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Performance of 'Fuji' and 'McIntosh' Apple Trees after 10 Years as Affected by Several Dwarf Rootstocks in the 1999 NC-140 Apple Rootstock Trial[1]

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Abstract

'Fuji' and 'McIntosh' apple trees (*Malus x domestica* Borkh.) on Geneva® 41 (G.41), CG.4013, CG.5179, Geneva® 202 (G.202), Geneva® 16 (G.16) (N, liners from normal stool beds; T, liners from stool beds established with tissue cultured plants), M.9 NAKBT337, M.26 EMLA, Supporter 1, Supporter 2, and Supporter 3 rootstocks were planted at several sites per cultivar throughout North America as a uniform trial coordinated by the NC-140 Multi-State Research Committee. Partial plantings were established at two sites per cultivar. Geneva® 935 (G.935) was included in two 'Fuji' and four 'McIntosh' plantings. After ten growing seasons, 'Fuji' mortality was greater than 'McIntosh,' and trees on M.9 NAKBT337 showed the greatest loss, with more than 35% mortality. Tree size measurements of trunk cross-sectional area, tree height, and canopy spread were all affected by rootstock and were used to allocate each rootstock into one of four size categories. Trees on CG.4013 were semidwarfs, larger than those on M.26 EMLA. Trees on G.202 and G.935 were large dwarfs, similar in size to M.26 EMLA. Trees on CG.5179, G.41, G.16N, and G.16T were moderate dwarfs, between trees on M.26 EMLA and M.9 NAKBT337 and likely similar to the larger M.9 clones. Trees on Supporter 1, Supporter 2, and Supporter 3 were small dwarfs, similar in size to trees on M.9 NAKBT337. Burr knot development was reasonably low but affected the greatest portion of the rootstock shank's circumference of both 'Fuji' and 'McIntosh' trees on CG.5179, G.16N, and G.16T. Root suckering was greatest from 'Fuji' trees on CG.4013, CG.5179, G.202, and M.9 NAKBT337. Very little root suckering was seen with 'McIntosh,' but the greatest numbers were from trees on CG.4013, CG.5179, and M.9 NAKBT337. Cumulative yield per tree was positively related to tree size. The most yield efficient 'Fuji' trees were on CG.5179, G.41, and Supporter 1, and the least efficient were on M.26 EMLA and CG.4013. The most yield efficient 'McIntosh' trees were on Supporter 1, Supporter 2, Supporter 3, G.41, and CG.5179, and the least efficient were on G.202, M.26 EMLA, and CG.4013. Average fruit weight was only modestly affected by rootstock. Generally, trees on G.41, M.9 NAKBT337, and M.26 EMLA had the largest fruit size, while trees on Supporter 2 and Supporter 3 had the smallest fruit size.

Introduction

Rootstock selection requires an understanding of the level of vigor that the rootstock can induce, the precocity and productivity that may result, the longevity of the grafted tree, resistance to biotic and abiotic stresses, and ultimately, the overall economic impact on a commercial orchard system. For new rootstocks, this understanding is not possible without extensive study. The NC-140 Technical Committee began in 1976 with the goal of evaluating rootstocks over a wide variety of environments across North America in uniform trials to assist orchardists in managing rootstock selection decisions. Initial studies focused on East Malling, Michigan, Budagovsky, and Polish rootstocks (8, 9). Many other rootstocks have been released since that time.

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The Cornell-Geneva Apple Rootstock Breeding Program began a number of years ago with the work of Dr. James Cummins. After Dr. Cummins retirement, Cornell University entered into a relationship with the United States Department of Agriculture to continue this important rootstock breeding effort. The main focus of this breeding program is disease resistance. To date, a number of highly productive and disease resistant rootstock cultivars have been named and released for commercial use (4). Another productive breeding program is at the Institut für Obstforschung Dresden-Pillnitz in Germany. Their goals included the improvement of propagation, resistance to stresses, and better anchorage (5, 6). They have released a number of dwarfing rootstocks, reported to be similar in size but more productive than trees on M.9 (5, 6).

The objective of the 1999 NC-140 Dwarf Apple Rootstock Trial reported here was to evaluate Cornell-Geneva and Dresden-Pillnitz dwarf rootstocks in comparison to current industry standards, M.9 NAKBT337 and M.26 EMLA, across a diverse array of commercial North American apple growing regions.

Materials & Methods

In spring, 1999, two trials of dwarf apple rootstocks were established under the coordination of the NC-140 Multi-State Research Committee. One trial included 'Fuji' as the scion cultivar, and the other 'McIntosh.' The 'Fuji' trial was planted in California, Kentucky, Missouri, North Carolina, Pennsylvania (Biglerville), and Utah, with partial plantings in Pennsylvania (Rock Springs) and South Carolina (Table 1). The 'McIntosh' trial was planted in Massachusetts, Michigan, Minnesota, Nova Scotia (Canada), New York (Williamson), Ontario (Canada), Vermont, and Wisconsin, with partial plantings in New York (Peru) and Pennsylvania (Rock Springs) (Table 1). Rootstocks were CG.4013, CG.5179, Geneva® 41 (G.41), Geneva® 202 (G.202), Geneva® 16 (G.16) (N, liners from normal stool beds; T, liners from stool beds established with tissue cultured plants), M.9 NAKBT337, M.26 EMLA, Supporter 1, Supporter 2, and Supporter 3. At some sites (CA, MI, MN, Williamson, NY, NC, and VT) Geneva® 935 (G.935) was an additional rootstock treatment.

Trees were spaced 3 m x 5 m and trained as vertical axes. At planting, the bud union was set approximately 10 cm above the soil. Water, fertility, and pest control were applied per local recommendations. The experimental design was a randomized complete block at each site, with six blocks and a single tree representing each rootstock treatment in a block. Trunk circumference at 25 cm above the bud union was measured annually in October and transformed to trunk cross-sectional area (TCA). Tree height and canopy spread were measured in October, 2008. Root suckers were counted and removed annually during the growing season. Yield per tree was assessed annually from 2001 through 2008 as total weight of the harvested and dropped fruit. Yield efficiency in 2008 was calculated as yield in 2008 divided by TCA in 2008. Cumulative yield efficiency (2001-08) was calculated as cumulative yield (2001-08) divided by TCA in 2008. Fruit size in 2008 was derived from the total weight of fruit harvested per tree in 2008 divided by the total number of harvested fruit per tree. Average fruit weight (2001-08) was calculated as the cumulative yield (2001-08) divided by the cumulative number of fruit per tree.

Data were analyzed with the MIXED procedure of the SAS statistical analysis software (SAS Institute, Cary, NC). The two trials ('Fuji' and 'McIntosh') were analyzed separately. Data from the core rootstocks and sites were analyzed as a randomized-complete-block-split-plot design, with location (L) and block within location (B:L) in the whole plot and rootstock (R) and the associated interactions (RL and RB:L) in the split plot. Rootstock and location were treated as fixed effects, and block was considered random. In general, the interaction of location and rootstock was significant. Additional analyses, therefore, were conducted for each site, including all

Table 1. Planting locations in the 1999 NC-140 Dwarf Apple Rootstock Trials.

Site	Planting location	Cooperator	Cooperator Affiliation & Address
Fuji			
California	Parlier	S. Johnson	Kearney Agric. Center, University of California, 9240 S. Riverbend Ave., Parlier, CA 93648 USA
Kentucky	Princeton	D. Wolfe	Research & Education Center, University of Kentucky, P.O. Box 469, Princeton, KY 42445 USA
Missouri	New Franklin	M. Warmund	Dept. Horticulture, University of Missouri, I-31 Agriculture Building, Columbia, MO 65211 USA
North Carolina	Mills River	M. Parker	Dept. Horticulture, North Carolina State University, Box 7609, Raleigh, NC 27695 USA
Pennsylvania	Biglerville	J. Schupp	Fruit Research & Ext. Center., Pennsylvania State Univ., P.O. Box 330, Biglerville, PA 17307 USA
Pennsylvania	Rock Springs	R. Crassweller	Dept. Horticulture, Pennsylvania State University, 102 Tyson Building, University Park, PA 16802 USA
South Carolina	Clemson	G. Reighard	Dept. Horticulture, Clemson University, Box 340319, Clemson, SC 29634 USA
Utah	Kaysville	B. Black	Plants, Soils, & Climate Dept., Utah State University, Logan, UT 84322 USA
McIntosh			
Massachusetts	Belchertown	W. Autio	Dept. Plant, Soil, & Insect Sci., Univ. Massachusetts, 205 Bowditch Hall, Amherst, MA 01003 USA
Michigan	Clarksville	G. Lang	Dept. Horticulture, Michigan State University, East Lansing, MI 48824 USA
Minnesota	Excelsior	E. Hoover	Dept. Horticultural Sci., University of Minnesota, 1970 Folwell Ave, St. Paul, MN 55108 USA
Nova Scotia	Kentville	C. Embree	Agriculture & Agri-Food Canada, Kentville, NS B4N 1J5 Canada
New York	Williamson	T. Robinson	Dept. Horticulture, Cornell University, NYS Agric. Experiment Station, Geneva, NY 14456 USA
New York	Peru	T. Robinson	Dept. Horticulture, Cornell University, NYS Agric. Experiment Station, Geneva, NY 14456 USA
Ontario	Simcoe	J. Cline	Dept. Plant Agriculture, University of Guelph, Box 587, Simcoe, ONT N3Y 4N5 Canada
Pennsylvania	Rock Springs	R. Crassweller	Dept. Horticulture, Pennsylvania State University, 102 Tyson Building, University Park, PA 16802 USA
Vermont	South Burlington	T. Bradshaw	Dept. Plant & Soil Science, University of Vermont, 206 Hills Building, Burlington, VT 05405 USA
Wisconsin	Sturgeon Bay	M. Stasiak	Peninsular Agric. Research Station, University of Wisconsin, 4312 Hwy 42, Sturgeon Bay, WI 54235 USA

of the rootstocks at that site. Least-squares means, adjusted for missing subclasses, were generated by the analyses. Rootstock means were separated by Tukey’s HSD ($P = 0.05$).

Results

Overall Rootstock Effects

After 10 growing seasons, survival among ‘Fuji’ trees on the various rootstocks did not differ significantly (Table 2). If the age at which the tree died is accounted for and longevity is assessed, ‘Fuji’ trees on CG.4013 lived the longest, significantly longer than those on G.16T or M.9 NAKBT337. For ‘McIntosh’ trees, however, lowest survival was recorded for trees on M.9 NAKBT337, significantly lower than those on G.41, CG.4013, CG.5179, G.202, G.16N G.16T, M.26 EMLA, and Supporter 3. The average longevity of ‘McIntosh’ trees on M.9 NAKBT337 was significantly lower than trees on all other rootstocks.

Because of tree loss, M.9 NAKBT337 and Supporter 3 were eliminated from the analyses

Table 2. Survival, longevity, tree size, burr knots, and root suckering of ‘Fuji and ‘McIntosh’ apple trees on various rootstocks through ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	Survival (%)[y]	Longevity (years)[y]	Trunk cross-sectional area (2008, cm^2)[y]	Tree height (2008, m)[x]	Canopy spread (2008, m)[x]	Burr knots (2008, % of circumference affected)[w]	Cumulative root suckers (1999-2008, no.)[v]
Fuji							
G.41	75 a	8.1 abc	80 cd	3.5 bc	2.9 cde	1.5 ab	8 c
CG.4013	100 a	9.6 a	180 a	4.1 a	3.6 a	0.5 b	52 a
CG.5179	94 a	9.3 ab	88 cd	3.8 ab	3.2 bc	7.0 a	33 b
G.202	83 a	8.7 abc	118 b	4.0 ab	3.4 ab	2.5 ab	34 b
G.16N[u]	87 a	8.6 abc	99 bc	3.6 b	3.0 cd	6.4 ab	9 c
G.16T[u]	80 a	8.0 bc	102 bc	3.6 b	3.3 abc	5.6 ab	13 bc
M.9 NAKBT337	64 a	7.8 c	---	---	---	---	---
M.26 EMLA	72 a	8.2 abc	125 b	3.6 b	3.1 bc	2.8 ab	4 c
Supporter 1	69 a	8.2 abc	59 d	2.8 c	2.5 e	0.0 b	11 c
Supporter 2	78 a	8.7 abc	73 cd	3.0 c	2.6 de	0.7 ab	7 c
Supporter 3	68 a	8.4 abc	---	---	---	---	---
McIntosh							
G.41	98 a	9.9 a	61 cde	3.1 cd	3.3 b	3.3 bc	1 c
CG.4013	100 a	10.0 a	112 a	3.6 a	3.7 a	4.2 bc	10 a
CG.5179	94 a	9.9 a	66 cd	3.3 bc	3.4 b	11.4 ab	7 ab
G.202	95 a	9.6 a	96 b	3.5 ab	3.4 b	6.2 bc	2 c
G.16N[u]	98 a	10.0 a	56 de	2.9 d	3.0 cd	12.5 ab	1 c
G.16T[u]	100 a	10.0 a	58 de	3.0 d	3.0 cd	21.1 a	4 bc
M.9 NAKBT337	61 b	6.8 b	48 e	2.9 d	3.0 cd	10.7 abc	6 abc
M.26 EMLA	95 a	10.0 a	74 c	3.3 bc	3.2 bc	11.9 ab	1 c
Supporter 1	86 ab	8.8 a	48 e	2.9 d	2.9 cd	3.6 bc	5 bc
Supporter 2	84 ab	8.9 a	49 e	2.9 d	2.8 d	0.8 c	2 c
Supporter 3	89 a	9.0 a	54 de	3.1 cd	2.9 cd	4.1 bc	3 bc

[z] Mean separation within column and cultivar by Tukey’s HSD ($P = 0.05$).
[y] ‘Fuji’ data from CA, KY, MO, NC, PA, and UT (8 seasons only), and ‘McIntosh’ data from MA, MI, MN, NS, NY, VT, and WI.
[x] ‘Fuji’ data from CA, KY, MO, NC, and PA, and ‘McIntosh’ data from MA, MN, NS, and NY.
[w] ‘Fuji’ data from CA, KY, NC, and PA, and ‘McIntosh’ data from MA, NS, and NY.
[v] ‘Fuji’ data from CA, KY, MO, NC, PA, and UT (8 seasons only), and ‘McIntosh’ data from MA, MI, MN, NS, NY, and VT.
[u] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

associated with tree size (Table 2) and yield (Table 3) in 'Fuji' plantings, but individual-site data were analyzed and are presented. 'Fuji' trees with the largest TCA were on CG.4013, followed in descending order by M.26 EMLA, G.202, G.16T, G.16N, CG.5179, G.41, Supporter 2, and Supporter 1 (Table 2). Consistent with relative TCA, 'Fuji' trees on CG.4013 were the tallest and had the greatest canopy spread, and those on Supporter 1 and Sup-

Table 3. Yield, yield efficiency, and fruit size of 'Fuji' and 'McIntosh' apple trees on various rootstocks through ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

	Yield per tree (kg)		Yield efficiency ($kg \cdot cm^{-2}$ TCA)		Fruit weight (g)	
Rootstock	2008 [y]	Cumulative (2001-08) [y]	2008 [y]	Cumulative (2001-08) [y]	2008[y,x]	Average (2001-08) [w]
Fuji						
G.41	67 bcd	241 bcd	0.9 ab	3.4 a	210 a	194 a
CG.4013	110 a	357 a	0.7 b	2.3 b	191 a	195 a
CG.5179	90 abc	312 ab	1.0 a	3.5 a	200 a	194 a
G.202	105 ab	302 ab	1.0 a	3.1 ab	194 a	193 a
G.16N[v]	90 abc	282 bc	1.0 a	3.1 ab	195 a	189 ab
G.16T[v]	77 bc	289 abc	0.8 ab	3.1 ab	202 a	195 a
M.9 NAKBT337	---	---	---	---	---	---
M.26 EMLA	66 cd	224 cd	0.7 b	2.4 b	195 a	197 a
Supporter 1	35 d	154 d	0.8 ab	3.4 a	163 b	175 c
Supporter 2	37 d	148 d	0.7 b	2.8 ab	184 ab	177 bc
Supporter 3	---	---	---	---	---	---
McIntosh						
G.41	41 bc	214 bcd	0.7 ab	3.6 ab	164 a	156 a
CG.4013	57 a	281 a	0.7 ab	3.1 bcd	156 a	148 b
CG.5179	45 b	216 bc	0.8 a	3.5 ab	159 a	148 b
G.202	42 bc	227 b	0.5 b	2.8 d	159 a	150 ab
G.16N[v]	37 bc	179 e	0.7 ab	3.4 abc	157 a	148 b
G.16T[v]	38 bc	180 e	0.7 ab	3.4 abc	159 a	147 b
M.9 NAKBT337	34 bc	162 e	0.8 a	3.7 ab	160 a	149 ab
M.26 EMLA	41 bc	193 cde	0.6 ab	2.9 cd	160 a	151 ab
Supporter 1	33 c	175 e	0.8 a	4.0 a	154 a	150 ab
Supporter 2	32 c	179 e	0.7 ab	3.7 ab	153 a	144 b
Supporter 3	35 bc	186 de	0.7 ab	3.6 ab	153 a	144 b

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] 'Fuji' data from KY, MO, NC, and PA, and 'McIntosh' data from MA, MI, MN, NS, NY, VT, and WI.
[x] Fruit weight in 2008 was affected by crop load, and therefore least-squares means were adjusted to account for crop load.
[w] 'Fuji' data from CA (4 harvest seasons only), KY, MO, NC, PA, and UT (6 harvest seasons only) and 'McIntosh' data from MA, MI, MN, NS, NY, VT, and WI.
[v] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

porter 2 were the shortest and had the smallest canopy spread (Table 2)

'McIntosh' trees with the largest TCA were also on CG.4013, followed in descending order by those on G.202, M.26 EMLA, CG.5179, G.41, G.16N, G.16T, Supporter 3, Supporter 2, Supporter 1, and M.9 NAKBT337 (Table 2). As with 'Fuji,' 'McIntosh' tree height and canopy spread generally followed differences noted in TCA (Table 2).

'Fuji' trees on CG.5179 had burr knots affecting a greater portion of the trunk circumference than those on CG.4013 or Supporter 1 (Table 2). 'McIntosh' trees also had low amounts of burr knots, but, on average, considerably more than 'Fuji' trees. The greatest portion of the trunk circumference affected was measured for trees on G.16T, significantly more than for those on G.41, CG.4013, G.202, Supporter 1, Supporter 2, or Supporter 3. Trees on Supporter 2 had almost no burr knots with both cultivars.

Root suckering was much more prominent with 'Fuji' as the scion cultivar compared to 'McIntosh' (Table 2). CG.4013 produced the greatest number of root suckers with both cultivars. G.202 and CG.5179 also had substantial root suckering with 'Fuji' compared to the other rootstocks.

The greatest yields of both cultivars in 2008 and cumulatively came from trees on CG.4013 (Table 3). Lowest 'Fuji' yields in 2008 and cumulatively came from trees on Supporter 1 and on Supporter 2. Lowest 'McIntosh' yields in 2008 came from trees on Supporter 1 and on Supporter 2, and cumulatively from trees on M.9 NAKBT337, Supporter 2, Supporter 1, and G.16T.

In 2008, 'Fuji' trees on CG.5179, G.202, and G.16N were more yield efficient than those on CG.4013, M.26 EMLA or Supporter 2 (Table 3). 'McIntosh' trees on CG.5179, M.9 NAKBT337, and Supporter 1 were more yield efficient than those on G.202. Cumulatively, the most yield efficient 'Fuji' trees were on G.41, CG.5179, and Supporter 1, and least efficient were on M.26 EMLA and CG.4013. The most cumulatively yield efficient 'McIntosh' trees were on Supporter 1, and the least efficient were on G.202.

Rootstock caused few differences in fruit weight in 2008 (Table 3). On average (2001-08), however, 'Fuji' fruit were larger from trees on G.41, CG.4013, CG.5179, G.202, G.16T, and M.26 EMLA than from trees on Supporter 1 or Supporter 2. 'McIntosh' fruit (2001-08) were largest from trees on G.41, and smallest from trees on CG.4013, CG.5179, G.16N, G.16T, Supporter 2, and Supporter 3. The range in size (2001-08) influenced by rootstock was only 12 g with 'McIntosh' and 22 g with 'Fuji.'

Rootstock Effects By Site

For all measured parameters, site and rootstock interacted to affect the results. These interactions come partially from site-mediated effects but also from high analysis sensitivity. Only prominent site-related deviations in relative rootstock effects will be presented.

Tree losses varied greatly from site to site (Table 4). No sites reported losses of 17% or greater for 'Fuji' trees on CG.4013, CG.5179, and G.935. However, half of the sites reported losses of 50% or greater of 'Fuji' trees on at least one of the following rootstocks: G.41, M.9 NAKBT337, Supporter 1, and Supporter 2. No sites reported losses of 50% or greater for 'McIntosh' trees on G.41, CG.4013, CG.5179, G.202, G.935, G.16N, G.16T, M.26 EMLA, and Supporter 3. Losses of 50% or greater occurred for M.9 NAKBT337 in MN, Williamson, NY, and WI; for Supporter 1 in MN and WI; and for Supporter 2 in WI. Tree loss, generally, occurred throughout the 10 years of the trial, thus average longevity generally followed percent survival (Table 5).

A statistically significant interaction of location and rootstock, as they affect TCA, indicated variation in the relative effects of rootstock from site to site (Table 6). Using simple correlation analyses to compare site-specific means to the overall rootstock means showed the greatest deviation from average for TCA in CA, SC, and UT for 'Fuji' and in MN, NS, Peru, NY, VT, and WI for 'McIntosh.' In

Table 4. Survival (%) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC	UT [y]		
Fuji										
G.41	100	50	33	100	100	---	---	67		
CG.4013	100	100	100	100	100	---	---	100		
CG.5179	100	83	83	100	100	---	100	100		
G.202	100	60	40	100	100	---	---	100		
G.935	100	---	---	100	---	---	---	---		
G.16N [x]	100	100	40	80	100	---	80	100		
G.16T [x]	100	100	33	80	100	---	---	67		
M.9 NAKBT337	67	67	0	100	100	100	50	50		
M.26 EMLA	50	83	33	83	100	100	---	83		
Supporter 1	50	100	33	100	33	83	100	100		
Supporter 2	100	100	50	100	17	100	40	100		
Supporter 3	100	67	60	80	0	100	83	100		
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	100	100	100	100	---	83	100	---	100	100
CG.4013	100	100	100	100	---	100	83	---	100	100
CG.5179	100	100	60	100	---	100	100	---	100	100
G.202	100	83	100	100	---	100	80	---	80	100
G.935	---	100	100	---	---	100	---	---	100	---
G.16N [x]	100	83	100	100	---	100	100	---	100	100
G.16T [x]	100	100	100	100	---	100	100	---	100	100
M.9 NAKBT337	80	83	17	83	100	50	100	100	100	17
M.26 EMLA	100	67	100	100	100	100	---	100	100	100
Supporter 1	100	100	50	100	100	100	100	100	100	50
Supporter 2	100	83	67	100	100	100	100	100	100	50
Supporter 3	100	100	75	83	100	80	67	83	100	83

[z] Mean separation was not performed on individual-location values because of the lack of replication for survival data.
[y] The UT planting was removed after 8 seasons.
[x] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 5. Longevity (years) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC	UT [y]
Fuji								
G.41	10.0 a	6.9 a	4.6 ab	10.0 a	10.0 a	---	---	7.0 a
CG.4013	10.0 a	10.0 a	10.0 a	10.0 a	9.9 a	---	---	8.0 a
CG.5179	10.0 a	8.8 a	8.8 a	10.0 a	10.0 a	---	10.0 a	8.0 a
G.202	10.0 a	8.4 a	5.7 ab	10.0 a	9.9 a	---	---	8.0 a
G.935	10.0 a	---	---	9.9 a	---	---	---	---
G.16N [x]	10.0 a	10.0 a	5.7 ab	8.0 a	9.9 a	---	8.0 a	8.0 a
G.16T [x]	10.0 a	10.0 a	4.8 ab	8.0 a	9.8 a	---	---	5.3 a
M.9 NAKBT337	8.8 a	9.2 a	3.3 b	10.0 a	10.0 a	10.0 a	8.7 a	5.5 a
M.26 EMLA	8.0 a	9.2 a	5.7 ab	8.8 a	10.0 a	10.0 a	---	7.5 a
Supporter 1	7.8 a	10.0 a	6.0 ab	10.0 a	7.8 b	9.8 a	10.0 a	8.0 a
Supporter 2	10.0 a	10.0 a	7.0 ab	10.0 a	7.0 b	10.0 a	7.2 a	8.0 a
Supporter 3	10.0 a	9.7 a	7.1 ab	8.9 a	7.0 b	10.0 a	9.7 a	8.0 a

Rootstock	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	10.0 a	10.0 a	10.0 a	10.0 a	---	9.3 a	10.0 a	---	10.0 a	10.0 a
CG.4013	10.0 a	10.0 a	10.0 a	10.0 a	---	10.0 a	9.0 a	---	10.0 a	10.0 a
CG.5179	10.0 a	10.0 a	9.4 a	10.0 a	---	10.0 a	10.0 a	---	10.0 a	10.0 a
G.202	10.0 a	8.3 a	10.0 a	10.0 a	---	10.0 a	9.8 a	---	8.4 a	10.0 a
G.935	---	10.0 a	10.0 a	---	---	10.0 a	---	---	10.0 a	---
G.16N [x]	10.0 a	9.7 a	10.0 a	10.0 a	---	10.0 a	8.8 a	---	10.0 a	10.0 a
G.16T [x]	10.0 a	10.0 a	10.0 a	10.0 a	---	10.0 a	9.8 a	---	10.0 a	10.0 a
M.9 NAKBT337	9.8 a	9.8 a	2.8 b	8.3 a	10.0 a	5.0 b	10.0 a	10.0 a	10.0 a	1.7 b
M.26 EMLA	10.0 a	9.7 a	10.0 a	10.0 a	10.0 a	10.0 a	---	10.0 a	10.0 a	10.0 a
Supporter 1	10.0 a	10.0 a	6.3 ab	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	5.0 ab
Supporter 2	10.0 a	9.7 a	7.3 ab	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	5.0 ab
Supporter 3	10.0 a	10.0 a	8.0 ab	8.7 a	10.0 a	8.0 ab	8.7 a	8.7 a	10.0 a	8.3 a

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] The UT planting was removed after 8 seasons, so the maximum age is 8 years.
[x] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 6. Trunk cross-sectional area (cm^2) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC	UT[y]		
Fuji										
G.41	124 bc	92 b	80 bc	63 bc	60 bc	---	---	57 c		
CG.4013	278 a	139 a	251 a	160 a	127 a	---	---	122 a		
CG.5179	84 c	89 b	124 bc	84 bc	81 bc	---	106 b	66 bc		
G.202	180 abc	95 b	165 b	110 b	76 bc	---	---	83 b		
G.935	104 bc	---	---	97 bc	---	---	---	---		
G.16N [x]	152 abc	95 b	132 bc	94 bc	69 bc	---	202 a	51 c		
G.16T [x]	165 abc	94 b	114 bc	88 bc	90 abc	---	---	62 bc		
M.9 NAKBT337	102 bc	82 bc	---	56 bc	50 c	81 b	113 ab	57 c		
M.26 EMLA	267 ab	76 bc	107 bc	114 bc	100 ab	118 a	---	84 b		
Supporter 1	105 bc	52 c	60 c	35 c	42 c	37 c	89 b	60 c		
Supporter 2	153 abc	66 bc	71 c	41 c	44 c	34 c	91 b	64 bc		
Supporter 3	200 abc	59 bc	72 c	43 c	---	50 c	68 b	71 bc		
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	64 bcd	99 bc	53 abc	45 bc	---	78 cd	95 bcd	---	43 bcd	47 abc
CG.4013	110 a	245 a	66 a	72 a	---	178 a	155 a	---	59 ab	50 ab
CG.5179	72 bc	117 bc	52 abcd	42 bc	---	86 bcd	97 bc	---	53 ab	39 bcd
G.202	76 b	244 a	56 ab	58 ab	---	123 b	134 ab	---	63 a	54 a
G.935	---	149 bc	46 abcd	---	---	124 b	---	---	58 ab	---
G.16N [x]	52 bcde	113 bc	32 cd	49 b	---	64 d	65 cd	---	44 bcd	36 cd
G.16T [x]	51 bcde	120 bc	36 bcd	41 bc	---	79 cd	68 cd	---	44 bcd	37 bcd
M.9 NAKBT337	39 de	119 bc	30 cd	26 b	25 b	65 d	73 cd	69 ab	31 cd	25 d
M.26 EMLA	57 bcde	167 b	44 abcd	47 b	46 a	109 bc	---	107 a	49 abc	41 abcd
Supporter 1	37 e	98 bc	27 d	42 bc	39 ab	70 d	79 cd	65 b	28 d	31 d
Supporter 2	47 cde	85 c	38 bcd	41 bc	32 b	70 d	54 d	62 b	34 cd	30 d
Supporter 3	47 cde	96 c	37 bcd	46 bc	38 ab	77 cd	65 cd	74 ab	37 cd	40 bcd

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] Trees in UT were removed at the end of 8 growing seasons.
[x] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

CA, 'Fuji' trees on Supporter 2, Supporter 3, and M.26 EMLA were larger and those on CG.5179 were smaller than the overall average while in SC, those on M.9 NAKBT337 and on G.16N were larger than average, and those in UT on Supporter 1, Supporter 2, Supporter 3, and M.9 NAKBT337 were larger than average. 'McIntosh' trees in MN on G.41 and on CG.5179 were larger than average; those in Peru, NY on Supporter 1 and Supporter 3 were larger while those in VT on CG.4013 were smaller than average. 'McIntosh' trees in WI on G.41 were larger and those on CG.4013 were smaller than average. Although these differences in relative rootstock effects were statistically significant, careful review of the means and mean separations suggests that substantial variation in the effects of rootstock did not occur with respects to TCA. Comparable results were seen for tree height (Table 7) and canopy spread (Table 8): however, in both cases, rootstock effects were of lower magnitude than with TCA.

Only five sites each for 'Fuji' and 'McIntosh' evaluated the severity of burr knots (Table 9). For 'Fuji' among those five sites, differences in burr knot incidence were significant only in NC. G.935 resulted in more than 23% of the trunk circumference being affected by burr knots. Rootstock affected burr knot development of 'McIntosh' only in NS and Williamson, NY. In NS, G.16T, M.26 EMLA, G.16N, and M.9 NAKBT337 resulted in the most severe burr knots. Both G.16N and G.16T resulted in the most severe burr knots in Williamson NY.

Root suckering generally was more pronounced at 'Fuji' sites than at 'McIntosh' sites (Table 10). Among the eight 'Fuji' sites, rootstock affected suckering significantly only in KY, NC, Biglerville, PA, and UT. Generally, CG.5179 and CG.4013 resulted in larger numbers of root suckers than average. Of the nine 'McIntosh' sites where root suckering data were collected, significant rootstock differences were observed only in MA, MI, Peru, NY, Rock Springs, PA, and VT, but in no case were substantial numbers of suckers produced by a rootstock.

Cumulative yield per tree (2001-08) was affected by rootstock and rootstock interacted significantly with location for both cultivars (Table 11). For all 'Fuji' sites and most 'McIntosh' sites, a positive relationship between tree size and yield largely governed cumulative yield per tree. Exceptions include MI, where all trees yielded heavily, and rootstock effects were nonsignificant. In ON, smallest trees yielded the most.

Cumulative yield efficiency (2001-08) also was affected by rootstock and the interaction of rootstock and site (Table 12). However, most rootstocks resulted in reasonably high yield efficiency, and there was low variation from rootstock to rootstock. In only three of the six 'Fuji' sites were the rootstock differences significant. In all but one of the 'McIntosh' sites, these differences were significant, but for none of the rootstocks were any of the differences statistically large. Generally, across both cultivars where rootstock differences were significant, CG.4013 and M.26 EMLA resulted in among the lowest yield efficiencies. For 'McIntosh,' G.202 also resulted in low efficiency in MI, NS, Williamson, NY, ON, VT, and WI. G.16N in MA and Supporter 2 in MO and VT resulted in low efficiency.

Average fruit weight (2001-08) differences caused by rootstock were modest, and those differences varied with site (Table 13). In CA, MO, NC, Biglerville, PA, and UT, the rootstock effects on 'Fuji' fruit size were nonsignificant, and in MA, MI, NS, and Williamson, NY, the rootstock effects on 'McIntosh' size were nonsignificant. Among the remaining sites the relative effects of rootstock were similar to those observed in the overall averages (Table 3). Generally, G.41, M.9 NAKBT337, and M.26 EMLA resulted in fruit amongst the largest, and Supporter 2 and Supporter 3 resulted in fruit amongst the smallest. 'McIntosh' fruit in WI deviated from this trend, with the largest fruit harvested from trees on Supporter 3 and M.26 EMLA and the smallest from trees on M.9 NAKBT337 and G.16N.

Table 7. Tree height (m) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC		
Fuji									
G.41	3.9 a	4.0 a	2.8 ab	2.9 bc	3.6 ab	---	---		
CG.4013	4.9 a	3.7 a	4.3 a	3.8 a	4.0 a	---	---		
CG.5179	3.7 a	3.7 a	3.9 ab	3.8 a	3.8 ab	---	4.1 a		
G.202	4.5 a	3.5 ab	4.4 a	3.9 a	3.6 ab	---	---		
G.935	3.6 a	---	---	3.7 ab	---	---	---		
G.16N [y]	4.0 a	3.2 abc	4.2 ab	3.4 ab	3.3 ab	---	4.5 a		
G.16T [y]	4.6 a	3.3 abc	3.4 ab	3.3 ab	3.6 ab	---	---		
M.9 NAKBT337	3.6 a	3.3 ab	---	2.8 bc	3.3 b	3.6 b	4.0 ab		
M.26 EMLA	4.9 a	3.0 abc	3.1 ab	3.3 ab	3.6 ab	4.3 a	---		
Supporter 1	3.3 a	2.6 c	2.7 b	2.1 c	3.0 b	2.7 c	3.2 b		
Supporter 2	3.7 a	2.8 bc	3.1 ab	2.3 c	3.0 b	2.5 c	3.9 b		
Supporter 3	4.1 a	2.8 bc	3.0 ab	2.2 c	---	3.0 c	3.2 b		
	MA	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh									
G.41	3.4 bc	2.6 a	2.9 b	---	3.5 c	3.2 a	---	3.3 abc	2.9 ab
CG.4013	4.0 a	2.5 ab	3.4 a	---	5.2 a	3.2 a	---	3.7 ab	2.9 ab
CG.5179	3.8 ab	2.4 ab	3.2 ab	---	3.9 bc	3.3 a	---	3.8 a	2.9 ab
G.202	3.8 ab	2.7 a	3.0 ab	---	4.8 a	3.3 a	---	3.4 abc	3.2 a
G.935	---	2.6 a	---	---	4.9 a	---	---	3.8 a	---
G.16N [y]	3.0 cd	2.4 ab	2.9 b	---	3.6 c	3.4 a	---	3.1 abcd	2.6 b
G.16T [y]	3.2 c	2.2 b	2.9 b	---	3.6 c	3.5 a	---	3.2 abcd	2.7 ab
M.9 NAKBT337	2.5 d	2.4 ab	2.8 b	3.4 a	3.9 bc	3.2 a	4.1 a	3.2 abcd	2.5 b
M.26 EMLA	3.4 bc	2.6 a	2.9 b	3.3 a	4.5 ab	---	4.4 a	3.5 abc	2.9 ab
Supporter 1	3.0 cd	2.1 b	2.9 b	3.4 a	3.5 c	3.3 a	3.9 a	3.0 bcd	2.6 b
Supporter 2	3.1 c	2.4 ab	2.8 b	3.4 a	4.0 bc	3.6 a	4.1 a	2.6 d	2.7 ab
Supporter 3	3.4 bc	2.5 ab	3.1 ab	3.5 a	3.9 bc	3.5 a	3.9 a	2.9 cd	3.0 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 8. Canopy spread (m) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC		
Fuji									
G.41	3.1 b	3.1 ab	2.5 bc	2.3 bcd	3.5 ab	---	---		
CG.4013	4.3 a	3.3 ab	3.0 a	2.9 a	4.3 a	---	---		
CG.5179	3.0 b	3.3 ab	2.9 ab	2.7 ab	4.0 ab	---	3.9 a		
G.202	3.6 ab	3.5 a	3.0 a	2.9 a	4.1 ab	---	---		
G.935	3.0 b	---	---	2.7 ab	---	---	---		
G.16N [y]	3.2 b	3.1 ab	2.7 abc	2.6 abc	3.3 ab	---	4.4 a		
G.16T [y]	3.6 ab	3.2 ab	2.9 ab	2.4 abc	4.0 ab	---	---		
M.9 NAKBT337	3.0 b	3.1 ab	---	2.2 cd	3.3 ab	3.8 a	3.5 ab		
M.26 EMLA	3.7 ab	3.0 b	2.6 bc	2.4 abc	4.0 ab	4.1 a	---		
Supporter 1	2.6 b	2.9 b	2.6 bc	1.7 e	2.9 b	2.5 b	2.9 b		
Supporter 2	2.7 b	3.1 ab	2.5 c	1.7 e	3.1 ab	2.6 b	3.3 ab		
Supporter 3	3.2 b	2.9 b	2.8 abc	1.9 de	---	2.7 b	2.6 b		
	MA	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh									
G.41	3.6 abc	3.5 a	2.9 bc	---	3.3 bcd	2.9 a	---	3.1 ab	3.7 a
CG.4013	4.2 a	3.6 a	3.6 a	---	3.9 a	2.8 a	---	3.2 a	3.7 a
CG.5179	3.9 ab	3.6 a	3.1 bc	---	3.3 bcd	2.8 a	---	3.2 a	3.4 ab
G.202	3.8 ab	3.2 ab	3.2 ab	---	3.5 abc	2.8 a	---	3.0 ab	3.7 a
G.935	---	3.2 ab	---	---	3.8 ab	---	---	3.3 a	---
G.16N [y]	3.4 bc	2.6 b	3.2 ab	---	3.0 cd	2.9 a	---	2.7 ab	2.9 b
G.16T [y]	3.4 bc	2.6 b	2.8 bc	---	3.0 cd	3.1 a	---	2.7 ab	3.2 ab
M.9 NAKBT337	3.2 bc	3.0 ab	2.6 c	2.0 a	3.9 bcd	2.7 a	3.1 a	2.8 ab	3.1 ab
M.26 EMLA	3.7 ab	2.6 b	3.1 bc	2.3 a	3.5 abc	---	3.2 a	2.9 ab	3.3 ab
Supporter 1	2.9 c	2.7 b	3.0 bc	2.1 a	3.2 bcd	3.1 a	3.2 a	2.5 b	3.2 ab
Supporter 2	3.2 bc	2.8 b	2.7 bc	2.1 a	3.2 bcd	3.0 a	3.1 a	2.4 b	2.6 b
Supporter 3	2.9 c	2.7 b	2.9 bc	2.1 a	2.8 d	2.8 a	3.2 a	2.5 b	3.4 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 9. Burr knot severity (% of rootstock circumference affected) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	NC	PA-BI	PA-RO
Fuji					
G.41	3.3 a	0.0 a	0.0 b	2.6 a	---
CG.4013	0.8 a	0.0 a	1.2 b	0.0 a	---
CG.5179	12.5 a	2.6 a	13.0 ab	0.0 a	---
G.202	1.7 a	0.7 a	5.2 ab	2.4 a	---
G.935	1.3 a	---	23.3 a	---	---
G.16N [y]	11.7 a	0.5 a	11.3 ab	1.9 a	---
G.16T [y]	8.3 a	0.2 a	10.0 ab	3.4 a	---
M.9 NAKBT337	3.8 a	0.0 a	2.5 b	2.5 a	0.0 a
M.26 EMLA	3.3 a	1.4 a	3.0 b	3.3 a	1.7 a
Supporter 1	0.0 a	0.0 a	0.0 b	0.0 a	0.0 a
Supporter 2	1.7 a	0.2 a	0.8 b	0.0 a	0.0 a
Supporter 3	3.3 a	2.5 a	0.5 b	---	0.0 a
	MA	NS	NY-PE	NY-WI	PA-RO
McIntosh					
G.41	0.0 a	6.0 bc	---	4.0 ab	---
CG.4013	0.0 a	2.5 c	---	10.0 ab	---
CG.5179	15.8 a	1.7 c	---	16.7 ab	---
G.202	4.6 a	8.8 bc	---	5.0 ab	---
G.935	---	---	---	12.0 ab	---
G.16N [y]	2.9 a	12.5 abc	---	22.0 a	---
G.16T [y]	9.6 a	31.3 a	---	22.0 a	---
M.9 NAKBT337	0.9 a	11.0 abc	3.3 a	20.0 ab	0.0 a
M.26 EMLA	0.8 a	23.3 ab	3.3 a	11.7 ab	0.0 a
Supporter 1	0.0 a	0.8 c	1.7 a	10.0 ab	0.0 a
Supporter 2	0.0 a	2.5 c	3.3 a	0.0 b	0.8 a
Supporter 3	0.0 a	2.0 c	0.0 a	10.0 ab	0.0 a

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Discussion

G.41 was tested as CG.3041. It was named and released from the Cornell-Geneva Apple Rootstock Breeding Program in 2005 and is reported to be fireblight and phytophthora resistant (4). In this trial, it performed well, resulting in moderate-dwarf trees, with size between those on M.9 NAKBT337 and M.26 EMLA. It survived well, had a low incidence of burr knots and root suckers, induced high yield efficiency, and resulted in large fruit. A report on the first five years of this trial indicated similar performance of G.41 (1). Robinson et al. (10), Marini et al. (7), and Czynczyk et al. (2) all reported comparable performance of G.41. These results indicate

Table 10. Cumulative number of root suckers (1999-2008) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	PA-BI	PA-RO	SC	UT [y]	
Fuji									
G.41	1 a	20 b	5 a	2 c	7 b	---	---	19 c	
CG.4013	9 a	118 a	12 a	13 ab	114 a	---	---	48 bc	
CG.5179	3 a	58 ab	3 a	10 bc	48 ab	---	12 a	81 ab	
G.202	1 a	42 b	23 a	7 bc	28 b	---	---	102 a	
G.935	7 a	---	---	21 a	---	---	---	---	
G.16N [x]	8 a	22 b	2 a	3 c	6 b	---	67 a	11 c	
G.16T [x]	1 a	26 b	4 a	2 c	24 b	---	---	20 c	
M.9 NAKBT337	0 a	30 b	---	8 bc	35 b	26 a	9 a	32 bc	
M.26 EMLA	1 a	3 b	3 a	4 bc	12 b	2 a	---	0 c	
Supporter 1	0 a	22 b	2 a	1 c	2 b	6 a	24 a	40 bc	
Supporter 2	17 a	1 b	8 a	1 c	10 b	2 a	7 a	2 c	
Supporter 3	24 a	20 b	1 a	5 bc	---	11 a	20 a	7 c	
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT
McIntosh									
G.41	5 c	3 bc	0 a	0 a	---	0 a	2 a	---	0 b
CG.4013	23 ab	16 b	2 a	0 a	---	11 a	4 a	---	8 ab
CG.5179	26 a	6 bc	1 a	1 a	---	10 a	3 a	---	2 b
G.202	4 c	4 bc	1 a	1 a	---	2 a	5 a	---	1 b
G.935	---	34 a	1 a	---	---	6 a	---	---	14 a
G.16N [x]	0 c	2 bc	0 a	0 a	---	1 a	2 a	---	0 b
G.16T [x]	3 c	11 bc	1 a	3 a	---	3 a	1 a	---	4 ab
M.9 NAKBT337	11 bc	9 bc	0 a	0 a	6 a	14 a	6 a	51 ab	1 b
M.26 EMLA	0 c	3 bc	0 a	0 a	1 ab	1 a	---	1 b	0 b
Supporter 1	2 c	12 bc	1 a	0 a	0 b	15 a	8 a	54 a	2 b
Supporter 2	3 c	1 c	1 a	0 a	1 ab	5 a	4 a	17 ab	3 ab
Supporter 3	8 c	10 bc	0 a	1 a	1 ab	2 a	6 a	34 ab	1 b

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] Trees in UT were removed at the end of 8 growing seasons.
[x] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 11. Cumulative yield per tree (kg, 2001-08) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock [y]	KY	MO	NC	PA-BI	PA-RO	SC
Fuji						
G.41	354 a	78 c	168 cde	358 ab	---	---
CG.4013	331 a	359 a	288 ab	448 a	---	---
CG.5179	329 a	242 abc	273 ab	393 ab	---	331 ab
G.202	296 a	267 ab	267 ab	366 ab	---	---
G.935	---	---	328 a	---	---	---
G.16N[y]	293 a	295 abc	233 abc	299 ab	---	363 a
G.16T[y]	325 a	208 abc	239 abc	377 ab	---	---
M.9 NAKBT337	265 a	---	173 cde	268 b	313 b	323 abc
M.26 EMLA	218 a	116 bc	201 bcd	364 ab	373 a	---
Supporter 1	226 a	67 c	82 e	237 b	150 cd	201 c
Supporter 2	246 a	78 c	99 e	163 b	134 d	311 abc
Supporter 3	214 a	172 bc	105 de	---	209 c	210 bc

Rootstock [y]	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	239 bc	300 a	150 ab	176 bc	---	268 bc	179 abc	---	158 abcd	210 a
CG.4013	364 a	319 a	180 a	322 a	---	350 ab	196 ab	---	216 a	213 a
CG.5179	301 ab	316 a	152 ab	194 b	---	212 c	155 bc	---	162 abc	179 ab
G.202	296 ab	315 a	152 ab	190 bc	---	277 bc	129 c	---	175 ab	187 ab
G.935	---	390 a	136 ab	---	---	382 a	---	---	214 a	---
G.16N[y]	167 c	306 a	96 b	184 bc	---	219 c	200 ab	---	140 cd	146 b
G.16T[y]	202 bc	296 a	99 b	176 bc	---	191 c	181 abc	---	143 cd	154 b
M.9 NAKBT337	146 c	315 a	57 b	128 c	121 bc	234 bc	178 abc	192 b	129 cd	114 b
M.26 EMLA	210 bc	320 a	83 b	160 bc	117 c	282 abc	---	222 ab	148 bcd	140 b
Supporter 1	173 c	291 a	91 b	185 bc	162 a	213 c	216 a	223 ab	115 cd	162 ab
Supporter 2	212 bc	296 a	93 b	165 bc	144 abc	250 bc	199 ab	224 ab	96 d	142 b
Supporter 3	217 bc	294 a	70 b	167 bc	159 ab	245 bc	207 ab	269 a	128 cd	169 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 12. Cumulative yield efficiency (kg•cm^{-2} TCA, 2001-08) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	KY	MO	NC	PA-BI	PA-RO	SC
Fuji						
G.41	4.0 a	0.9 ab	2.9 a	6.0 a	---	---
CG.4013	2.3 b	1.4 ab	1.8 a	3.5 b	---	---
CG.5179	3.8 ab	1.9 ab	3.4 a	4.9 ab	---	3.2 a
G.202	3.3 ab	1.6 ab	2.5 a	4.8 ab	---	---
G.935	---	---	3.6 a	---	---	---
G.16N[y]	3.1 ab	2.2 ab	2.5 a	4.4 ab	---	2.0 a
G.16T[y]	3.5 ab	1.8 ab	2.8 a	4.2 ab	---	---
M.9 NAKBT337	3.4 ab	---	3.1 a	5.4 a	4.1 a	2.9 a
M.26 EMLA	2.9 b	1.1 b	1.9 a	3.7 ab	3.2 a	---
Supporter 1	4.4 a	1.2 ab	2.6 a	5.6 a	4.0 a	2.7 a
Supporter 2	3.7 ab	1.1 b	2.5 a	3.7 ab	3.8 a	3.5 a
Supporter 3	3.7 ab	2.4 a	2.6 a	---	4.1 a	3.2 a

Rootstock	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	3.7 ab	3.2 a	2.9 a	3.9 ab	---	3.4 ab	1.9 bcde	---	3.8 ab	4.5 ab
CG.4013	3.4 ab	1.3 b	2.9 a	4.5 ab	---	2.0 e	1.4 de	---	3.6 ab	4.3 ab
CG.5179	4.3 ab	2.7 ab	3.1 a	4.7 ab	---	2.4 cde	1.7 cde	---	3.0 ab	4.6 a
G.202	3.9 ab	1.3 b	2.7 a	3.5 b	---	2.2 de	1.0 e	---	2.7 b	3.4 b
G.935	---	2.7 ab	2.9 a	---	---	3.1 abcd	---	---	3.7 ab	---
G.16N[y]	3.2 b	2.9 a	3.0 a	3.7 ab	---	3.5 ab	3.2 abc	---	3.3 ab	4.1 ab
G.16T[y]	4.0 ab	2.7 ab	2.8 a	4.4 ab	---	2.4 cde	2.8 abc	---	3.2 ab	4.2 ab
M.9 NAKBT337	3.7 ab	2.8 a	2.4 a	4.9 a	5.1 a	3.6 ab	2.6 abcd	2.8 ab	4.1 a	4.5 ab
M.26 EMLA	3.7 ab	2.0 ab	2.0 a	3.5 b	2.6 b	2.7 bcde	---	2.3 b	3.0 ab	3.5 b
Supporter 1	4.7 a	3.6 a	3.2 a	4.4 ab	4.3 a	3.0 abcd	2.8 abc	3.4 ab	3.8 ab	5.4 a
Supporter 2	4.5 ab	3.6 a	2.4 a	4.1 ab	4.5 a	3.7 a	3.8 a	3.7 a	2.6 b	4.8 a
Supporter 3	4.6 ab	3.3 a	2.3 a	4.0 ab	4.2 a	3.3 abc	3.4 ab	3.6 a	3.6 ab	4.3 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

Table 13. Average fruit weight (g, 2001-08) by location of 'Fuji' and 'McIntosh' apple trees on various rootstocks at the end of ten growing seasons as part of the 1999 NC-140 Dwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA[y]	KY	MO	NC	PA-BI	PA-RO	SC	UT[x]
Fuji								
G.41	180 a	173 a	209 a	181 a	225 a	---	---	204 a
CG.4013	181 a	167 ab	223 a	168 a	221 a	---	---	211 a
CG.5179	189 a	165 ab	201 a	176 a	227 a	---	185 ab	204 a
G.202	176 a	167 ab	230 a	174 a	215 a	---	---	203 a
G.935	188 a	---	---	183 a	---	---	---	---
G.16N[w]	179 a	153 abcd	224 a	170 a	216 a	---	190 a	197 a
G.16T[w]	193 a	160 abc	209 a	181 a	230 a	---	---	202 a
M.9 NAKBT337	198 a	177 a	---	185 a	232 a	191 a	189 ab	213 a
M.26 EMLA	199 a	156 abc	216 a	168 a	229 a	191 a	---	217 a
Supporter 1	173 a	135 d	194 a	154 a	204 a	135 b	172 bc	199 a
Supporter 2	180 a	149 bcd	193 a	169 a	177 a	135 b	171 bc	193 a
Supporter 3	175 a	139 cd	201 a	168 a	---	141 b	169 c	202 a

Rootstock	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
G.41	171 a	174 a	131 a	131 a	---	154 a	170 a	---	170 ab	162 ab
CG.4013	167 a	161 a	124 a	124 a	---	146 a	161 ab	---	157 bcde	158 ab
CG.5179	162 a	168 a	131 a	118 a	---	145 a	161 ab	---	159 abcd	157 ab
G.202	169 a	175 a	122 a	127 a	---	147 a	158 ab	---	150 de	161 ab
G.935	---	173 a	121 ab	---	---	152 a	---	---	174 a	---
G.16N[w]	167 a	180 a	108 ab	128 a	---	145 a	154 ab	---	159 abcd	148 b
G.16T[w]	163 a	171 a	120 ab	120 a	---	153 a	159 ab	---	153 bcde	153 ab
M.9 NAKBT337	174 a	164 a	136 a	128 a	143 a	143 a	163 ab	166 a	164 abcd	139 b
M.26 EMLA	166 a	167 a	114 ab	128 a	143 a	150 a	---	165 ab	168 abc	166 a
Supporter 1	166 a	174 a	121 ab	126 a	140 ab	150 a	155 ab	154 bc	152 cde	161 ab
Supporter 2	157 a	165 a	113 ab	121 a	137 ab	148 a	149 b	152 c	145 e	159 ab
Supporter 3	161 a	165 a	98 b	117 a	132 b	144 a	151 b	158 abc	154 bcde	167 a

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] Fruit size was assessed only through the fourth harvest year (2004) in CA.
[x] Fruit size was assessed only through the sixth harvest year (2006) in UT.
[w] G.16N was propagated from normal stool beds, and G.16T came from stool beds established with tissue cultured plants.

that G.41, particularly in light of its disease resistance, could be a suitable alternative to M.9 in the moderate dwarfing range.

G.202 was tested as CG.4202 and named and released in the U.S. from the Cornell-Geneva Apple Rootstock Breeding Program in 2004. It is reported to be fireblight, phytophthora, and woolly apple aphid resistant (4). In this trial, 'Fuji' trees on G.202 were comparable in size to those on M.26 EMLA, but 'McIntosh' trees on G.202 were significantly larger than those on M.26 EMLA. G.202 resulted in few burr knots and root suckers. Cumulative yield efficiency with 'Fuji' was high but with 'McIntosh,' was low. Resulting fruit size was high. Early observations from this trial gave similar results (1). With 'Liberty' as the scion cultivar, Robinson et al. (11, 12) found trees on G.202 to be somewhat larger than those on M.26 with comparable yield efficiency. Czynczyk et al. (2) found 'Golden Delicious Reinders' trees on G.202 to be similar in size and yield efficiency to those on M.26.

G.16 is a 1998 release from the Cornell-Geneva Apple Rootstock Breeding Program and is reported to be fireblight and phytophthora resistant (4). In this trial, trees on G.16 were between those on M.9 NAKBT337 and those on M.26 EMLA in size, placing them in a moderate-dwarf category. Survival was high, burr knot incidence was higher with G.16 than other rootstocks, but root suckering was relatively low. Yield efficiency and fruit size were both reasonably high. Five-year results from this trial had similar findings (1). Robinson et al. (10) reported similar results with 'Gala' and 'Jonagold' across several North American locations, as did Marini et al. (7) with 'Golden Delicious' in several comparable locations. As a rootstock resulting in moderate dwarfing and with resistance to fireblight and phytophthora, G.16 is a good alternative to M.9 in North America. A secondary objective of this trial was to compare trees on G.16 liners from normal stool beds (designated G.16N) with those from stool beds established with tissue cultured plants (designated G.16T). Differences between the two were not statistically significant; therefore, there is no reason to be concerned about the method of stool bed propagation of G.16.

G.935 was released from the Cornell-Geneva Apple Rootstock Breeding Program in 2004 and is reported to be resistant to fireblight and phytophthora (4). In this trial, it was included in only two 'Fuji' and four 'McIntosh' sites. All trees at all six sites survived for the length of the trial. With the exception of CA, size of trees on G.935 was not significantly different from that of trees on M.26 EMLA. Burr knot severity was high in NC, and root suckering was high at several sites. Yield efficiency of trees on G.935 was high. Comparable results were observed in this trial after 5 years (1). Marini et al. (7) found also that 'Golden Delicious' trees on G.935 were comparable to those on M.26 in size, produced a large number of root suckers, and were very yield efficient.

CG.4013 is a product of the Cornell-Geneva Apple Rootstock Breeding Program but has not yet been named. In this trial, trees were the largest and probably were in the semi-dwarf size category. Survival was among the best. Burr knot incidence was low, but root suckering was high. Yield per tree was high, but yield efficiency was low or moderate. Performance over 10 years was similar to that reported at year five of this trial (1). Robinson et al. (12) reported similar effects of CG.4013 on 'Liberty' tree size, yield, and yield efficiency.

CG.5179 also is a product of the Cornell-Geneva Apple Rootstock Breeding Program which has not been named and has been discarded from further consideration (13). Tree size was between those on M.9 NAKBT337 and M.26 EMLA, placing it in a moderate-dwarf category. Survival was high, burr knot incidence was moderate to high, and root suckering was high. Yield efficiency of trees on CG.5179 was high, and fruit size was good. Robinson et al. (12) reported results from two trials with 'Liberty' as the scion cultivar, both with similar results to those presented here.

Supporter 1 (tested as PiAu 7-33), **Supporter 2** (tested as PiAu 9-16), and **Supporter 3** (tested as PiAu 9-82) are all products of the Dresden-Pillnitz Apple and Pear Rootstock Breeding Program. They are not resistant to fireblight but are highly resistant to apple scab and moderately resistant to mildew (5). In this trial, the size of trees on the three Supporter rootstocks was similar to that of trees on M.9 NAKBT337, and therefore, all would be considered small dwarfs. Survival was moderate to good. Burr knot severity and root suckering were both low. Yield efficiency was high, but fruit size tended to be small. Similar observations were made after 5 years of this trial (1). Dierend and Bier-Kamotzke (3) found 'Elstar,' 'Boskoop,' and 'Jonagold' trees on Supporter 1 to be similar or slightly smaller than comparable trees on M.9. Stehr (14), likewise, found trees on Supporter 1 to be similar in size to those on M.9, but also found trees on Supporter 2 and Supporter 3 to be larger than comparable trees on M.9. The reason for the discrepancy between Stehr's results and those reported has not yet been determined.

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