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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]

| 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*** | | | | | | |
| 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 | | |
| | 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 (cm²) 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 |

| Rootstock | 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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