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Performance of 'Fuji' and 'McIntosh' Apple Trees after 10 Years as Affected by Several Semidwarf 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 CG.4814, CG.7707, Geneva® 30 (G.30N, liners from normal stool beds), M.7 EMLA, M.26 EMLA, and Supporter 4 rootstocks were planted at six sites with 'Fuji' and ten sites with 'McIntosh' as the scion cultivar throughout North America as a uniform trial coordinated by the NC-140 Multi-State Research Committee. Partial plantings were established at one 'Fuji' and two 'McIntosh' sites, and Geneva® 210 (G.210) and G.30T (liners from stool beds established with tissue cultured plants) were included in two 'Fuji' and four 'McIntosh' plantings. After ten growing seasons, survival did not differ among rootstocks overall with either scion cultivar; however, within sites, rootstock survival did vary. After 10 years, few differences in size were noted among 'Fuji' trees on the different rootstocks in the trial. 'McIntosh' trees, however, separated into clear size categories, with the largest trees on M.7 EMLA. Those on G.30 and on Supporter 4 were similar and slightly smaller than trees on M.7 EMLA but still would be considered semidwarfs. Smallest trees were on CG.4814, M.26 EMLA, and CG.7707 and would be considered large dwarf trees. 'Fuji' trees did not have many burr knots. 'McIntosh' trees, however, had more severe burr knots, with M.7 EMLA encouraging the greatest portion of the rootstock's shank circumference affected. Irrespective of scion cultivar, M.7 produced the most root suckers, followed by CG.4814, and G.30. Cumulative yield was greatest for trees on G.30N for both cultivars. Lowest yielding 'Fuji' trees were on M.7 EMLA, and the lowest yielding 'McIntosh' trees were on M.26 EMLA. The most yield efficient 'Fuji' trees were on G.30N, followed by those on CG.7707 and CG.4814. The most yield efficient 'McIntosh' trees were on CG.4814, followed by those on CG.7707 and G.30N. The least yield efficient trees of both cultivars were on M.7 EMLA. Average fruit size over the life of the trial was greatest from trees on CG.7707. The smallest 'Fuji' fruit were from trees on CG.4814, and the smallest 'McIntosh' fruit were from trees on M.26 EMLA.

Introduction

Growers interested in semidwarf rootstocks for free-standing apple production historically have had few options, and those rootstocks tended to have low precocity and low yield efficiency. Several rootstocks have been evaluated by the NC-140 Multi-State Research Committee (6, 7), but few have performed better than M.7. A number of new semidwarf rootstocks have become available in recent years.

The Cornell-Geneva Apple Rootstock Breeding Program is a cooperative effort between Cornell University and the United States Department of Agriculture. They have released some new rootstocks in the semidwarf category (2), and have several in various stages of testing. The primary objective of the Cornell-Geneva program is disease resistance, so all releases have a high degree of fireblight resistance, and most are phytophthora resistant as well.

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The Institut für Obstforschung Dresden-Pillnitz in Germany also has released new rootstocks in recent years. Supporter 4 from their program as a semidwarf apple rootstock, reported to be similar size to trees on M.26 and more productive (4).

The objective of the 1999 NC-140 Semidwarf Apple Rootstock Trial was to evaluate Cornell-Geneva and Dresden-Pillnitz rootstocks in comparison to M.7 EMLA and M.26 EMLA, utilizing several locations with uniform plantings.

Materials & Methods

In spring, 1999, two trials of semidwarf 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 and Utah, with a partial planting in South Carolina (Table 1). The 'McIntosh' trial was planted in Massachusetts, Michigan, Minnesota, Nova Scotia, New York (Williamson), Ontario, Vermont, and Wisconsin, with partial plantings in New York (Peru) and Pennsylvania (Rock Springs) (Table 1). Rootstocks were CG.4814, CG.7707, Geneva® 30 (G.30N, liners from normal stool beds), M.7 EMLA, M.26 EMLA, and Supporter 4. Plantings at two 'Fuji' (CA and NC) and four 'McIntosh' (MI, MY, Williamson, NY, and VT) sites also included Geneva® 210 (G.210) and G.30T (liners from stool beds established with tissue cultured plants) as rootstock treatments.

Trees were spaced 4 m x 6 m and trained as free-standing central leaders. At planting, the bud union was set approximately 10 cm above the soil. Water, fertility, and pest control were 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 was measured in October, 2008. Canopy spread was assessed in October, 2008 as the average of the in-row and across-row canopy widths. Root suckers were counted and removed annually in August. Burr knot severity was assessed in October, 2008 as the percent of the rootstock shank's circumference affected by burr knots. Yield per tree was assessed in 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.

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 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 ten growing seasons, rootstock did not affect survival of 'Fuji' or 'McIntosh' trees (Table 2). Rootstock also did not affect longevity of 'Fuji' trees, but 'McIntosh' trees on CG.7707 were significantly shorter lived than those on G.30N, M.26 EMLA, or M.7

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	Fletcher	M. Parker	Dept. Horticulture, North Carolina State University, Box 7609, Raleigh, NC 27695 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

EMLA. That is to say, within the life of the trial, those trees on CG.7707 which did not survive died earlier in the trial than trees on other rootstocks.

Rootstock-induced differences in 'Fuji' tree size, as assessed with TCA, tree height, or canopy spread, were not significantly different (Table 2). The largest 'McIntosh' trees were on M.7 EMLA, followed in descending order by G.30N, CG.7707, Supporter 4, M.26 EMLA, and CG.4814 (Table 2).

Burr knot development on 'Fuji' trees was not affected by rootstock. M.7 EMLA induced more severe burr knots with 'McIntosh' than did Supporter 4, CG.7707, or G.30N.

Root suckering was much more prominent with 'Fuji' as the scion cultivar compared to 'McIntosh' (Table 2). M.7 EMLA and CG.4814 resulted in the most root suckering with both scion cultivars, and M.26 EMLA resulted in the least root suckering.

In 2008, yield of 'Fuji' trees was not affected by rootstock, but cumulatively (2001-08), trees on G.30N yielded the most per tree, and those on M.7 EMLA yielded the least (Table 3). 'McIntosh' trees on G.30N and those on M.7 EMLA yielded more than trees on CG.4814 in 2008 (Table 3). Cumulatively (2001-08), 'McIntosh' trees on G.30N yielded more than those on M.26 EMLA, CG.4814, or CG.7707. Trees on M.26 EMLA yielded the least.

In 2008, rootstock did not affect yield efficiency of 'Fuji,' but 'McIntosh' trees on CG.4814 and those on CG.7707 were more yield efficient than those on M.7 EMLA (Table 3). Cumulatively (2001-08), 'Fuji' trees on G.30N were significantly more yield efficient than those on M.26 EMLA or M.7 EMLA (Table 3). 'Fuji' trees on M.7 EMLA were the least efficient. 'McIntosh' trees on CG.4814 were cumulatively more yield efficient than

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 Semidwarf 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)[x]	Tree height (2008, m)[w]	Canopy spread (2008, m)[w]	Burr knots (2008, % of circumference affected)[v]	Cumulative root suckers (1999-2008, no.)[u]
Fuji							
CG.4814	89 a	8.8 a	114 a	3.5 a	3.3 a	6.9 a	57.5 b
CG.7707	85 a	8.6 a	119 a	3.6 a	3.3 a	4.4 a	20.3 bc
G.30N	80 a	8.4 a	117 a	3.9 a	3.6 a	1.0 a	28.1 bc
M.26 EMLA	67 a	7.6 a	134 a	3.6 a	3.3 a	1.8 a	4.5 c
M.7 EMLA	90 a	9.0 a	127 a	3.4 a	3.2 a	3.6 a	154.8 a
McIntosh							
CG.4814	88 a	9.5 ab	62 e	3.0 c	3.3 b	10.9 ab	14.1 b
CG.7707	64 a	7.6 b	81 cd	3.0 c	3.5 ab	4.6 b	2.8 bc
G.30N	76 a	9.2 a	100 b	3.4 ab	3.7 a	2.0 b	11.7 bc
M.26 EMLA	92 a	9.6 a	77 de	3.1 bc	3.3 b	12.0 ab	1.2 c
M.7 EMLA	92 a	9.6 a	117 a	3.5 a	3.8 a	19.2 a	42.2 a
Supporter 4	81 a	8.7 ab	99 bc	3.4 ab	3.5 ab	8.1 b	10.6 bc

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] 'Fuji' data from CA, KY, MO, NC, and UT (8 seasons only), and 'McIntosh' data from MA, MI, MN, NS, NY, ON, and WI.
[x] 'Fuji' data from CA, KY, NC, and UT (8 seasons only), and 'McIntosh' data from MA, MI, MN, NS, NY, and WI.
[w] 'Fuji' data from CA, KY, and NC, and 'McIntosh' data from MA, MN, NS, NY, ON and WI.
[v] 'Fuji' data from CA, KY, and NC, and 'McIntosh' data from MA, NS, and NY.
[u] 'Fuji' data from CA, KY, NC, and UT (8 seasons only), and 'McIntosh' data from MA, MI, MN, NS, NY, and ON.

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 Semidwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	Yield per tree (kg)		Yield efficiency (kg·cm^{-2} TCA)		Fruit weight (g)	
	2008[y]	Cumulative (2001-08)[y]	2008[y]	Cumulative (2001-08)[y]	2008[y,x]	Average (2001-08)[w]
Fuji						
CG.4814	90 a	256 bc	0.9 a	2.7 ab	161 a	182 b
CG.7707	114 a	326 ab	1.0 a	2.8 ab	172 a	195 a
G.30N	125 a	370 a	1.1 a	3.2 a	176 a	193 ab
M.26 EMLA	92 a	236 bc	0.9 a	2.3 bc	162 a	187 ab
M.7 EMLA	81 a	227 c	0.6 b	2.0 c	161 a	188 ab
McIntosh[v]						
CG.4814	37 b	187 b	0.7 a	3.3 a	168 a	153 ab
CG.7707	45 ab	189 b	0.7 a	2.7 b	166 a	157 a
G.30N	50 a	234 a	0.5 ab	2.5 bc	159 ab	153 ab
M.26 EMLA	39 ab	153 c	0.6 ab	2.2 c	153 bc	148 b
M.7 EMLA	50 a	203 ab	0.4 b	1.8 d	163 a	153 ab
Supporter 4	44 ab	211 ab	0.5 ab	2.4 bc	147 c	152 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).
[y] 'Fuji' data from KY and NC only.
[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, NC, and UT (6 harvest seasons only).
[v] All 'McIntosh' data from MA, MI, MN, NS, NY, ON, and WI.

trees on any of the other rootstocks. 'McIntosh' trees on CG.7707 were cumulatively more yield efficient than trees on M.26 EMLA or M.7 EMLA, and trees on M.7 EMLA were the least efficient (Table 3).

Effects of rootstock on fruit weight were modest (Tables 3). In 2008, rootstock did not affect 'Fuji' size. CG.4814, CG.7707, and M.7 EMLA resulted in larger 'McIntosh' fruit in 2008 than did M.26 EMLA or Supporter 4. Average 'Fuji' fruit size over the life of the trial was larger from trees on CG.7707 than from those on CG.4814, and average 'McIntosh' fruit size was larger from trees on CG.7707 than from those on M.26 EMLA.

Rootstock Effects by Site

For most measured parameters, site and rootstock interacted to affect the results. For the 'Fuji' trial, however, site did not interact with rootstock to affect burr knot development, cumulative yield, or cumulative yield efficiency. It should be noted that 'Fuji' data are limited because of the small number of sites and a large amount of tree loss at some locations. For the 'McIntosh' trial, site and rootstock interacted to affect all parameters except burr knot development. All prominent site-related deviations will be presented, regardless of the significance of the interaction, because of the inclusion of additional rootstocks (as originally intended or through survival) at some sites and not others.

Tree loss was high for some 'Fuji' sites and with some rootstocks. Survival of 'Fuji' trees on CG.4814, G.210, CG.7707, and G.30T was

reasonably good for all sites (Table 4). Trees on G.30 survived well, except in MO, where all trees died. Only 17% and 50% of trees on M.26 EMLA in MO and UT, respectively, survived until termination of the trial at that site. Only 50% of trees on M.7 EMLA survived in MO. Only 17% of trees on Supporter 4 survived in KY. No trees on Supporter 4 survived in MO, and 50% died in SC. For 'McIntosh', only VT reported losses of 50% or more of trees on CG.4814, and only MI reported losses of 50% or more of trees on G.210. In MI, MN, and ON, 50% or fewer of 'McIntosh' trees on CG.7707 survived until the end of the trial. No site reported 50% or more loss of trees on G.30N, G.30T, or M.26 EMLA. MN lost 50% of 'McIntosh' trees on M.7 EMLA and 83% of those on Supporter 4. Otherwise, losses of 'McIntosh' trees on M.7 EMLA or on Supporter 4 were low. Tree loss, generally, occurred throughout the 10 years of the trial, thus average longevity followed percent survival (Table 5).

Rootstock effects on tree size as measured by TCA varied amongst sites (Table 6). For 'Fuji,' although in some cases differences in TCA among rootstocks were large, those differences were statistically significant only in SC and UT. SC was a partial site, and trees on M.26 EMLA had a significantly larger TCA than those on CG.4814, with those on Supporter 4 intermediate between the two. In UT, Trees on M.7 EMLA had were larger than those on CG.4814 or CG.7707, with trees on G.30N and M.26 EMLA intermediate. For 'McIntosh,' differences among rootstocks were nonsignificant in MN, ON, and VT. Across the other seven sites, trees on M.7 EMLA were consistently the largest, and those on CG.4814 were consistently the smallest. In MA, trees on M.7 EMLA, G.30N, and Supporter 4 were statistically similar and larger than those on CG.4814, M.26 EMLA, and CG.7707. In MI, trees on M.7 EMLA were significantly larger than those on CG.4814 and CG.7707, and all other rootstocks were intermediate. In NS, trees on M.7 EMLA and G.30N were similar and larger than those on CG.4814 and M.26 EMLA. Trees in NS on the other rootstocks were intermediate in size between these two groups. In Peru, NY, trees on M.7 EMLA were larger than those on Supporter 4, which were larger than those on M.26 EMLA. In Williamson, NY, trees on M.7 EMLA and Supporter 4 were significantly larger than those on CG.4814, G.210, and CG.7707. In Rock Springs, PA, trees on M.7 EMLA and Supporter 4 were similar and larger than those on M.26 EMLA. In WI, trees on M.7 EMLA and M.26 EMLA were larger than those on CG.4814. 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 and were more often nonsignificant.

Burr knot severity was assessed only in CA, KY, and NC for 'Fuji' and in MA, NS, Peru, NY, Williamson, NY and Rock Springs, PA for 'McIntosh' (Table 9). Differences among rootstocks were nonsignificant at all three 'Fuji' sites and for 'McIntosh' in MA and Rock Springs, PA. In NS and Williamson, NY, burr knot severity was greater for M.7 EMLA than for G.30N. Other rootstocks resulted in intermediate severity. In Peru, NY, 'McIntosh' trees on M.7 EMLA had greater burr knot severity than those on M.26 EMLA or Supporter 4.

Root suckering generally was more pronounced at 'Fuji' sites than at 'McIntosh' sites (Table 10). Across both cultivars, however, M.7 EMLA induced the most root suckers. In general, CG.4814 also produced a large number of root suckers, and G.210 in NC, Williamson, NY, and VT and CG.7707 in KY produced larger numbers of root suckers. G.30N in KY, UT, MA, and Williamson, NY, G.30T in NC and Williamson, NY, and Supporter 4 in Williamson, NY and Rock Springs, PA also produced a significant number of root suckers.

Cumulative yield per tree (2001-08) was affected by rootstock (Table 11). For 'Fuji,' rootstock differences were significant only in KY, where trees on G.30N outyielded those on Supporter 4. For 'McIntosh,' rootstock

Table 4. Survival (%) by location of 'Fuji and 'McIntosh' apple trees on various rootstocks through ten growing seasons as part of the 1999 NC-140 Semidwarf Apple Rootstock Trials. All values are least-squares means adjusted for missing subclasses.[z]

Rootstock	CA	KY	MO	NC	SC	UT[y]				
Fuji										
CG.4814	100	80	67	100	80	100				
G.210	100	---	---	100	---	---				
CG.7707	100	60	67	100	---	100				
G.30N	100	100	0	100	---	100				
G.30T	83	---	---	100	---	---				
M.26 EMLA	83	67	17	100	100	50				
M.7 EMLA	100	100	50	100	---	100				
Supporter 4	100	17	0	100	50	---				
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	100	83	100	100	---	75	67	---	50	100
G.210	---	40	80	---	---	100	---	---	100	---
CG.7707	83	33	33	83	---	75	50	---	83	100
G.30N	100	100	83	100	---	100	75	---	83	67
G.30T	---	80	60	---	---	80	---	---	80	---
M.26 EMLA	100	100	67	100	100	100	83	100	---	100
M.7 EMLA	100	100	50	100	100	100	100	100	100	100
Supporter 4	83	100	17	100	100	100	67	100	100	100

[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.

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

Rootstock	CA	KY	MO	NC	SC	UT[y]				
Fuji										
CG.4814	10.0 a	8.6 ab	7.3 a	10.0 a	8.2 a	8.0 a				
G.210	10.0 a	---	---	10.0 a	---	---				
CG.7707	10.0 a	7.2 ab	7.8 a	10.0 a	---	8.0 a				
G.30N	10.0 a	10.0 a	4.1 ab	10.0 a	---	8.0 a				
G.30T	9.7 a	---	---	10.0 a	---	---				
M.26 EMLA	9.2 a	8.2 ab	4.5 ab	10.0 a	10.0 a	6.2 a				
M.7 EMLA	10.0 a	10.0 a	6.8 ab	10.0 a	---	8.0 a				
Supporter 4	10.0 a	5.0 b	1.8 b	10.0 a	7.5 a	---				
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	10.0 a	9.7 a	10.0 a	10.0 a	---	9.8 a	7.3 a	---	7.2 a	10.0 a
G.210	---	6.1 a	8.2 ab	---	---	10.0 a	---	---	10.0 a	---
CG.7707	9.2 a	4.7 b	5.7 ab	8.7 a	---	7.5 a	7.3 a	---	9.8 a	10.0 a
G.30N	10.0 a	10.0 a	9.0 a	10.0 a	---	10.0 a	8.8 a	---	9.2 a	6.7 a
G.30T	---	8.7 a	7.2 ab	---	---	9.0 a	---	---	9.0 a	---
M.26 EMLA	10.0 a	10.0 a	7.7 ab	10.0 a	10.0 a	10.0 a	9.5 a	10.0 a	---	10.0 a
M.7 EMLA	10.0 a	10.0 a	7.3 ab	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a	10.0 a
Supporter 4	9.5 a	10.0 a	3.0 b	10.0 a	10.0 a	10.0 a	8.2 a	10.0 a	10.0 a	10.0 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.

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

Rootstock	CA	KY	MO	NC	SC	UT[y]				
Fuji										
CG.4814	210 a	94 a	169 a	95 a	106 b	59 b				
G.210	164 a	---	---	146 a	---	---				
CG.7707	155 a	112 a	217 a	120 a	---	87 b				
G.30N	159 a	121 a	---	103 a	---	92 ab				
G.30T	167 a	---	---	115 a	---	---				
M.26 EMLA	247 a	91 a	146 a	112 a	173 a	88 ab				
M.7 EMLA	140 a	107 a	147 a	149 a	---	119 a				
Supporter 4	150 a	20 a	---	94 a	117 ab	---				
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	45 b	69 b	42 a	46 b	---	81 d	83 a	---	61 a	69 c
G.210	---	88 ab	76 a	---	---	98 cd	---	---	63 a	---
CG.7707	54 b	58 b	65 a	65 ab	---	105 cd	122 a	---	62 a	91 bc
G.30N	105 a	88 ab	73 a	70 a	---	131 bc	124 a	---	66 a	114 abc
G.30T	---	89 ab	65 a	---	---	125 bc	---	---	80 a	---
M.26 EMLA	50 b	78 ab	41 a	46 b	54 c	83 d	115 a	128 b	---	124 ab
M.7 EMLA	121 a	121 a	60 a	70 a	118 a	178 a	111 a	213 a	60 a	155 a
Supporter 4	101 a	98 ab	63 a	52 ab	86 b	159 ab	148 a	178 a	65 a	79 bc

[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.

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

Rootstock	CA	KY	MO	NC	SC				
Fuji									
CG.4814	4.3 a	2.9 a	3.9 a	3.1 a	3.9 a				
G.210	4.0 a	---	---	3.5 a	---				
CG.7707	4.0 a	3.2 a	3.8 a	3.7 a	---				
G.30N	4.3 a	3.7 a	---	3.7 a	---				
G.30T	4.2 a	---	---	3.7 a	---				
M.26 EMLA	4.3 a	3.0 a	3.2 a	3.5 a	4.0 a				
M.7 EMLA	4.4 a	3.0 a	3.2 a	3.9 a	---				
Supporter 4	3.6 a	1.5 b	---	3.2 a	3.9 a				
	MA	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh									
CG.4814	2.7 b	2.1 a	2.7 a	---	4.0 ab	3.5 a	---	3.5 a	3.0 b
G.210	---	2.6 a	---	---	3.9 b	---	---	3.4 a	---
CG.7707	2.6 b	2.5 a	2.8 a	---	3.6 b	3.5 a	---	3.1 a	3.3 ab
G.30N	3.3 ab	2.6 a	3.1 a	---	4.4 ab	3.1 a	---	3.8 a	3.7 ab
G.30T	---	2.7 a	---	---	4.3 ab	---	---	3.8 a	---
M.26 EMLA	2.9 ab	2.4 a	2.4 a	3.7 b	3.8 b	3.1 a	4.8 a	---	3.9 a
M.7 EMLA	3.5 a	2.6 a	3.0 a	4.5 a	5.0 a	3.2 a	5.2 a	3.7 a	3.9 a
Supporter 4	3.4 a	2.5 a	2.7 a	4.3 a	5.0 a	3.6 a	5.2 a	3.6 a	3.3 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).

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

Rootstock	CA	KY	MO	NC	SC				
Fuji									
CG.4814	3.7 ab	3.5 ab	3.7 a	2.6 a	3.7 a				
G.210	3.4 ab	---	---	3.1 a	---				
CG.7707	2.9 b	3.8 ab	3.9 a	3.1 a	---				
G.30N	3.9 ab	3.9 a	---	3.0 a	---				
G.30T	4.2 a	---	---	3.1 a	---				
M.26 EMLA	3.8 ab	3.3 ab	3.9 a	2.9 a	3.8 a				
M.7 EMLA	3.1 b	3.3 ab	3.1 a	3.0 a	---				
Supporter 4	3.2 b	1.8 b	---	2.8 a	3.5 a				
	MA	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh									
CG.4814	3.6 b	2.9 bc	3.1 b	---	3.2 b	3.0 a	---	3.0 a	3.9 ab
G.210	---	3.6 a	---	---	3.1 b	---	---	3.3 a	---
CG.7707	3.6 b	3.5 a	3.3 ab	---	3.3 b	3.2 a	---	3.8 a	3.9 ab
G.30N	4.3 ab	3.7 a	3.5 ab	---	3.8 ab	2.8 a	---	3.4 a	4.1 ab
G.30T	---	3.3 ab	---	---	3.8 ab	---	---	3.2 a	---
M.26 EMLA	3.6 b	2.6 c	3.1 b	2.5 b	3.3 b	2.9 a	3.9 b	---	4.3 a
M.7 EMLA	4.6 a	2.8 bc	3.7 a	3.0 a	4.2 a	2.7 a	4.6 a	3.4 a	4.5 a
Supporter 4	4.1 ab	3.2 abc	3.2 ab	2.7 b	4.1 a	3.0 a	4.5 a	3.1 a	3.5 b

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).

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

Rootstock	CA	KY	NC		
Fuji					
CG.4814	6.7 a	0.0 a	14.2 a		
G.210	0.0 a	---	2.6 a		
CG.7707	6.7 a	0.0 a	6.6 a		
G.30N	2.5 a	0.5 a	0.6 a		
G.30T	0.0 a	---	2.8 a		
M.26 EMLA	3.0 a	0.3 a	2.2 a		
M.7 EMLA	2.5 a	0.2 a	8.5 a		
Supporter 4	2.5 a	0.0 a	2.4 a		
	MA	NS	NY-PE	NY-WI	PA-RO
McIntosh					
CG.4814	10.0 a	10.0 ab	---	12.4 ab	---
G.210	---	---	---	14.8 ab	---
CG.7707	4.9 a	5.0 ab	---	3.8 ab	---
G.30N	0.4 a	1.1 b	---	4.0 b	---
G.30T	---	---	---	9.6 ab	---
M.26 EMLA	0.0 a	20.0 ab	8.3 b	16.0 ab	0.0 a
M.7 EMLA	6.9 a	26.7 a	31.7 a	24.0 a	0.0 a
Supporter 4	4.0 a	8.3 ab	1.7 b	12.0 ab	0.0 a

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).

differences were significant at all sites except ON. Among 'McIntosh' sites with significant differences, trees on G.30N, G.30T, G.210, and Supporter 4 were consistently among the highest yielding, and those on CG.4814 and M.26 EMLA were consistently among the lowest yielding per tree. In MN, trees on G.210 and on CG.7707 also were among the highest yielding, and in MN and in VT, trees on M.7 EMLA were the lowest yielding. In Williamson, NY and in WI, trees on CG.7707 were also among the lowest yielding per tree.

Cumulative yield efficiency (2001-08) also was affected by rootstock (Table 12). Among sites with 'Fuji' as the scion cultivar, rootstock differences were nonsignificant in KY and MO. In NC, trees on G.30 (N or T) were significantly more yield efficient than those on M.7 EMLA. In SC, with a partial planting, trees on CG.4814 were more yield efficient than those on M.26 EMLA. Among 'McIntosh' sites, rootstock differences in yield efficiency were nonsignificant in NS, Peru, NY, Williamson, NY, and VT. Among the other six sites, considerable variability was observed. The only consistent observation was that trees on CG.4814 were amongst the most yield efficient, and those on M.7 EMLA were among the least yield efficient.

Average fruit weight (2001-08) was affected by rootstock in only two 'Fuji' sites and five 'McIntosh' sites (Table 13). Across both cultivars, CG.7707 resulted in among the largest fruit in six of the 13 sites which included CG.7707. M.7 EMLA resulted in among the largest at six of the 15 sites with M.7 EMLA. M.26 EMLA resulted in among the smallest fruit at four of the 15 sites which

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

Rootstock	CA	KY	MO	NC	SC	UT[y]			
Fuji									
CG.4814	35 b	62 b	20 a	30 ab	28 a	103 ab			
G.210	0 b	---	---	30 ab	---	---			
CG.7707	8 b	35 b	11 a	12 b	---	28 b			
G.30N	3 b	51 b	---	20 b	---	39 ab			
G.30T	3 b	---	---	41 ab	---	---			
M.26 EMLA	0 b	4 b	3 a	3 b	0 b	11 b			
M.7 EMLA	110 a	179 a	34 a	60 a	---	270 a			
Supporter 4	3 b	26 b	---	3 b	8 ab	---			
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT
McIntosh									
CG.4814	35 b	10 a	0 a	6 ab	---	21 b	13 a	---	27 b
G.210	---	5 a	0 a	---	---	23 b	---	---	27 b
CG.7707	8 bc	0 a	0 a	1 ab	---	6 b	2 a	---	2 b
G.30N	31 bc	10 a	1 a	1 ab	---	24 b	4 a	---	11 b
G.30T	---	13 a	0 a	---	---	25 b	---	---	13 b
M.26 EMLA	4 c	0 a	0 a	0 b	0 b	1 b	3 a	2 b	---
M.7 EMLA	104 a	15 a	9 a	14 a	34 a	99 a	13 a	210 a	112 a
Supporter 4	18 bc	3 a	3 a	2 ab	3 b	32 b	5 a	37 b	8 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.

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

Rootstock	KY	MO	NC	SC						
Fuji										
CG.4814	269 ab	334 a	241 a	331 a						
G.210	---	---	378 a	---						
CG.7707	285 ab	277 a	366 a	---						
G.30N	417 a	---	316 a	---						
G.30T	---	---	357 a	---						
M.26 EMLA	224 ab	238 a	247 a	318 a						
M.7 EMLA	222 ab	155 a	228 a	---						
Supporter 4	85 b	---	235 a	308 a						
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	225 bc	184 ab	131 ab	200 ab	---	173 b	168 a	---	174 ab	227 ab
G.210	---	172 ab	173 a	---	---	200 ab	---	---	177 ab	---
CG.7707	239 bc	186 ab	175 a	226 ab	---	171 b	116 a	---	160 ab	200 b
G.30N	334 a	224 ab	153 a	249 a	---	237 ab	126 a	---	186 ab	319 a
G.30T	---	271 a	114 ab	---	---	217 ab	---	---	240 a	---
M.26 EMLA	182 c	147 b	60 ab	153 b	114 b	174 b	144 a	325 b	---	208 ab
M.7 EMLA	290 ab	182 ab	51 b	222 ab	180 a	294 a	112 a	378 a	142 b	271 ab
Supporter 4	259 ab	201 ab	118 ab	220 ab	205 a	282 a	127 a	417 a	175 ab	271 ab

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).

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

Rootstock	KY	MO	NC	SC						
Fuji										
CG.4814	2.8 a	2.0 a	2.7 ab	3.1 a						
G.210	---	---	2.8 ab	---						
CG.7707	2.6 a	1.3 a	3.0 ab	---						
G.30N	3.3 a	---	3.1 a	---						
G.30T	---	---	3.2 a	---						
M.26 EMLA	2.5 a	1.6 a	2.2 ab	1.8 b						
M.7 EMLA	2.3 a	1.0 a	1.7 b	---						
Supporter 4	4.0 a	---	2.6 ab	2.5 ab						
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	5.0 a	2.6 ab	3.1 a	4.4 a	---	2.2 a	2.2 a	---	2.7 a	3.4 a
G.210	---	2.0 abc	2.3 ab	---	---	2.0 a	---	---	2.7 a	---
CG.7707	4.5 ab	3.2 a	2.8 ab	3.8 a	---	1.6 a	1.0 ab	---	2.7 a	2.2 b
G.30N	3.2 cd	2.8 a	2.1 abc	3.6 a	---	1.8 a	1.1 ab	---	2.8 a	2.7 ab
G.30T	---	3.2 a	1.6 bc	---	---	1.7 a	---	---	2.9 a	---
M.26 EMLA	3.6 bc	1.8 bc	1.5 bc	3.4 a	2.1 a	2.1 a	1.4 ab	2.6 a	---	1.8 b
M.7 EMLA	2.5 d	1.6 c	1.0 c	3.2 a	1.5 a	1.7 a	1.1 ab	1.8 b	2.3 a	1.8 b
Supporter 4	2.7 d	2.0 abc	2.0 abc	4.2 a	2.4 a	1.8 a	0.9 b	2.4 ab	2.8 a	3.5 a

[z] Mean separation within column and cultivar by Tukey's HSD ($P = 0.05$).

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

Rootstock	CA[y]	KY	MO	NC	SC	UT[x]				
Fuji										
CG.4814	198 a	180 ab	219 a	159 a	179 a	193 b				
G.210	195 a	---	---	178 a	---	---				
CG.7707	197 a	192 a	234 a	173 a	---	218 a				
G.30N	195 a	196 a	---	179 a	---	205 ab				
G.30T	198 a	---	---	171 a	---	---				
M.26 EMLA	204 a	179 ab	198 a	165 a	185 a	203 ab				
M.7 EMLA	187 a	178 ab	237 a	163 a	---	224 a				
Supporter 4	200 a	154 b	---	160 a	187 a	---				
	MA	MI	MN	NS	NY-PE	NY-WI	ON	PA-RO	VT	WI
McIntosh										
CG.4814	175 a	150 a	132 a	134 ab	---	146 b	165 a	---	166 a	168 b
G.210	---	150 a	145 a	---	---	153 ab	---	---	169 a	---
CG.7707	168 ab	150 a	130 a	140 a	---	161 a	155 a	---	166 a	190 a
G.30N	167 ab	160 a	135 a	124 b	---	153 ab	160 a	---	166 a	169 ab
G.30T	---	156 a	126 a	---	---	147 b	---	---	165 a	---
M.26 EMLA	165 b	148 a	130 a	128 ab	145 b	147 b	154 a	174 a	---	164 b
M.7 EMLA	175 a	154 a	128 a	138 ab	170 a	148 b	153 a	175 a	175 a	180 ab
Supporter 4	173 ab	157 a	121 a	131 ab	163 a	149 b	158 a	172 a	167 a	176 ab

[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.

included M.26 EMLA. Other rootstocks were less consistent in their effect on fruit size. Trees on CG.4814 produced among the largest at one site and among the smallest at three of the 14 that had CG.4814. G.30 (N or T) resulted in among the smallest fruit at one site and among the largest at another out of 12 sites, and Supporter 4 resulted in among the largest at one site and among the smallest at two sites out of the 14 sites.

Discussion

G.30 is a fireblight-resistant rootstock released from the Cornell-Geneva Apple Rootstock Breeding Program in 1994 (9). Among the rootstocks in this trial, it performed very well. Trees were somewhat smaller than those on M.7 EMLA and resulted in less intense burr knot development, fewer root suckers, significantly greater yield efficiency, and comparable fruit size. The 5-year summary of data from this trial (1) suggested that G.30 resulted in trees comparable in size to those on M.7 EMLA but more productive and more yield efficient. Robinson et al. (9) found similar results with 'Liberty' as the scion cultivar after 8 years of the 1992 and 1993 NC-140 Apple Rootstock Trials. Marini et al. (5) found that with 'Gala', G.30 was similar in size as M.26 in the 1994 NC-140 Apple Rootstock Trial but was more yield efficient. With 'Gala,' they reported greater graft union breakage at some sites with G.30 than M.26. These observations have led to the conclusion by NC-140 that G.30 has a brittle graft union with some cultivars and to the recommendation that it needs good tree support with those cultivars. At some sites, trees on G.30 from stool beds established from tissue cultured plantlets were included in the planting, and in no case were the differences significant between trees on G.30 from normal stool beds (N) and those on G.30 from tissue-culture based stool beds (T).

CG.4814 is a rootstock in the Cornell-Geneva Breeding Program which is still being tested. It appears resistant to fireblight (8). It was previously planted in 1995 and 1996 trials in New York (10), but virtually no results have been reported regarding its performance to date. In this trial, survival was high, and tree size was comparable to M.26 EMLA. Burr knot development was not extensive, but it produced a number of root suckers. Yield efficiency was high. Results after 5 years in this trial (1) were comparable to those observed after 10 years.

G.210, tested as CG.6210, is another rootstock from the Cornell-Geneva Program which was named in 2010. It appears to be resistant to fireblight (8). It was included at only a few sites in this trial where survival was high, with the exception of trees in MI, where 60% died before the end of the trial. 'Fuji' trees and 'McIntosh' trees in MI, MN, and VT on G.210 were similar in size to those on M.7 EMLA. In Williamson, NY, however, trees on G.210 were closer in size to those on M.26 EMLA than those on M.7 EMLA. Burr knot severity and root suckering were low. Trees on G.210 were among the most yield efficient, and fruit size was good. In the 1992 NC-140 Apple Rootstock Trial, 'Liberty' trees on G.210 were comparable in size to those on M.7 and G.30, had somewhat smaller fruit size than those on M.7, and were more yield efficient that trees on M.7 and comparably efficient to those on G.30 (9). In the 1993 NC-140 Trial, 'Liberty' trees on G.210 were also similar in size to those on G.30 and M.7, but fruit size was comparable to that from trees on M.7, and were more yield efficient than those on M.7 but less efficient than those on G.30 (9) Robinson and Hoying (10) found 'Empire' trees on G.210 over 10 years at several locations in New York to be very similar to comparable trees on G.30, smaller than those on M.7 but much more yield efficient.

CG.7707 is another selection from the Cornell-Geneva Breeding Program that has not been released. It has had limited testing outside of New York, but it was included in the 1992 and 1993 NC-140 Apple Rootstock Trials. In the trial reported here, trees were smaller than those on M.7 EMLA, developed few burr knots, and produced reasonably low numbers of root suckers. Trees on CG.7707

were comparably yield efficient to those on G.30, and fruit size was the largest for both cultivars. These results differ from observations in the 1992 and 1993 NC-140 trials (9). With 'Liberty' as the scion cultivar, trees on CG.7707 were larger than those on M.7 and similar to trees on MM.106 in the 1992 Trial, and similar to those on MM.111 in the 1993 Trial. Yield efficiency of trees on CG.7707 was between that of trees on M.7 and MM.106 in the 1992 Trial and better than that of trees on MM.111 in the 1993 Trial. The reason for the apparently much smaller trees in the 1999 Trials compared to those in the 1992 and 1993 Trials is as yet undetermined.

Supporter 4, tested as Pi 80, was released by the Institut für Obstforschung Dresden-Pillnitz Rootstock Breeding Program (3, 4). In this trial, survival was good at 11 of 15 sites. With 'McIntosh,' tree size was smaller than that of trees on M.7 EMLA but larger than those on M.26 EMLA. Burr knot incidence and root suckering were low. Yield efficiency and fruit size were only moderate. Results after 5 years (1) showed 'Fuji' trees on Supporter 4 to be comparable in size to those on M.26 EMLA, but 'McIntosh' trees on Supporter 4 were similar in size to those on M.7 EMLA. For both cultivars, trees on Supporter 4 were similarly yield efficient to those on M.26 EMLA and with similar fruit size. Fischer (4) reported that trees on Supporter 4 were comparable in size to those on M.26 but generally with greater yields. Russo et al. (11) reported that Supporter 4 was susceptible to fire blight when the scion ('Gala' or 'Honeycrisp') were inoculated with the fire blight bacteria.

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