-G	239	266	---	278	190	272	281	---	
PiAu 36-2	---	474	---	---	408	---	---	---	
PiAu 51-11	300	351	---	385	393	397	491	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Rootstocks less vigorous than M.9 NAKBT337. At all locations except BC and ME, TCA of trees on B.9 was half as large as for trees on M.9 NAKBT337 (Table 2) and at most locations tree survival was similar to M.9 NAKBT337 (Table 3). At two locations most trees on B.9 were shorter and narrower than trees on M.9 NAKBT337 (Tables 4 and 5). Trees on B.9 and M.9 NAKBT337 had similar numbers of root suckers (Table 6), but B.9 had more severe burrknots at most locations (Table 7). Cumulative yield was similar for trees on B.9 and M.9 NAKBT337 at three of the eight locations, but when averaged over all locations, yield was 84% higher for M.9 NAKBT337 (Table 8). Cumulative yield efficiency (YE) was generally similar for the two rootstocks (Table 9). At most locations average fruit weight (FW) was higher for trees on M.9 NAKBT337 and averaged over all locations the difference was 17 g (Table 10). In general, the biennial bearing index (BI) for trees on B.9 was similar to trees on M.9 NAKBT337 (Table 13). J-TE-G was tested at six locations and, depending on the location, the TCAs of trees on J-TE-G was 44 to 94% as large as trees on B.9 (Table 2). Trees on J-TE-G and B.9 had similar YE and BI (Tables 9 and 13), and FW was generally higher for B.9.

Rootstocks in the M.9 NAKBT337 size class. In general, rootstocks similar in vigor to M.9 NAKBT337 included G.41, G.16, B.10, G.935, and M.9 Pajam 2 (Table 2). At only PA and WI were trees on G.41 significantly smaller than M.9 NAKBT337 and at IA and PA, trees on G.16 were smaller than on M.9 NAKBT337. At only ME and WI were trees on B.10 larger than trees on M.9 NAKBT337 and only at ME were trees on G.935 larger than trees on M.9 NAKBT337. The non-core rootstocks in the M.9 NAKBT337 size class included CG.5179 and JM.1; for JM.1 there was considerable variation in TCA among sites.

Tree survival is an important rootstock characteristic and survival was generally

Table 5. Canopy spread (cm) of 10-year-old 'Golden Delicious' trees as influenced by various rootstocks.

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	**Mean**
					Canopy spread (cm)				
B.9	162 a	230 a	173 a	292 a	192 a	301 a	247 a	266 a	233
G.41	252 c	282 bc	272 b	295 ab	255 b	306 a	333 b	296 b	286
G.16	197 ab	269 b	285 b	292 ab	206 a	305 a	318 b	289 b	270
M.9 T337	193 ab	315 c	270 b	262 a	250 b	323 a	357 b	318 b	286
B.10	202 b	301 c	261 b	316 b	238 b	317 ab	322 b	310 b	283
G.935	245 c	302 c	244 b	375 c	262 b	323 abc	343 b	330 b	303
M.9 Pajam 2	208 b	305 c	294 b	298 bc	260 bc	336 bc	336 b	315 b	294
J-TE-H	245 c	316 c	274 b	312 b	290 c	347 bcd	356 b	319 b	307
M.26	232 bc	311 c	280 b	354 c	245 b	353 cd	356 b	347 b	310
PiAu 51-4	317 d	375 d	353 d	358 c	323 c	376 d	421 c	383 c	363
PiAu 56-83	332 d	387 d	366 d	388 c	320 c	410 e	436 c	409 c	381
Mean	235	309	279	322	258	336	347	325	
					Non-core rootstocks				
CG.5179	---	265	---	---	184	---	---	---	
G.210	242	285	---	336	198	297	314	---	
JM.1	112	239	---	304	196	277	263	---	
JM.2	332	305	---	353	208	329	317	---	
JM.4	---	266	---	---	195	---	---	---	
JM.5	---	300	---	---	215	---	---	---	
JM.7	230	269	---	336	188	285	294	---	
JM.8	183	280	---	375	197	310	472	---	
JM.10	---	246	---	---	193	---	---	---	
J-TE-G	158	207	---	233	113	242	196	---	
PiAu 36-2	---	336	---	---	237	---	---	---	
PiAu 51-11	226	251	---	312	185	288	351	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 6. Number of root suckers per tree for 'Golden Delicious' trees after 10 years as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Number of root suckers per tree								
B.9	11.8 b	7.6 b	1.4 a	4.6 a	0.6	9.4 b	13.2 b	3.1 a	6.5
G.41	1.4 a	0.0 a	0.0 a	0.1 a	0.0	0.4 a	2.7 a	0.4 a	0.6
G.16	7.0 ab	0.6 a	0.0 a	0.1 a	0.7	0.5 a	12.3 b	0.5 a	2.7
M.9 T337	3.8 a	4.9 b	1.3 a	0.0 a	0.6	4.6 a	19.4 b	1.9 a	5.0
B.10	1.7 a	0.2 a	0.0 a	0.0 a	0.4	3.5 a	4.6 a	0.1 a	1.2
G.935	12.0 b	1.5 ab	0.2 a	0.7 a	0.5	1.5 a	50.5 d	0.7 a	8.5
M.9 Pajam 2	7.1 a	3.0 ab	0.1 a	0.8 a	0.1	5.5 ab	40.9 c	4.0 a	8.0
J-TE-H	5.0 a	1.4 ab	0.9 a	0.1 a	0.1	0.0 a	4.0 a	0.5 a	1.5
M.26	1.0 a	0.2 a	0.0 a	0.1 a	0.2	0.4 a	0.1 a	0.1 a	0.4
PiAu 51-4	3.5 a	9.4 b	0.6 a	2.4 a	0.4	18.8 c	38.5 c	2.4 a	9.5
PiAu 56-83	1.7 a	1.5 ab	0.5 a	2.7 a	0.6	0.5 a	1.5 a	1.2 a	0.9
Mean	5.1	2.7	0.5	1.4	0.4	4.1	17.0	1.4	
	Non-core rootstocks								
CG5179	---	2.0	---	---	0.3	---	---	---	
G.210	16.4	6.1	---	16.5	0.4	27.4	51.1	---	
JM.1	1.0	0.0	---	0.1	0.3	0.0	0.0	---	
JM.2	1.3	2.5	---	2.8	0.7	5.3	18.9	---	
JM.4	---	0.0	---	---	0.1	---	---	---	
JM.5	---	0.2	---	---	2.1	---	---	---	
JM.7	0.8	0.0	---	0.0	0.0	1.0	---	---	
JM.8	2.9	2.3	---	0.5	0.8	0.9	16.4	---	
JM.10	---	0.4	---	---	0.0	---	---	---	
JTEG	0.4	0.0	---	0.1	0.7	0.0	4.7	---	
PI362	---	0.5	---	---	0.1	---	---	---	
PI5111	14.3	2.2	---	2.9	0.1	6.1	24.8	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 7. Percentage of rootstock covered with burrknots for 10-year old 'Golden Delicious' trees as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Proportion of rootstock covered with burrknots (%)								
B.9	21.2 c	6.9 b	0.0 a	2.0 a	14.4 c	---	6.9 b	---	8.6
G.41	0.0 a	0.0 a	0.0 a	0.0 a	0.0 a	---	0.0 a	---	0.0
G.16	4.3 a	0.0 a	0.0 a	2.2 a	0.6 a	---	0.0 a	---	1.2
M.9 T337	5.3 a	0.0 a	0.0 a	0.0 a	4.4 ab	---	3.1 b	---	2.1
B.10	6.5 ab	2.2 ab	0.0 a	1.2 a	6.2 b	---	0.9 ab	---	2.8
G.935	0.0 a	0.0 a	0.0 a	0.0 a	1.9 ab	---	2.8 b	---	0.8
M.9 Pajam 2	1.1 a	0.0 a	0.0 a	0.7 a	3.1 ab	---	0.0 a	---	0.7
J-TE-H	4.6 a	0.0 a	0.0 a	0.8 a	3.7 ab	---	1.8 b	---	1.8
M-26	10.8 b	4.4 b	0.0 a	1.9 a	5.6 b	---	0.0 a	---	3.7
PiAu 51-4	0.7 a	0.0 a	0.0 a	0.0 a	0.0 a	---	0.0 a	---	0.1
PiAu 56-83	0.8 a	0.6 a	0.0 a	0.0 a	1.9 ab	---	0.0 a	---	0.5
Mean	5.0	1.3	0.0	0.8	3.8 a		1.3		
	Non-core rootstocks								
CG.5179	---	0.0	---	---	2.1	---	---	---	
G.210	1.9	0.0	---	0.0	2.8	---	0.0	---	
JM.1	0.6	0.0	---	0.0	0.0	---	0.0	---	
JM.2	0.7	0.0	---	0.0	0.7	---	0.0	---	
JM.4	---	0.0	---	---	0.7	---	---	---	
JM.5	---	0.0	---	---	3.1	---	---	---	
JM.7	1.0	0.2	---	2.2	2.8	---	---	---	
JM.8	3.2	0.1	---	0.0	4.0	---	2.5	---	
JM.10	---	0.0	---	---	0.0	---	---	---	
J-TE-G	0.2	0.1	---	1.5	1.9	---	0.0	---	
PiAu 36-2	---	0.0	---	---	0.1	---	---	---	
PiAu 51-11	48.2	20.0	---	14.1	6.4	---	0.2	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

good at most locations (Table 3). Tree mortality was highest in UT with 29% tree loss, and the three industry standards, M.9 NAKBT337, M.9 Pajam 2, and M.26, along with B.10, had the most mortality. Most of the mortality at UT was due to fire blight or wind damage. Tree height can be controlled by pruning and varied from 308 cm in NY to 381 cm in ME (Table 4). Averaged over all locations, height of trees in the M.9 size class ranged only from 310 for G.16 to 353 cm for G.935, and tree spread ranged from 235 to 347 cm (Table 5). Trees on G.41 and B.10 produced few root suckers (Table 6). Less than 5% of the trunk circumference was covered by burrknots for all rootstocks in the M.9 NAKBT337 size class (Table 7). When averaged over all locations, cumulative yield per tree varied from 177 kg for G.16 to 225 kg for G.935 and 193 kg for M.9 NAKBT337 (Table 8). YE was similar for all rootstocks in the M.9 size class except it was relatively low for JM.10 at the two locations where it was planted (Table 9). Although FW was significantly affected by rootstock at some locations, when averaged over all locations and years, FW varied from 174 g for G.16 to 194 g for B.10 and was 192 g for M.9 NAKBT337 (Table 10). Within this group of rootstocks no consistent differences in BI were apparent (Table 13).

Rootstocks in the M.26 EMLA size class. Although TCA varied with location, based on TCA and tree height and spread, rootstocks that were usually in the M.26 EMLA size class included J-TE-H, G.210 and JM.7 (Tables 2, 4 and 5). J-TE-H was the only rootstock with 100% survival at every location in this trial, and JM.7 averaged only 86% survival at the six locations where it was tested (Table 3). All rootstocks in this size class produced few suckers and had little burrknot development except G.210 which had numerous root suckers (Tables 6 and 7). Cumulative yield was similar for M.26 EMLA, JM.8 and J-TE-H. Trees on G.210 had higher yield than trees on M.26 EMLA at five of six locations where it was

Table 8. Cumulative yield (kg per surviving tree) of 'Golden Delicious' trees as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Cumulative yield (kg per surviving tree)								
B.9	124 a	74 ab	87 a	91 a	126 a	124 a	97 a	159 a	110
G.41	214 d	133 b	307 bcd	150 cd	197 b	151 ab	213 b	208 b	196
G.16	156 ab	119 b	298 bcd	138 bc	131 a	178 b	206 b	189 ab	177
M.9 T337	164 abc	115 b	295 bc	125 abc	194 b	167 b	248 b	234 b	193
B.10	185 bcd	107 b	310 bcd	154 cd	190 b	175 bc	208 b	217 b	193
G.935	250 de	149 b	296 bc	222 e	202 bc	178 bc	254 cd	247 bc	225
M.9 Pajam 2	177 bcd	117 b	347 d	123 abc	217 bc	183 bc	263 cde	223 b	206
J-TE-H	188 bcd	123 b	333 cd	103 ab	234 c	159 ab	261 cd	216 b	202
M.26	209 cd	117 b	287 b	156 c	206 bc	168 b	241 bc	272 cd	207
PiAu 51-4	272 e	94 ab	441 e	172 d	328 d	251 d	318 e	332 e	276
PiAu 56-83	211 d	61 a	425 e	230 e	294 d	210 c	294 de	297 de	253
Mean	195	110	311	151	211	177	237	236	
	Non-core rootstocks								
GC.5179	---	114	---	---	204	---	---	---	
G.210	213	166	---	174	327	227	288	---	
JM.1	67	89	---	157	168	164	170	---	
JM.2	252	130	---	230	228	130	208	---	
JM.4	---	53	---	---	221	---	---	---	
JM.5	---	53	---	---	285	---	---	---	
JM.7	204	151	---	165	230	198	---	---	
JM.8	164	141	---	178	219	159	270	---	
JM.10	---	74	---	---	172	---	---	---	
J-TE-G	98	86	---	78	74	112	142	---	
PiAu 36-2	---	100	---	---	313	---	---	---	
PiAu 51-11	171	103	---	111	208	157	318	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 9. Cumulative yield efficiency (kg•cm^{-2} trunk cross-sectional area) of surviving 10-year old 'Golden Delicious' trees as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Cumulative yield efficiency (kg·cm^{-2} trunk cross-sectional area)								
B.9	6.1 b	3.5 c	3.3 a	4.0 a	4.5 c	4.1 bc	4.6 c	4.5 b	4.2
G.41	4.5 ab	3.4 c	3.7 ab	4.6 c	4.4 c	4.2 bc	3.6 ab	4.7 b	4.2
G.16	3.8 ab	3.9 c	3.4 ab	4.1 b	4.1 abc	4.2 bc	3.9 b	4.3 b	4.1
M.9 T337	5.0 ab	3.1 bc	3.5 ab	4.5 bc	4.5 c	3.7 ab	3.3 ab	4.5 b	4.0
B.10	5.2 ab	2.8 bc	4.0 b	3.9 a	4.3 b	4.4 c	3.9 b	4.4 b	4.1
G.935	5.1 b	3.4 c	3.6 ab	4.3 bc	4.6 c	4.0 b	3.7 b	4.5 b	4.1
M.9 Pajam 2	4.7 a	3.2 bc	3.2 a	4.7 c	4.3 bc	4.3 c	2.6 a	4.6 b	3.9
J-TE-H	3.6 ab	3.4 c	3.2 a	3.8 ab	3.9 ab	3.3 a	3.0 a	3.7 a	3.6
M.26	4.0 ab	2.8 b	3.7 ab	3.8 ab	4.4 c	4.0 bc	2.8 a	3.7 a	3.7
PiAu 51-4	2.2 a	2.1 a	3.7 ab	3.8 ab	3.8 a	4.4 c	2.9 a	3.5 a	3.5
PiAu 56-83	1.6 a	2.0 a	3.9 b	3.6 a	3.8 a	4.3 c	2.6 a	3.3 a	3.4
Mean	4.6	3.1	3.6	4.1	4.2	4.1	3.3	4.2	
	Non-core rootstocks								
CG.5179	---	2.8	---	---	4.7	---	---	---	
G.210	4.0	3.2	---	4.2	4.8	4.1	4.1	---	
JM.1	5.4	4.0	---	4.5	3.3	3.4	3.3	---	
JM.2	1.9	2.7	---	4.6	3.6	3.7	2.6	---	
JM.4	---	2.2	---	---	4.1	---	---	---	
JM.5	---	2.1	---	---	4.0	---	---	---	
JM.7	4.3	3.6	---	4.1	4.4	3.6	3.5	---	
JM.8	4.1	2.8	---	3.9	4.3	3.7	2.7	---	
JM.10	---	2.8	---	---	3.9	---	---	---	
J-TE-G	6.5	3.4	---	4.5	4.4	3.9	4.8	---	
PiAu 36-2	---	1.9	---	---	3.8	---	---	---	
PiAu 51-11	3.6	3.1	---	3.9	4.6	4.1	2.7	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

planted and averaged 27% higher yields than M.26 EMLA (Table 9). Trees on J-TE-H had YE similar to M.26 EMLA, but G.210 and JM.7 had higher YE than M.26 EMLA at most locations (Table 9). The three new core rootstocks in the M.26 EMLA size class all had FW equal to or greater than M.26 EMLA (Table 10). Of the non-core rootstocks, JM.7, JM.8 and PiAu 51-11 were similar in vigor to M.26 EMLA. Trees on JM.8 and PiAu 51-11 had a tendency to produce root suckers and PiAu 51-11 developed a high level of burrknots. Trees on G.210 produced many root suckers at all locations except NY (Table 6). Yield for these rootstocks was generally no higher than for M.26 EMLA and YE was low for PiAu 51-11, but JM.7 had high YE in BC and NY. J-TE-H and M.26 EMLA had similar values for BI at most locations, but trees on JM.7 tended to have lower BI values than M.26 EMLA (Table 13).

Rootstocks more vigorous than M.26 EMLA. PiAu 51-4, PiAu 56-83, PiAu 36-2, JM.2, JM.4, JM.5, and JM.10 composed the most vigorous rootstock category (Tables 2, 4 and 5). Averaged over all locations, TCA for PiAu 51-4 and PiAu 56-83 was 83% and 100% greater, respectively, than for M.26 EMLA (Table 2). Tree survival was very good for all of the vigorous rootstocks (Table 3). Root sucker production was high for PiAu 51-4 and JM.2 (Table 6), but burrknot development was minimal for all vigorous rootstocks (Table 7). At all locations except IA, cumulative yield for PiAu 51-4 and PiAu 56-83 was higher than for M.26 (Table 8) and averaged over all eight locations, yield was 33% and 22% higher for PiAu 51-4 and PiAu 56-83, respectively, than for M.26. Yield for the other vigorous rootstocks was similar to M.26 EMLA. Although cumulative yield was high for some of the vigorous rootstocks, YE was lower for all of the vigorous rootstocks than for M.26 EMLA (Table 9). Averaged over all locations, FW was higher for PiAu 56-83 and PiAu 51-4 than for any of the core rootstocks (Table 10), possibly due to relatively low crop loads. Trees on PiAu 51-4 and PiAu 56-83 tended to have BI values lower than trees on M.26 EMLA and higher than trees on M.9 NAKBT337 (Table 13).

For most rootstock trials, cumulative yield is expressed as yield of surviving trees, but tree survival is critical to orchard profitability. In an attempt to take into consideration the life span of a tree (Table 11), cumulative yield per planted tree was calculated (Table 12). For example, if a tree died the first year, then cumulative yield was 0.0 kg; if a tree produced 5.0 kg the third year and 10.4 kg the fourth year and died the fifth year, then cumulative yield was 15.4 kg. For this study, the maximum potential lifespan of a tree was 10 years. Tree survival was very high for J-TE-H, PiAu 51-4 and PiAu 56-83, so yield per planted tree was high for trees on those rootstocks. Theoretically, mean yield for J-TE-H should be identical in Tables 8 and 12 because there was no tree mortality. However, the least squares means differ slightly from marginal means because least squares means are within-group means adjusted for the other effects in the model. The average life span for trees on G.16 was only 8.6 years; yield per surviving tree was 177 kg but yield per planted tree was only 142.0 kg. Based on surviving trees, average cumulative yield was 9% higher for G.935 than for M.26 EMLA, but based on tree life span, the difference was only 7%.

Discussion

Tree mortality. In most instances, the causes of tree death were not recorded. However, at Utah, some trees on G.41, G.935 and B.10 broke at the bud union due to exceptionally high wind. Most of the tree loss at Utah on PiAu 51-4, PiAu 51-11, JM.1, JM.7, J-TE-G, M.9 Pajam 2, M.9 NAKBT337, M.26 EMLA and G.210 was due to fireblight. In Maine, the tree loss of G.16 was due to poor establishment at planting and of JM.7 to

Table 10. Average fruit weight (g) over all fruiting years for 'Golden Delicious' trees as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Average fruit weight (g)								
B.9	219 a	164 a	158 a	167 ab	153 ab	184 ab	185 a	168 a	175
G.41	240 cd	179 bc	191 d	156 a	168 b	183 ab	220 b	160 a	187
G.16	225 ab	157 a	177 b	155 a	146 a	175 a	201 b	160 a	174
M.9 T337	232 b	182 bc	201 f	157 a	171 c	193 b	228 cd	170 a	192
B.10	242 d	182 c	197 def	176 c	171 cd	190 b	224 bcd	169 a	194
G.935	238 bcd	173 abc	198 ef	162 ab	150 a	178 ab	223 b	171 a	187
M.9 Pajam 2	234 bcd	173 abc	193 de	162 a	165 bc	192 b	222 c	168 a	188
J-TE-H	230 abc	183 bc	191 cde	177 c	170 c	198 b	234 d	164 a	193
M.26	236 bcd	180 bc	180 bc	183 c	164 b	195 b	228 cd	159 a	191
PiAu 56-83	236 b	192 c	205 f	172 bc	179 d	191 b	247 e	162 a	198
PiAu 51-4	246 cd	184 c	199 e	177 c	185 de	193 b	245 de	160 a	199
Mean	234	177	190	168	166	188	223	165	
	Non-core rootstocks								
CG.5179	---	179	---	---	142	---	---	---	
G.210	239	178	---	156	160	187	211	---	
JM.1	207	164	---	159	172	180	218	---	
JM.2	249	173	---	170	187	189	---	---	
JM.4	---	172	---	---	174	---	239	---	
JM.5	---	176	---	---	183	---	---	---	
JM.7	231	172	---	167	170	184	---	---	
JM.8	231	167	---	160	164	186	227	---	
JM.10	---	166	---	---	179	---	---	---	
J-TE-G	243	166	---	173	160	182	236	---	
PiAu 36-2	---	182	---	---	180	198	---	---	
PiAu 51-11	226	170	---	173	174	224	222	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 11. Average life span (years) of 'Golden Delicious' trees after 10 years as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Average life span (years)								
B.9	10.0	10.0	6.9 a	10.0	10.0	10.0	10.0 b	10.0	9.4
G.41	10.0	10.0	9.0 b	10.0	10.0	10.0	8.5 b	10.0	9.4
G.16	6.2	10.0	6.0 a	8.8	8.8	8.8	9.5 b	10.0	8.6
M.9 T337	9.9	10.0	8.8 b	10.0	10.0	10.0	8.2 b	10.0	9.4
B.10	9.6	10.0	10.0 b	10.0	10.0	8.8	8.1 b	10.0	9.7
G.935	10.0	10.0	5.4 a	10.0	10.0	10.0	9.2 b	10.0	9.1
M.9 Pajam 2	10.0	10.0	9.5 b	10.0	10.0	10.0	5.6 a	10.0	9.3
J-TE-H	10.0	10.0	10.0 b	10.0	10.0	10.0	10.0 b	10.0	10.0
M.26	10.0	10.0	8.6 b	10.0	10.0	10.0	6.0 a	10.0	9.4
PiAu 51-4	10.0	10.0	10.0 b	10.0	10.0	10.0	8.0 b	10.0	9.8
PiAu 56-83	9.6	10.0	10.0	10.0	10.0	10.0	10.0 b	10.0	9.9
Mean	9.4	10.0	8.6	9.9	9.9	9.9	8.5	10.0	
	Non-core rootstocks								
CG.5179	---	10.0	---	---	10.0	---	---	---	
G.210	8.6	10.0	---	10.0	10.0	10.0	8.0	---	
JM.1	4.6	10.0	---	10.0	10.0	8.5	7.0	---	
JM.2	9.0	10.0	---	8.6	10.0	10.0	10.0	---	
JM.4	---	10.0	---	---	10.0	---	---	---	
JM.5	---	10.0	---	---	10.0	---	---	---	
JM.7	7.1	10.0	---	8.6	10.0	8.7	---	---	
JM.8	6.2	10.0	---	10.0	9.6	9.8	8.3	---	
JM.10	---	10.0	---	---	10.0	---	---	---	
J-TE-G	8.6	10.0	---	10.0	10.0	10.0	8.8	---	
PiAu 36-2	---	10.0	---	---	10.0	---	---	---	
PiAu 51-11	9.4	9.5	---	10.0	10.0	10.0	4.8	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 12. Cumulative yield per planted tree (kg) after 10 years for 'Golden Delicious' trees as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Cumulative yield per planted tree (kg)								
B.9	124 a	74 a	43 a	91 a	126 a	110 a	97 a	159 a	103
G.41	214 bc	127 ab	266 c	141 ab	197 b	151 ab	164 b	208 b	180
G.16	155 a	100 ab	150 b	120 a	116 a	178 b	186 b	189 a	142
M.9 T337	160 a	115 ab	243 c	119 a	194 b	167 a	172 bc	234 b	173
B.10	176 b	108 ab	310 cd	145 ab	190 b	175 b	150 ab	217 ab	184
G.935	249 c	140 b	133 b	170 bc	202 b	178 b	229 cd	248 bc	194
M.9 Pajam 2	177 b	113 ab	310 d	119 a	217 b	183 b	90 a	223 b	179
J-TE-H	187 b	123 ab	333 d	103 a	234 b	159 ab	261 cd	216 b	202
M.26	209 bc	118 ab	228 c	156 b	206 b	167 ab	96 a	272 bcd	181
PiAu 51-4	271 c	94 ab	440 e	172 bc	329 c	252 c	245 d	330 d	266
PiAu 56-83	197 bc	60 a	425 e	230 c	294 c	210 bc	294 d	297 cd	251
Mean	193	106	262	142	210	175	180	236	
	Non-core rootstocks								
GC.5179	---	103	---	---	181	---	---	---	
G.210	211	137	---	174	328	227	223	---	
JM.1	65	73	---	157	159	136	117	---	
JM.2	251	125	---	174	229	131	208	---	
JM.4	---	53	---	---	222	---	---	---	
JM.5	---	44	---	---	287	---	---	---	
JM.7	201	57	---	140	230	171	197	---	
JM.8	90	116	---	177	194	165	207	---	
JM.10	---	63	---	---	172	---	---	---	
J-TE-G	97	74	---	74	74	112	30	---	
PuiAu 36-2	---	102	---	---	316	---	---	---	
PiAu 51-11	152	95	---	104	208	158	149	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

Table 13. Biennial bearing index for 2008-2012 for 'Golden Delicious' trees planted in 2003 as influenced by rootstock and location.[z]

Rootstock	BC	IA	KY	ME	NY	PA	UT	WI	Mean
	Biennial bearing index (2008-2012)								
B.9	0.177 a	0.627 b	0.320 a	0.198 ab	0.236 a	0.218 a	0.205 a	0.199 a	0.314
G.41	0.234 ab	0.551 b	0.496 ab	0.172 ab	0.344 ab	0.172 a	0.386 b	0.240 ab	0.272
G.16	0.254 ab	0.645 bc	0.416 ab	0.280 bc	0.336 ab	0.159 a	0.297 a	0.244 ab	0.321
M.9 T337	0.268 ab	0.268 a	0.528 bc	0.147 a	0.338 ab	0.260 a	0.559 cde	0.243 ab	0.293
B.10	0.193 a	0.738 c	0.308 a	0.335 c	0.283 a	0.154 a	0.205 a	0.291 abc	0.329
G.935	0.169 a	0.656 bc	0.259 a	0.338 c	0.270 a	0.221 a	0.255 ab	0.176 a	0.441
M.9 Pajam 2	0.324 b	0.731 c	0.731 c	0.179 ab	0.265 a	0.189 a	0.442 bc	0.215 a	0.395
J-TE-H	0.236 ab	0.626 bc	0.641 c	0.368 c	0.460 b	0.279 a	0.560 c	0.360 bc	0.432
M.26	0.197 b	0.700 c	0.440 ab	0.267 abc	0.351 ab	0.210 a	0.649 d	0.348 bc	0.442
PiAu 51-4	0.234 ab	0.904 d	0.483 ab	0.194 ab	0.401 b	0.168 a	0.731 e	0.342 bc	0.355
PiAu 56-83	0.251 ab	0.925 d	0.318 a	0.286 bc	0.327ab	0.213 a	0.825 ef	0.392 c	0.384
Mean	0.228	0.712	0.429	0.251	0.329	0.204	0.465	0.277	
	Non-core rootstocks								
GC.5179	---	0.714	---	---	0.250	---	---	---	
G.210	0.177	0.658	---	0.273	0.169	0.201	0.374	---	
JM.1	0.444	0.619	---	0.147	0.278	0.290	0.512	---	
JM.2	0.260	0.770	---	0.146	0.213	0.258	0.789	---	
JM.4	---	0.906	---	---	0.375	---	---	---	
JM.5	---	0.892	---	---	0.221	---	---	---	
JM.7	0.202	0.574	---	0.216	0.321	0.183	0.414	---	
JM.8	0.216	0.692	---	0.203	0.398	0.297	0.609	---	
JM.10	---	0.741	---	---	0.269	---	---	---	
J-TE-G	0.226	0.666	---	0.185	0.225	0.225	0.129	---	
PuiAu 36-2	---	0.942	---	---	0.439	---	---	---	
PiAu 51-11	0.266	0.722	---	0.324	0.259	0.152	---	---	

[z] Least squares means within columns for the core group of 11 rootstocks were compared within a location with the slicediff option of the PROC GLIMMIX at the 5% level of significance.

union breakage following mechanical injury.

Biennial bearing. Since annual cropping is essential for orchard profitability, it is important to know if rootstock vigor can influence biennial bearing. The data for all eight locations were combined in a multiple regression model where BI was the response variable, site was an indicator variable and TCA was the regressor variable. Significant variables in the model included site, TCA, site x tca and site x tca^2 (R^2 = 0.86, P = 0.0001). Scatter plots indicated that the relationship between BI and TCA varied from no relationship, to a positive linear relationship, to a positive curvilinear relationship. Therefore, linear and quadratic regression models were fitted for each site. The relationship between BI and TCA was significant at only three sites. At IA and WI, BI was linearly related to TCA in a positive manner; the R^2 value was 0.42 and 0.66, respectively and the slopes were 0.0018 and 0.0013, respectively. At UT, the relationship was quadratic (R^2 = 0.861). At the other five locations, the R^2 values ranged from less than 0.1 in KY, ME, NY and PA to 0.26 in BC. These analyses indicate that BI is related to rootstock vigor in some environments. However, a proper study of rootstock effects on biennial bearing may involve imposing cropping treatments intended to provide a range of BI values because in multi-location trials it is impossible to obtain uniformity of many factors influencing return bloom, such as time of fruit thinning, initial fruit set and final crop load (Marini et al., 2012).

Rootstocks less vigorous than M.9 NAKBT337. In previous NC-140 trials, B.9 was usually more dwarfing than M.9 NAKBT337 (Autio et al., 2013), and those results are supported by the current trial. After five years of the current trial, trees on J-TE-G were similar in size and had slightly higher YE than trees on B.9 (Marini et al., 2009), but after 10 years, J-TE-G was more dwarfing than B.9. There is little information on rootstocks from the Czech Republic. However, in a 10-year Polish trial with 'Rubin' as the scion, TCA for J-TE-G was 22% less than for trees on M.9 EMLA and 28% less than trees on P.2 (Piestrzenieniewicz et al., 2013) and YE was 130% higher than M.9 EMLA. In previous NC-140 trials, P.2 was considered too dwarfing for commercial use (Marini et al., 2006). Based on tree size in relation to M.9 EMLA, J-TE-G is too dwarfing for commercial situations in the USA.

Rootstocks in the M.9 NAKBT337 size class. Assigning a rootstock to a vigor class is somewhat subjective because the relative vigor of a rootstock varied with location. After five years, rootstocks in the current trial considered similar to M.9 NAKBT337 included B.10 and G.41, whereas G.935, G.16, M.9 Pajam 2, and J-TE-H were similar to M.26 (Marini et al., 2009). Marini (2013), performed a repeated measures analysis on the current data set, and reported that seven to nine years were required to statistically separate ($P = 0.05\%$) trees on M.9 NAKBT337 and M.26 EMLA based on TCA, so it should be expected that vigor classification from 5-year-old trees would differ from 10-year-old trees. In a trial with three cultivars in New York, after five years TCA and YE were similar for trees on M.9 NAKBT337, G.41, and G.935 (Russo et al., 2007). After 10 years, 'Gala' trees on G.41 and G.935 had significantly larger trunks than trees on M.9 NAKBT337 in Cuauhtemoc, Chihuahua, Mexico, but in NY the three rootstocks did not differ and TCA varied by less than 12% (Autio et al., 2013). In the 2002 NC-140 rootstock trial, TCA did not differ for trees on JM.1 and M.9 NAKBT337 in BC, but in NY TCA was 37% larger for JM.1 (Autio et al., 2013). Results for YE were inconsistent in the Czech Republic, where YE relative to M.9 varied with the scion cultivar (Kosina, 2010). At most locations, the non-core rootstocks CG.5179, G.210, and JM.1 had reasonably high YE.

Rootstocks in the M.26 EMLA size class. None of the rootstocks in the M.26 EMLA size class have been widely tested previously. Based on two or three locations in the 2002 NC-140 trial, the TCA and YE of JM.7 and PiAu 51-11 usually did not differ from M.26 EMLA (Autio et al., 2013). In the current trial both JM.7 and PiAu 51-11 were evaluated at five or six locations and performed similarly to M.26 EMLA. This is the first time that JM.8 has been tested in North America and in most respects provides no advantages over M.26 EMLA. Averaged over all eight locations in the current trial, TCA for trees on J-TE-H was 12% larger than trees on M.26 EMLA (Table 2). However, in a 20-year trial in the Czech Republic, 'Rubin' trees on J-TE-H had TCAs 51% larger than trees on M.26 EMLA (Kosina, 2010). Compared to M.9 in the Czech trial, the vigor for four cultivars on J-TE-H was substantially greater than we observed for M.9 NAKBT337. We found that YE for J-TE-H was similar to M.26 EMLA and about 30% less than M.9 NAKBT337, but in the Czech trial YE was 57% to 71% lower for trees on J-TE-H than for trees on M.9 depending on the cultivar. Although J-TE-H was released from the Czech program, it seems to be slightly less vigorous and more productive in North America than in the Czech Republic, and it seems very similar to M.26 EMLA, possibly with better tree survival. In NY after just five years, trees on G.210 had similar vigor and higher YE than trees on M.26 EMLA (Russo et al., 2007) and results from the current trial support those observations.

Rootstocks more vigorous than M.26 EMLA. Of the core group, the only rootstocks that were substantially more vigorous than M.26 were PiAu 51-4 and PiAu 56-83. In the 2002 NC-140 trial, PiAu 56-83 was also more vigorous with lower YE than trees on M.26 EMLA (Autio et al., 2013). The Pillnitzer rootstocks were bred for improved propagation ability and resistance to diseases and abiotic stresses (Fischer, 1997, 2001). Five-year-old-trees of PiAu 51-4, PiAu 56-83, and PiAu 51-11 had crown volumes

26% greater, and 6% and 32% less than trees on M.9, respectively, whereas yield was 9% less, and 22% and 11% higher than M.9, respectively (Fischer, 2001). All of the Pillnitz rootstocks except PiAu 56-83 had more root suckers than the Malling rootstocks, possibly because they were bred for easy rooting. Although tested at only two or six locations, the vigorous rootstocks PiAu 36-2, JM.2, JM.4, JM.5, and JM.10 all had YE substantially lower than M.26 EMLA and do not seem worthy of further evaluation in North America.

The Geneva rootstock series was selected for disease resistance and the two that were not included in the core group deserve some discussion. The rootstock CG.5179 was evaluated at IA and NY and in most respects performed very similarly to M.9 NAKBT337. Since tree survival tended to be better than M.9 NAKBT337, trees on CG.5179 had higher cumulative yield per planted tree (Table 12). G.210 was planted at six locations and was more vigorous than M.26 EMLA and had better tree survival in UT where survival of the three Malling rootstocks was poor. Despite its relatively high vigor, YE of surviving trees and cumulative yield per tree planted were higher for trees on G.210 than trees on M.26. G.210 may have potential on very weak sites, with low-vigor cultivars, and in western areas of North America where Malling rootstocks have poor survival. Further testing at more locations is needed to determine if these two new CG rootstocks have commercial potential.

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About the cover: 'Bays' cherimoyas on the tree at Anthony Brown's Rincon Del Mar Ranch in Carpinteria, California

The cherimoya is a peculiar-looking, almost intimidating fruit – "like a pre-Columbian jade pine cone, or the finial for a giant Inca four-poster bed," in Elizabeth Schneider's memorable words. But at its best it tastes sublime, with sweet, juicy, flan-like flesh, and rich flavor blending papaya, banana and pineapple. Mark Twain famously called it "the most delicious fruit known to men," and if taste were all that counted, cherimoyas might outsell apples. Unfortunately cherimoyas are exceptionally challenging to grow, select, and ripen, and thus are not well adapted to American industrial fruiticulture and marketing. They are best bought at farmers markets, where informed shoppers can match the variety to the season and growing area, and where the fruit's flavor hasn't been diminished by storage or refrigeration.

A key producer of cherimoyas in California is Anthony Brown. Brown's family came west by covered wagon in 1862, and settled in 1871 in Carpinteria, where they farmed walnuts, lemons, and later avocados. That same year the first cherimoya was planted 16 km (10 miles) up the coast in Santa Barbara, where the equable climate – moderated by the ocean, and protected from cold north winds by mountains – somewhat mimics conditions in the fruit's native range, at around 1,500 m (5,000 feet) in the Andes.

Several times over the next century, growers tried to commercialize cherimoyas, most notably in Hollywood, where Jacob Miller and A.Z. Taft established small orchards. These attempts were never very successful, partly because problems with pollination were not fully understood and resolved. Moreover, although the cherimoya looks rugged, it is among the

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