The Geneva Series of Apple Rootstocks from Cornell: Performance, Disease Resistance, and Commercialization

Terence Robinson
Dept. of Hort. Sciences
New York State Agricultural Experiment Station
Cornell University
Geneva, New York 14456, USA

Herb Aldwinckle
Dept. of Plant Pathology
New York State Agricultural Experiment Station
Cornell University
Geneva, New York 14456, USA

Gennaro Fazio and Todd Holleran
Plant Genetics Resource Unit, USDA
New York State Agricultural Experiment Station
Geneva, New York 14456, USA

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Abstract

The Geneva series of apple rootstocks has been bred for tolerance to fire blight and *Phytophthora* root rot, high yield efficiency and good tree survival. Four clones from the program have been released. 'Geneva™ 30' rootstock, which produces a tree about 50% the size of seedling, has continued to show good resistance to fire blight, high yield efficiency in several field plantings on growers farms and in the US national rootstock testing program. However, it has shown graft union brittleness with 'Gala'. 'G.30' also has the deficiency of producing many lateral spines on stoolbed shoots. This has limited its production by commercial stoolbed operators. 'Geneva™ 16', which produces a tree about 30% the size of seedling, has been slightly more vigorous than 'M.9NAKB337', but has been equally productive. It has shown very high resistance to fire blight. It has had excellent performance in the nursery except where virus infected scionwood has been used. Tests have shown that 'G.16' is sensitive to one or more latent viruses. 'Geneva™ 11' rootstock, which produces a tree about 40% the size of seedling, has shown very high productivity and good tree survival, but not immunity to fire blight. A field planting of 'Gala' on 'G.11' showed 25% tree loses when inoculated with fire blight while 'M.9' and 'M.26' trees showed 80–100% tree death. 'Geneva™ 202', which is being commercialized in New Zealand, produces a tree about 40% the size of seedling. In addition to having high fire blight resistance, it is also woolly apple aphid resistant. In 2004, we expect to release two additional rootstocks: 'Geneva™ 3041' and 'Geneva™ 5935' which are both fire blight resistant, extremely productive and produces trees 30% and 50% the size of seedling, respectively.

INTRODUCTION

The Cornell University apple rootstock breeding project located at Geneva, NY was initiated in 1968 by James Cummins and Herbert Aldwinckle, with the objective of developing rootstock genotypes with improved nursery and orchard characteristics that are better adapted to the biotic stresses which are common in eastern North America of fire blight (*Erwinia amylovora*) and crown rot (*Phytophthora* spp). James Cummins led the program until his retirement in 1993. In 1998, the Cornell University rootstock breeding program was converted to a joint breeding program with the United States Department of Agriculture (USDA) with a USDA breeder as the lead scientist (William Johnson from 1998–2000 and currently Gennaro Fazio) and with several Cornell scientists as cooperators.

From the 30 year effort in apple rootstock breeding, a large number of selections have been developed and are in various stages of testing of propagation characteristics in

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the nursery, and productivity and dwarfing in the orchard (Johnson et al., 2001a). The most advanced selections have been tested in orchard trials at the New York State Agricultural Experiment Station in Geneva, New York, on growers farms across New York State, in multi-location national rootstock trials conducted by the NC-140, and in several other countries. From the advanced selections, the first rootstock have been released for commercial propagation. Several nurseries around the world have been licensed to propagate the CG stocks, but at the present time only nurseries in the USA and New Zealand have commercial production.

MATERIALS AND METHODS

From 1972 until 1993, planned crosses were made at Geneva to develop seedling progeny for evaluation as apple rootstocks (Cummins and Aldwinckle, 1983). To ensure fire blight resistance of all rootstock selections, seedlings from the breeding program were screened for fire blight and *Phytophthora* root rot resistance in the greenhouse. Surviving plants were planted in the field and grown as mother plants from which rootstock liners were produced. Liners were budded in the nursery and planted in the field for an orchard evaluation of rootstock performance with 2–3 replicates. In addition, the performance of the mother plant as a stoolbed plant was evaluated. Selections were made from the orchard trial based on survival, tree size and productivity.

From 1991 through 1998, a series of replicated rootstock trials of advanced selections was planted on growers farms in the 3 apple growing regions of New York state (Lake Ontario, Lake Champlain, and Hudson River regions) (Johnson et al., 2001b; Robinson and Hoying, 2003). Each trial had from 1–20 CG and rootstock clones with appropriate Malling rootstock controls and 8-10 replicates. The plots were managed by the growers and annual yield, tree size, and survival data were collected by the project leaders.

In 1992, 1993, 1994, 1998, and 1999 replicated rootstock trials were planted at multi-locations in the United States and Canada (Robinson et al., 2003). Each trial had from 1–21 CG rootstock clones with appropriate Malling rootstock controls and other rootstocks of interest to the NC-140 group with 7–10 replicates. For each planting, the plots had a uniform tree spacing across sites and trees were also managed in a uniform manner with certain orchard practices such as fertilization, irrigation and thinning were left to local control. The individual cooperators collected annual yield, fruit size, tree size, and survival data.

Also in the early 1990s, rootstock selections were distributed to researchers in France (Masseron and Simard, 2002), Italy, South Africa, Brazil, New Zealand and Australia. Cooperating researchers in each of those areas have conducted orchard trials with one or more CG rootstocks.

To confirm the fire blight resistance of the elite CG clones, a field trial was planted in 1997 with ‘Gala’ as the scion. In 1999, the trees were inoculated at bloom by spraying the trees with a solution of the fire blight bacteria. Rootstock infection was recorded mid-summer and tree death at the end of the year.

Based on the data from the orchard and nursery trials, four rootstocks have been released since 1993. Three are being commercialized in the United States and one in New Zealand. Progress in other countries has been more limited.

RESULTS

In the 1991 grower plots in New York State the best performing rootstocks were ‘CG.3041’ which was similar in size to ‘M.9’ and ‘CG.5935’, which was similar in size to ‘M.26’. ‘G.65’ was more dwarfing than ‘M.9’ and produced smaller fruit size than ‘M.9’ (Table 1). ‘G.202’ was similar in size as ‘M.26’, but more productive than ‘M.26’ and not as productive as ‘CG.5935’. Among more vigorous stocks, ‘G.30’ and ‘GC.6210’ were the most productive and produced trees slightly smaller than ‘M.7’.

In the 1992 plots, ‘G.11’ had the highest cumulative yield efficiency, good tree survival and also had good average fruit size (Table 2). It had similar tree size as ‘M.9’, but exceeded the yield performance of 'M.9'. 'G.65' was more dwarfing than 'M.9', but had significantly lower cumulative yield efficiency and smaller fruit size than 'M.9'. Among semi-dwarf stocks, 'G.30' and 'CG.6210' were top performers. They exceeded the performance of 'M.7'. 'G.30' generally had good survival; however, in a few sites several trees broke off at the graft union.

In the 1993 plots 'CG.4247', 'CG.3041' and 'CG.3007' had the highest yield efficiencies and had good tree survival (Table 3). All were similar in size to 'M.9', but performed significantly better than 'M.9' or 'M.26'. Among this group, 'CG.3041' has also been tested on several grower's farms where it has been a top performer and will likely be introduced by Cornell University in 2004. Among the semi-dwarf stocks top performers were 'G.30' and 'G.202'. All performed significantly better than 'M.7'. Among this group, 'G.202' has also been tested in New Zealand where it has been a top performer and was introduced by Cornell University in May 2002.

In the 1994 plots, 'G.30' was smaller in size than 'M.26' at 7 sites and larger than 'M.26' at 8 sites. It was significantly larger than 'M.26' at the western North America sites where 'M.26' was stunted. 'G.30' had higher yield efficiency than 'M.26' (Table 4). The yield efficiency of 'G.30' was similar to 'M.9'. 'G.30' had significantly more root suckers than either 'M.9' or 'M.26'. Although 'G.30' had excellent tree performance, it had the lowest tree survival. At several sites a significant number of trees of 'Gala' on 'G.30' broke off at the graft union in years 4–7 during high winds. Other work by Johnson and Robinson (unpubl.) has shown that the graft union of 'Gala' and 'G.30' is more brittle than 'M.26'.

In the 1998 plots, 'G.16' and 'CG.3041' were similar in size and yield efficiency to 'M.9' with 'Jonagold', but with 'Gala' 'G.16' was significantly larger than 'M.9' (Table 5). Although the trees were larger, the yield efficiency of 'Gala'/'G.16' was similar in size to 'M.9'. The trees in the 'Gala' plot were derived from tissue cultured liners which may have been the reason for the increased tree vigor with 'Gala'/'G.16' compared to 'Gala'/'M.9'.

The inoculation of grafted trees in the 1997 orchard/fire blight trial at Geneva showed that 'G.16', 'G.30', 'G.202' and 'CG.3041' are essentially immune to fire blight with 'G.11' showing a high level of resistance (Table 6) (Norelli, et al. 2003). In contrast, 'M.9' and 'M.26' were highly susceptible. In 2000, a natural infection occurred in one of the on-farm plots which resulted in 75–95% tree death of 'M.9' and 'M.26'. In contrast, the CG stock had losses of 15–20% (Table 7).

ROOTSTOCK

The results of these replicated trials have helped identify the best CG rootstock genotypes and also helped identify the strengths and weaknesses of each stock. The results have also helped eliminate other poor performing CG stocks. Since 1991, 5 clones have been named and released for commercialization:

'Geneva™ 65' released in 1991
'Geneva™ 30' released in 1994
'Geneva™ 11' released in 1997
'Geneva™ 16' released in 1998
'Geneva™ 202' released in 2002.

Two other promising rootstocks are close to release as a result of this and other testing:

'CG.3041' to be released in December 2004.
'CG.5935' to be released in December 2004.

'G.65' (1974 cross of 'M.27' × 'Beauty Crab')

'G.65' has proven to be highly resistant to infection of fire blight and *Phytophthora*. Its tree vigor has been significantly less than 'M.9'; however its yield efficiency and fruit size have also been less than 'M.9'. It has also been found to be difficult to propagate in stoolbeds. Although many growers are looking for a rootstock that is more dwarfing than 'M.9', 'G.65' may be too dwarfing in most situations except very high planting densities with large fruited varieties. Under these conditions 'G.65' may have significant advantages to 'M.27' and may find a market niche. Presently, there is a very small commercial production of about 2000 liners per year from only 2 licensed nurseries.

'G.30' (1974 cross of 'Robusta 5' × 'Malling 9')

'G.30' has proven to be a very productive semi-dwarf rootstock with large fruit size that is very resistant to fire blight. It also has been shown to be very tolerant of replant disease in New York (Isutsa and Merwin, 2000) and have wide climate and soil adaptability. It has been especially useful in Northern climates with short growing seasons. It appears to be very winter hardy having survived the test winter of 1994 (-35°C) which caused visible bud damage on 'M.7', but not on 'G.30' (Robinson and Hoying, 2003). In the early years tree growth and vigor are very similar to 'M.7', but the heavy crops on 'G.30' starting in year 3 limited tree growth and vigor in later years so that by year 10 it is usually significantly smaller than 'M.7' and often close to the size of 'M.26' in the New York climate. Cumulative yield efficiency has been 3–5 times better than 'M.7' and is very similar to 'M.9'. Branch angles have been wider than 'M.7'. The superlative orchard performance has been countered by two significant problems with 'G.30'. First, it produces numerous side shoots (spines) on each shoot in the stoolbed. This requires manual trimming of these shoots either before or after harvest from the stoolbed. The removal of the lateral shoots on the liner also removes essentially all of the lateral buds so that new growth the next year in the nursery row must depend on the development of adventitious buds. This is a slow process which allows 10–30% of the plants to dry out and die before they begin to grow. A solution to this problem is to remove only the side shoots on the lower 25 cm of the liner leaving 5–10 cm at the top of the liner untrimmed with live buds for the next year. The second problem with 'G.30' has been a relatively weak graft union with 'Gala' and possibly other brittle cultivars. At some sites, a significant number of trees have snapped off at the graft union during high winds. This means that although 'G.30' is a semidwarf tree, a trellis or support pole will be required. Despite its problems 'G.30' may be useful in the apple industry due to its high productivity and wide soil and climate adaptability. It should be used with moderate densities of 800–1,500 trees/ha, but it will require tree support in all situations.

'G.16' (1981 cross of 'Ottawa 3' × *Malus floribunda*)

'G.16' is a fully dwarfing rootstock with tree growth and vigor similar to vigorous clones of 'M.9' (i.e. 'Nic29' or 'Pajam2'). Precocity and cumulative yield efficiency have been similar or slightly better than 'M.9'. It is essentially immune to fire blight with no tree death from this disease in field trials. It has excellent performance in the stoolbed and produces a large tree in the nursery. Tree growth in the first 2 years in the orchard is vigorous, but with the onset of cropping tree vigor is moderated similar to 'M.9'. 'G.16' appears to have wide soil adaptability and some tolerance to replant disease. Its winter hardiness has not been evaluated. Its greatest deficiency it that it is sensitive to one or more latent viruses in scion wood. Infected scion wood results in death of the trees in the nursery or the first year in the orchard. This requires absolute use of virus free scion wood. A second problem is that a few trees of 'Gala' and 'Joburn' have snapped off at the graft union during high winds. The graft union strength has not been measured, but it likely is no different than 'M.9'. Despite the limitations of 'G.16', it is currently one of the best alternatives to 'M.9' in high fire blight areas. It should be planted at high densities of 2000–6,000 trees/ha.

'G.11' (1978 cross of 'Malling 26' × 'Robusta 5')

'G.11' is a semidwarfing rootstock that produces a tree similar in size to 'M.26'. 'G.11' has high yield efficiency (similar to 'M.9') and produces fruit size similar to 'M.26'. It has moderate fire blight tolerance (similar to 'M.7') and good resistance to

Phytophthora root rot, but it is not resistant to woolly apple aphids. In the 1997 inoculated orchard fire blight trial at Geneva, 'G.11' showed a high level of resistance, but was not immune. About 25% of the trees became infected and died, which is similar to 'M.7' (Table 7) (Norelli, et al. 2003). In contrast, 'M.9' and 'M.26' were highly susceptible with 75-95% tree death. 'G.11' has good layerbed and nursery characteristics. Presently 'G.11' is available only in North America and will be sold commercially for the first time in 2003 on a limited basis. It should prove to be an excellent replacement for 'M.26'.

'G.202' (1975 cross of 'Malling 27' × 'Robusta 5')

'G.202' produces a tree similar in size to 'M.26'. In addition to fire blight resistance like other CG stocks, it also has good resistance to woolly apple aphid which is an important rootstock pest in many warm climates. It performs very well in the stoolbed and produces good quality nursery trees. 'G.202' has been tested mostly in New York state and New Zealand. In New York, USA it is similar in productivity as 'M.26', but not as productive as 'CG.935'. In New Zealand, it has been found to be much more productive than 'M.26' and is one of the best stocks available. It appears that 'G.202' will be a useful alternative to 'M.9' and 'M.26' in climates that have problems with woolly apple aphid. Presently, it is only available in New Zealand.

'CG.3041' (1975 cross of 'Malling 27' × 'Robusta 5')

'CG3041' is a fully dwarfing stock with vigor similar to 'M.9'. It is highly resistant to fire blight and *Phytophthora* with no tree death from this disease in field trials. Its precocity and productivity have been exceptional surpassing 'M.9'. It also has excellent fruit size and induces wide crotch angles. It appears to be very winter hardy and showed no damage following the test winter of 1994 (Robinson and Hoying, 2003). It produces a smaller tree than 'G.16' in the nursery and similar to 'M.9' which is very acceptable. It also does not have the virus sensitivity of 'G.16'. Its only known flaws are it produces some side shoots in the stoolbed, but not as many as 'G.30' and a few trees in one study in New York (10%) broke at the graft union following a high wind event. It has not yet been released for commercial propagation. However, its continued outstanding performance has led us to plan for its release in December 2004. At the moment, it appears that 'CG.3041' will be a possible replacement for 'M.9'.

'CG.5935' (1976 cross of Ottawa 3 × 'Robusta 5')

'CG.5935' is a semidwarfing stock that produces a tree slightly larger than 'M.26'. CG.5935 is the most precocious and productive semidwarf CG rootstock. It has had similar efficiency to 'M.9' along with excellent fruit size and wide crotch angles. It showed no symptoms of winter damage during the 1994 test winter. It is highly resistant to fire blight and *Phytophthora*, but its resistance to woolly apple aphid is unknown. It has good propagability in the stoolbed and produces a large tree in the nursery. Due to its outstanding performance we expect to release this stock in December 2004. It appears that CG.5935 will be a possible replacement for 'M.26' when released.

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Tables

Table 1. Ten year performance of ‘Empire’ apple on elite CG rootstocks in several on-farm trials in New York State (from Robinson and Hoying, 2003).

Rootstock[1]	Trunk cross sectional area increase (% of M.9)	Cumulative fruit no. (% of M.9)	Cumulative yield (% of M.9)	Cumulative yield efficiency (% of M.9)	Average fruit size (% of M.9)	Cropload adjusted fruit size (% of M.9)
CG.2077	17	48	43	228	90	94
G.65	58	63	60	111	94	94
Mark	66	93	95	142	102	103
CG.3041	99	119	119	123	101	101
M.9	**100**	**100**	**100**	**100**	**100**	**100**
CG.5935	138	176	171	122	97	98
M.9/MM.111	147	98	100	73	101	100
M.26	150	114	116	83	101	101
CG.4202	153	138	143	101	103	103
CG.88	186	158	160	85	101	100
CG.6210	191	199	196	104	99	99
G.30	191	185	181	101	98	98
CG.222	203	201	197	97	99	98
CG.7707	229	207	203	92	99	99
CG.4013	232	177	167	76	94	94
M.7	276	126	130	46	103	102
CG.103	362	205	193	53	95	93
LSD $p \leq 0.05$	48	38	38	25	5	5

[1]Rootstocks ranked by final trunk cross sectional area

Table 2. Performance of CG rootstocks with 'Liberty' in the 1992 NC-140 trial at Geneva[1] (from Robinson et al., 2003).

Rootstock	Trunk cross sectional area (% of M.9)	Cumulative yield efficiency (% of M.9)
M.27	21 d	103 ab
G.65	31 d	83 c
G.11	84 c	115 a
M.9	**100 c**	**100 ab**
G.202	122 bc	88 bc
G.30	137 bc	97 ab
M.7	152 b	76 b
CG.6210	155 b	98 ab
MM.111	265 a	50 d
MM.106	275 a	58 d

[1]Mean separation by LSD $p<0.05$.

Table 3. Performance of CG rootstocks with 'Liberty' in the 1993 NC-140 trial at Geneva[1] (from Robinson et al., 2003).

Rootstock	Trunk cross sectional area (% of M.26)	Cumulative yield efficiency (% of M.26)
CG.3247	60 c	175 a
G.65	61 c	122 bc
CG.3041	71 c	138 b
CG.3007	79 c	131 bc
M.26	**100 bc**	**109 c**
G.11	100 bc	88 cd
G.202	116 b	106 cd
G.30	120 b	138 b
M.7	135 b	81 d
MM.111	182 a	56 d

[1]Mean separation by LSD $p<0.05$.

Table 4. Performance of 'G.30' with 'Gala' in the 1994 NC-140 trial at Geneva[1] (from Robinson et al., 2003).

Rootstock	Trunk cross sectional area (% of M.9)	Cumulative yield efficiency (% of M.9)	Root suckers
M.9T337[2]	100	100	1.7
B.9[2]	107	85	1.7
G.30	154 b	105 a	4.7 a
M.26	178 a	88 ab	0.1 b

[1]Mean separation by LSD $p<0.05$.
[2]M.9 and B.9 planted in adjacent replicated plot.

Table 5. Performance of CG rootstocks with 'Jonagold' and 'Gala' in the 1998 NC-140 trial at Geneva[1] (from Robinson et al., 2003).

Cultivar	Rootstock	Trunk cross sectional area (% of M.9)	Cumulative yield efficiency (% of M.9)
Jonagold	M.9 EMLA	100 a[3]	100 b
	CG.3041	111 a	142 a
	G.16	103 a	122 ab
	G.16 (LTC)[2]	111 a	102 b
Gala	M.9 EMLA	100 b	100 a
	G.16 (TC)[3]	133 a	87 ab
	M.26	135 a	76 b

[1]Mean separation by LSD $p<0.05$.
[2]LTC= Liners derived from tissue cultured stoolbed plants.
[3]TC= Tissue cultured plants used as liners.

Table 6. Rootstock infection with fire blight of 'Gala' after blossom inoculation during bloom in 1999 at Geneva (from Norelli et al., 2003).

Rootstock	% of trees with rootstock infection[1]	Tree death[2] (%)
M.26 EMLA	100	92
M.9EMLA	100	83
MM.111	0	8
Bud.9	0	0
G.11	25	25
G.16	0	0
G.30	0	0
G.202	0	0
CG.3041	0	0

[1]Recorded at the end of 1999.
[2]Recorded at the beginning of 2000

Table 7. Survival of 'Gala' apple trees on 'M.9', 'M.26', and CG rootstocks following a fire blight epidemic at an on-farm trial in New York State (from Robinson and Hoying, 2003).

Rootstock	Trees killed by fire blight (%)
M.9	93
M.26	75
G.11	19
CG.179	18
CG.30	15
CG.4202	14
CG.3041	13