On-Farm Trials of the Cornell-Geneva Apple Rootstocks in New York

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THE GENEVA ROOTSTOCK BREEDING PROGRAM

In 1968, James Cummins and Herbert Aldwinckle initiated the Cornell University apple rootstock breeding project located at the New York State Agricultural Experiment Station in Geneva, NY, with the objective of developing rootstock genotypes with improved nursery and orchard characteristics that were better adapted to the biotic stresses of fire blight (*Erwinia amylovora*) and crown rot (*Phytophthora* spp.) so common in New York State and surrounding areas (Cummins and Aldwinckle, 1983; Johnson et al., 2001). Progeny from planned crosses underwent rigorous greenhouse screening procedures at the small seedling stage to select for tolerance to fire blight and crown rot. Surviving genotypes were then tested for propagation characteristics in the nursery and productivity and dwarfing in the orchards at the station. Since 1991, the elite selections from the breeding program have been tested in second level field trials at various locations around the world. In this paper, we report on the performance of CG rootstocks at a series of on-farm grower trials in the three apple growing regions of New York where we assessed productivity, precocity and field tolerance to abiotic and biotic stresses.

Current Status of the Program

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. Currently in the program there are a large number of selections in various stages of testing for both nursery characteristics and orchard performance (Johnson et al., 2001). New crosses have been made in the last three years and Gennaro Fazio has begun new genetic studies aimed at identifying genes involved in dwarfing, precocity and disease resistance. From the advanced selections, five rootstocks have been released for commercial propagation since 1992 (Geneva™65, Geneva™30, Geneva™16, Geneva™11 and Geneva™202). These commercially available rootstocks are designated as "G" rootstocks in this paper while unreleased numbered selections are designated as "CG" rootstocks. Three are being commercialized in the United States and one in New Zealand. Several nurseries around the world have been licensed to propagate the CG rootstocks but progress in other countries has been more limited.

> ***. . . five rootstocks have been released for commercial propagation since 1992 (Geneva™65, Geneva™30, Geneva™16, Geneva™11 and Geneva™202).***

The New York On-Farm Trials

From 1991 through 1999, a series of replicated rootstock trials was planted on growers' farms in the three apple growing regions of New York State (Lake Ontario, Lake Champlain and Hudson River regions) (Table 1). Each trial had from 1 to 20 CG rootstock clones with appropriate Malling rootstock controls. Each experiment had 4 to 8 replications. The plots were managed by the growers with decisions on pruning, fertilization, ground cover management and chemical fruit thinning made by the growers. Annual yield, tree size and survival data were collected by the project leaders.

CG Rootstock Smaller than M.9. In the 1991 trials with Empire as the scion, G.65 was included at five of the locations. In all trials, it had lower tree vigor than M.9 or Mark rootstocks (Table 2). Precocity has been similar to M.9, but yield efficiency has been less than M.9. Fruit size has also been smaller than M.9. None of the trees in any of the trials died because of fire blight or phytophthora. In the trial at Gunnison's farm in the Champlain Region of New York State, G.65 survived a severe winter cold event in January 1994 where temperatures dropped to -35°C. Trees on G.65 showed very little bud or foliar damage the next spring, but trees on several other rootstocks were damaged severely (Table 3).

CG Rootstocks Similar to M.9. Among CG rootstocks similar in size to M.9, two rootstocks (G.16 and CG.3041) have performed as well or better than M.9. G.16 was not tested until 1998 which means our results are still preliminary. Tree growth and vigor of G.16 have been similar to the vigorous clones of M.9 (Table 4). Precocity has been similar to M.9 and cumulative yield efficiency has been slightly better than M.9. It has been highly resistant to natural infection of fire blight and phytophthora. In a trial planted in 1998 which received a massive natural infection of fire blight during bloom of 2000, none of the G.16 trees died while most of the M.9 and M.26 trees died (Table 5). CG.3041 was tested in 4 of the 1991 trials and in each case tree vigor was similar to M.9 EMLA (Table 2). Precocity was also similar to M.9. Cumulative yield efficiency after 10 years was numerically higher but not statistically different than M.9.

In a 1998 trial, CG.3041 has had significantly greater yield efficiency than M.9 but not greater than G.16 (Table 4). Fruit size has been similar to M.9 in both the 1991 trials and the 1998 trial and appeared to be larger than G.16 in the 1998 trial. We observed that trees on CG.3041 have wide crotch angles of the major scaffold branches. In a plot in the Champlain region, CG.3041 showed no signs of winter damage during the 1994 test winter (Table 3). It has been highly resistant to fire blight (Tables 5 and 6) and phytophthora in these field trials. It also has shown some tolerance to apple replant disease. A comparison of performance of rootstocks in an infected soil site and an uninfected soil site showed CG.3041 had similar growth in both sites while M.26 and M.9 showed significantly less growth in the infected site (Table 7). In one trial with Gala as the scion, a few trees (10%) broke at the graft union following a severe wind storm.

CG Rootstocks Similar to M.26. Among CG rootstocks similar in size to M.26, three rootstocks (G.5935, G.11 and G.202) have performed better than M.26. Tree vigor of CG.5935 and G.202 has been slightly greater than M.26 (Table 2). Precocity, yield efficiency and productivity of CG.5935 have been exceptional for a semi-dwarfing rootstock with similar efficiency as CG.3041 and M.9. Fruit size has been as good as M.9 or M.26 and the tree has wide crotch angles. It had no winter damage during the 1994 test winter (Table 3). It also has shown some tolerance to apple replant disease with similar growth in an infected site as an uninfected site (Table 7). There were no tree losses to fire blight or phytophthora in these field trials. G.202 has also been similar in tree vigor to M.26 (Table 2). It has had high precocity and higher yield efficiency than M.26. Its yield efficiency has been similar to M.9 but not quite as high as CG.3041 or CG.5935. It has had fruit size similar to M.26 and high resistance to fire blight (Tables 5 and 6) and phytophthora in these field trials. It also has shown very high tolerance to apple replant disease with similar growth in an infected site as an uninfected site (Table 7).

CG Rootstock Similar to M.7. Among semi-dwarfing CG rootstocks, G.30 and CG.6210 have performed better than M.7. With both CG rootstocks, tree growth and vigor through year 7 were similar to M.7, but after year 7 growth has been less than M.7, resulting in a final tree size between M.26 and M.7 (Table 2). Precocity has been similar to M.26 and much better than M.7. Cumulative yield efficiency has been 3 to 5 times better than M.7 and significantly better than M.26. Branch angles have been wider than M.7. Both G.30 and CG.6210 have high tolerance to apple replant disease with similar growth in an infected site as an uninfected site (Table 7). The test winter of 1994 (-35°F) caused very little bud damage on G.30 or CG.6210. Both rootstocks have been highly resistant to natural infection of fire blight (Tables 5 and 6) and phytophthora in these field trials. With G.30, a few trees (10%) in these trials snapped off at the graft union during high winds. With CG.6210, no trees snapped off, but a few trees leaned over following high winds with heavy rain.

Conclusions from New York Trials

The results of these on-farm replicated trials have helped identify superior CG rootstock genotypes and also helped identify the weaknesses of each elite rootstock. The results have also helped eliminate other poor performing rootstocks. Concurrently with the New York on-farm trials, other groups have conducted trials with the CG rootstocks such as the U.S. national rootstock testing group, NC-140

TABLE 2

Ten-year performance of Empire apple on elite CG rootstocks in several on-farm trials in New York State.

Rootstock*	Trunk cross-sectional area increase (% of M.9)	Cumulative yield (% of M.9)	Cumulative yield efficiency (% of M.9)	Average fruit size (% of M.9)
G.65	58	60	111	94
CG.3041	99	119	123	101
M.9	100	100	100	100
CG.5935	138	171	122	97
M.26	150	116	83	101
G.202	153	143	101	103
CG.6210	191	196	104	99
G.30	191	181	101	98
M.7	276	130	46	103
LSD p 0.05	48	38	25	5

*Rootstocks ranked by final trunk cross-sectional area.

TABLE 1

On-farm replicated rootstock trials planted in New York State.

Farm name	Region of New York	Year planted	Variety	Rootstocks in trial*
Wafler	Lake Ontario	1991	Empire	G.65, M.9, Mark, M.26
Furber	Lake Ontario	1991	Empire	G.65, M.9, M.9EMLA, Mark, M.26
Bittner	Lake Ontario	1991	Empire	G.65, M.9, Mark, M.26, B.9
DeMarree	Lake Ontario	1991	Empire	G.30, CG.3041, CG.4202, CG.4013, Mark, M.9/MM.106, M.7
Ophardt	Lake Ontario	1991	Empire	G.30, CG.3041, CG.4202, CG.4013, CG.8189, Mark, M.9/MM.106, M.7
Watt	Lake Ontario	1991	Empire	CG.6210, CG.7707, ~~CG.222,~~, ~~CG.103~~, M.26, M.7, MM.106
Debadts	Lake Ontario	1991	Empire	G.30, CG.4003, CG.4013, CG.4202, CG.4088, CG.6210, CG.6253, CG.7707, CG.8189, ~~CG.222,~~, ~~CG.103,~~ ~~CG.521,~~ ~~CG.602,~~ ~~CG.934~~, M.7a, MM.106, MM.111
Trapani	Hudson River Valley	1991	Empire	G.65, G.30, CG.3041, CG.4013, CG.4202, CG.4088, CG.5935, CG.6210, CG.7707, ~~CG.222,~~ ~~CG.103~~ M.9, B.9, M.9/MM.111, M.26, M.7
Gunnison	Lake Champlain	1991	Empire	G.65, G.30, CG.3041, CG.4013, CG.4202, CG.4088, CG.5935, CG.6210, CG.7707, ~~CG.222,~~ ~~CG.103~~ M.9, B.9, M.9/MM.111, M.26, M.7
Tantillo	Hudson River Valley	1991	Gala	CG.4013, CG.4202, CG.6239, CG.7707, CG.7760, CG.9778, ~~CG.001,~~, ~~CG.004, CG.103,~~, ~~CG.934,~~, ~~CG.071,~~, ~~CG.068,~~ M.7, MM.106, MM.111
Forrence	Lake Champlain	1993	Liberty	G.30, CG.4013, CG.4202, CG.6210, CG.7707, ~~CG.222,~~, ~~CG.934~~, M.7, MM.106, MM.111
Pettit	Lake Ontario	1995	Ace Delicious	CG.6253, CG.6239, CG.7707, CG.8189, ~~CG.008, CG.005, CG.93, CG.229, CG.96, CG.756, CG.602, CG.521,~~ ~~CG.934~~, MM.106, MM.111
Pettit	Lake Ontario	1995	Empire	CG.3902, CG.4809, CG.4003, CG.4202, CG.4214, CG.4013, CG.4814, CG.5087, CG.5156, CG.6143, CG.7707, CG.7760, ~~CG.134~~, ~~CG.103~~, M.7, M.106
Wilbert	Lake Ontario	1996	Delicious	CG.4013, CG.4202, CG.4814, CG.4214, CG.5701, G.30, CG.6253, CG.7707, CG.8189, CG.9778, ~~CG.228~~, ~~CG.103~~, ~~CG.521~~, B.9, M.26, M.7a, M.7EMLA, MM.111, Bemali
Wilbert	Lake Ontario	1996	Gala	CG.3041, CG.6210, CG.6143, ~~CG.222~~, M.9
Wilbert	Lake Ontario	1996	Empire	CG.3041, CG.4247, G.11, CG.6143, ~~CG.5179~~, ~~CG.222,~~ M.9
Smith	Lake Ontario	1997	Gala	CG.3041, G.16, CG.4003, CG.4202, CG.4214, CG.4247, G.11, G.30, CG.5757, CG.6210, CG.6723, CG.6737, CG.7760, CG.7511, ~~CG.005,~~, ~~CG.103,~~, ~~CG.134,~~, ~~CG.060,~~, ~~CG.602, CG.008~~, M.9EMLA, M.26EMLA, MM.111, Marubakaido, P.14
Burnap	Lake Ontario	1997	Gala	CG.3041, CG.4003, G.11, CG.4202, G.30, CG.5179, M.9, M.26
Everett	Lake Champlain	1998	Gala	G.16, M.9
Dembrowski	Hudson River	1998	Gala	G.16, M.9
Dembrowski	Hudson River	1998	Jonagold	CG.3041, G.16, M.9
Loomis	Lake Ontario	1998	Jonagold	CG.3041, G.16, M.9
Lamont	Lake Ontario	1998	Jonagold	G.16, M.9
Peters	Lake Ontario	1999	McIntosh	CG.3041, CG.4013, CG4202, CG5935, CG.5179, CG.6210, CG.6814, CG.7707, G.16, G.30, M.9, M.26, M.7, Supporter 1, Supporter 2, Supporter 3, Supporter 4

*Clones with a strike-through have been discarded from the program.

(Robinson et al., 2003), the CTIFL national trials in France (Masseron and Simard, 2002) and HortResearch in New Zealand (personal communication from Stuart Tustin). Since 1992, five CG clones have been named and released for commercialization and two more will be released in 2004.

Geneva™65, a cross of M.27 X Beauty Crab, was released in 1992. Although G.65 has proven to be highly resistant to infection of fire blight and phytophthora and tolerant to replant disease (Isutsa and Merwin, 2000), it has proven to be difficult to propagate in the stoolbed and has not found significant commercial acceptance. In addition, the results of our trials have shown that it is more dwarfing than M.9 with smaller fruit size. 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 at very high planting densities with large fruited varieties such as Jonagold and Mutsu. Under these conditions, G.65 may have significant advantages to M.27 and may find a market niche. Presently there is very limited commercial production of about 5000 liners per year from only two licensed nurseries.

Geneva™30, a cross of Robusta 5 X M.9, was released in 1994. In our trials and in commercial plantings, G.30 has proven to be a very productive semi-dwarf rootstock with large fruit size that is highly resistant to fire blight. The inoculation of grafted trees in a 1997 orchard/fire blight trial at Geneva showed that G.30 is essentially immune to fire blight (Norelli et al., 2002). Tree size has been between M.26 and M.7. 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 limit tree growth and vigor in later years so that, by year 10, it is usually significantly smaller than M.7 and often closer to the size of M.26. Cumulative yield efficiency has been 3 to 5 times better than M.7 and is very similar to M.9. Branch angles have been wider than M.7. It is also very winter hardy, having survived the test winter of 1994 in NY (-35°F). It also has been shown to be very tolerant of replant disease in New York (Isutsa and Merwin, 2000) and to have wide climate and soil adaptability (Robinson et al., 2003).

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 propagation bed. 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 to 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 to 10 cm at the top of the liner untrimmed with live buds for next year.

The second problem with G.30 is that it has a relatively weak graft union with Gala and possibly other similarly brittle varieties. Work by Johnson and Robinson (unpublished) has shown that the graft union of Gala and G.30 is more brittle than M.26 and the union of Empire and G.30 is more brittle than M.7. This means that, although G.30 is a semi-dwarf tree, it will require a multi-wire trellis to support the tree. 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 400 to 1,000 trees/acre, but it will require tree support in all situations.

Geneva™16, a 1981 cross of Ottawa 3 X *Malus floribunda*, was released in 1998. Our trials with G.16 are too young for firm conclusions. Our data show it to be a fully dwarfing rootstock with tree growth and vigor similar to vigorous clones of M.9 (i.e., Nic 29 or Pajam 2). It is essentially immune to fire blight. In the 1997 inoculated orchard fire blight trial at Geneva, none of the G.16 trees died while most of the M.9 and M.26 trees died (Norelli et al., 2002). In 2000 a natural infection occurred in one of the on-farm plots which resulted in 75 to 95% tree death of M.9 and M.26, but we did not lose a tree of G.16. 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, giving a tree similar in size to M.9. G.16 appears to have wide soil adaptability and some tolerance to replant disease (unpublished data). However, we do not yet know if it is cold hardy. Its greatest known deficiency is 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.

G.16 is still relatively new and untested. We know little about its winter hardiness or tolerance to replant disease. It has survived since

TABLE 3

Winter damage of 3-year-old Empire apple on elite CG rootstocks in the Champlain region of New York State (Gunnison plot).

Rootstock*	Winter damage rating** (1-4 scale)
CG.077	1.6 b***
G.65	1.4 bc
CG.3041	1.0 c
M.9	1.3 bc
CG.5935	1.2 bc
M.26	1.3 bc
G.202	1.2 bc
CG.4013	2.1 a
CG.6210	1.3 bc
G.30	1.3 bc
M.7	1.1 bc
CG.103	2.1 a
CG.7707	1.1 c

*Rootstocks ranked by final trunk cross-sectional area.
**Winter damage ratings taken on June 3, 1994, following a winter cold event in January 1995 of -35°F. Rating scale: 1=no damage, 2=Lateral bud death and shoot tip die back, 3=Dead branches, 4=Dead tree.
***Mean separation by Duncan's multiple range test p 0.05.

TABLE 5

Rootstock infection with fire blight of 3-year-old Gala trees following a massive natural infection in 2000 at the Smith plot (from Norelli et al., 2003).

Rootstock	% of trees with rootstock fire blight
M.9	36
M.26	93
M.7	31
MM.106	43
MM.111	15
CG.3041	0
G.16	0
G.11	23
G.202	7
CG.6210	7
G.30	4

TABLE 6

Survival of 5-year-old Gala trees on elite CG rootstocks after natural infection by fire blight in 2000 (Burnap plot).

Rootstock	Trees lost due to fire blight (%)
M.9	93
M.26	75
CG.3041	13
G.11	19
CG.4202	14
G.30	15

TABLE 4

Four-year performance of Jonagold on G.16 and CG.3041 rootstocks in the Lake Ontario region of New York State (Loomis plot).

Rootstock*	Trunk cross-sectional area 2001 (% of M.9)	Cumulative yield (% of M.9)	Cumulative yield efficiency (% of M.9)	Average fruit size (% of M.9)
M.9EMLA	100	100	100	100
G.16	103	133	122	89
CG.3041	111	166	142	98
LSD p 0.05	15	33	33	10

*Rootstocks ranked by trunk cross-sectional area.

TABLE 7

Relative tolerance of CG rootstocks to apple replant disease (Gunnison and Trapani plots).

Rootstock	Tree size from infected site as a percentage of tree size from uninfected site
CG.3041	96
M.9	92
CG.5935	97
M.26	70
G.202	121
CG.6210	108
G.30	105
M.7	101

1998 in northern New York, but we have not had a severe test winter since then. We have limited observations that indicate it may have good tolerance to replant disease, but more rigorous tests are needed to confirm that. We have not yet measured its graft union strength, but it likely is no different than M.9 in this regard. Despite the known limitations of G.16 and its unknown characteristics, it is currently one of the best alternatives to M.9 in high fire blight areas. It should be planted at high densities of 600 to 2,400 trees/acre. Several nurseries produce G.16 with a current production of about 100,000 liners.

Geneva™11, a 1978 cross of Malling 26 X Robusta 5, was released in 1999. Our trials with G.11 are too young for firm conclusions. Our data show it to be similar in size and yield efficiency to M.26 (Robinson et al., 2003). It has fire blight tolerance similar to M.7 (Norelli et al., 2002) and good resistance to phytophthora root rot, but it is not resistant to woolly apple aphid or apple replant disease (Isutsa and Merwin, 2000). G.11 has good layerbed and nursery characteristics. It may prove to be an excellent replacement for M.26. Presently G.11 is available only in North America and will be sold commercially for the first time in 2003 on a limited basis.

Geneva™202, a 1975 cross of Malling 27 X Robusta 5, was released in 2002 in New Zealand. It is not yet released in the U.S. Our data show G.202 produces a tree slightly larger than M.26. Like G.30 and G.16, G.202 is essentially immune to fire blight (Norelli et al., 2002). In addition, it has good resistance to phytophthora, apple replant disease and to woolly apple aphid which is an important rootstock pest in many climates. It performs very well in the stoolbed and produces good quality nursery trees. It has had higher yield efficiency than M.26, but it has not been as productive as CG.5935. In New Zealand, it has been more productive than M.26 and is one of the best rootstocks available (Stuart Tustin, personal communication). 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 available only in New Zealand but will be available in the U.S. in 2004.

CG.3041, a 1975 cross of Malling 27 X Robusta 5, is scheduled to be released in December 2004. Our data show that CG.3041 is the most productive M.9 size rootstock in our trials. It also has excellent fruit size and induces wide crotch angles. It is highly resistant to fire blight and phytophthora. In the 1997 orchard fire blight trial at Geneva, there were no trees lost with CG.3041 (Norelli et al., 2002). In a severe natural infection in 2000 with one of our on-farm plots, 75 to 95% of trees on M.9 and M.26 died but none of the trees on CG.3041 died. Its precocity and productivity have been exceptional, surpassing M.9. It has survived a winter cold event of -35°F in 1994. We believe it is very winter hardy. It is similar in size and yield efficiency to G.16 and M.9; however, it does not have the virus sensitivity of G.16. We have not yet tested its graft union strength, but we judge it to be similar to M.9. In one trial with Gala, a few trees (10%) broke at the graft union during a high wind event. It has not yet been released for commercial propagation. However, Cornell University has indicated it plans to release CG.3041 in December 2004. At the moment, it appears that CG.3041 will be a possible replacement for M.9.

CG.5935, a 1976 cross of Ottawa 3 X Robusta 5, is scheduled to be released in December 2004. Our data show that CG.5935 is slightly larger than M.26 size. CG.5935 is the most precocious and productive semi-dwarf CG rootstock. It has similar efficiency to M.9 along with excellent fruit size and wide crotch angles. In addition, 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. Cornell University has indicated that it plans to release it in December 2004. It appears that CG.5935 will be a possible replacement for M.26 when released. It has similar efficiency to M.9 along with excellent fruit size and wide crotch angles. It is highly resistant to fire blight (Norelli et al., 2002) and phytophthora and appears to have some tolerance of apple replant disease. It appears to be very winter hardy, but its resistance to woolly apple aphid is unknown. It appears that CG.5935 will be a possible replacement for M.26 when released.

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