

New Releases from the Geneva® Apple Rootstock Breeding Program

Gennaro Fazio¹ and Terence Robinson²

¹Plant Genetics Resources Unit, USDA/ARS, Geneva, NY 14456 | ²School of Integrative Plant Science, Horticulture Section, Cornell University AgriTech Campus, Geneva, NY 14456

Keywords: apple rootstock, fire blight resistance, semi-dwarfing, yield efficiency, fruit size, mineral nutrient profile

Since its inception the Geneva apple rootstock breeding program has had the objective of breeding rootstocks with disease resistance (Aldwinckle et al. 1974, Aldwinckle et al. 1976; Cummins and Aldwinckle 1974). This emphasis has resulted in the release of several apple rootstock varieties (G.11, G.16, G.41, G.935, G.214, G.213, G.210, G.969, G.890) which are resistant to several rootstock diseases such as fire blight, apple replant disease complex, crown and root rot caused by *P. cactosorum* (Fazio et al. 2022), and insects such as woolly apple aphid. While disease and insect resistance has been the main goal of the breeding program, whole orchard productivity, a trait influenced by dwarfing, early bearing and the propensity of the rootstock to impact partitioning of photosynthate away from excessive vegetative growth and into fruit production have been essential parameter used to select all new apple rootstocks.

More recently, the program has been focusing on additional traits that modulate fruit quality, including the ability of apple rootstocks to increase the average fruit size of grafted cultivars, or modify its nutrient profile including the ratio like potassium/calcium which can lead to more or less bitter pit in apples depending on what nutrients rootstocks promote in a particular environment (Fazio et al. 2018a; Fazio et al. 2018b). Among the rootstocks we have released we have discovered two contrasting apple rootstocks in G.41 and G.214 in terms of absorption of potassium and nitrogen (high in G.41 and low in G.214) which leads to very different outcomes with regards to fruit quality of ‘Honeycrisp’. This has resulted in very different fertilization management for each rootstock in order to produce the best outcome. In the same realm of tree nutrition, G.935 is exceptional at mining boron from the soil and sending it to scion – a trait which might contribute to yield efficiencies that are 110-135% of M.9 which is known to be very poor at up taking boron. This positive outcome is great for apple growers that remember this fact and apply less boron on G.935 trees to avoid phytotoxicity. Similarly, more apple growers are converting their operations from conventional management to organic management which requires apple rootstocks that are better able to mine nutrients from the soil like nitrogen, potassium, and phosphorous in a very different soil environment than conventionally managed orchards.

Another trait that might be important to apple growers in the Southern tier of U.S. apple orchards where chilling hours are often less than ideal is the ability of G.213 and other similar rootstocks to decrease the chilling requirement of grafted scions. This can result in more uniform bud break in the spring than currently seen with traditional rootstocks.

Another trait (or problem) that we have seen in the Geneva breeding program is one of brittle graft unions with some scion/rootstock combinations where Cripps Pink/G.41 is very brittle and Cripps Pink/G.214 is very strong. In addition, several novel

scion varieties like NY-1 (SnapDragon) have weak growing habits and need stronger rootstocks to support productivity and canopy development. Some apple orchards are also leveraging increased the increase vigor of semi-dwarfing Geneva rootstocks which induce early bearing to establish multi-leader training systems with planar canopies.

As we learn more about each of the Geneva® rootstocks, it is clear that each has many positive traits but also has negative traits. In addition, each orchard is unique in its soil and climate characteristics. This combined with different scion cultivar characteristics and vigor means that no one rootstock is the best choice in all situations. This leads us to continue to look for new rootstocks which are better in certain niche situations than all other rootstocks. All these considerations, in addition to new nursery and field performance results have led the Geneva® apple rootstock breeding program jointly conducted by U.S. Department of Agriculture – Agricultural Research Service, and Cornell University to release three new rootstocks this year: Geneva® 257 (G.257), Geneva® (G.484), and Geneva® (G.66).

Apple Rootstock Geneva® 257 (G.257)

This new semi-dwarfing apple rootstock named Geneva®257 (G.257) has been in testing in the breeding program since the late 1970’s and has appeared in national tests as CG.5257 (Figure 1). Apple rootstock G.257 was selected as a young seedling by surviving challenges with organisms that cause phytophthora crown



Figure 1. NY1 (SnapDragon) on G.257 in a field trial in the Hudson Valley, NY State.

This research was supported by the New York Apple Research and Development Program

In this article we announce the release of three semi-dwarfing, disease resistant and highly productive apple rootstocks. G.257, G.484 and G.66

rot in apple rootstocks and inoculation with fire blight (*Erwinia amylovora*) demonstrating tolerance or resistance to the pathogens that were used for these tests (Fazio et al. 2015b). This selection was followed by a decades long process that included multiple trial plantings in New York state as a finished tree grafted with different scions including Empire, Gala, Fuji, Golden Delicious, Honeycrisp, NY-1 and Mutsu.

The performance of G.257 in these trials showed it is a semi-dwarf (40-50% of seedling rootstock) whose productivity, yield efficiency and disease resistance are in the superior category among the rootstocks tested (Reig et al. 2018). This rootstock was particularly successful in displaying high productivity and fruit size of NY-1 scions (Table 1).

In the rootstock layer bed nursery, G.257 displays mostly straight shanks with low-medium spine production. The layer bed of G.257 is at least as productive as an M.26 layer bed. G.257 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties which can be improved by the application of prohexadione calcium after the first mounding. G.257 was subjected to bench grafting and budding tests with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing good healing and production of finished trees.

G.257 rootstock was also tested independently on apple grower farms located in multiple testing environments and in several U.S. states which revealed the ability of this rootstock to produce larger fruit and achieve high productivity (Auvil et al. 2011; Fazio and Robinson 2021; Robinson et al. 2011a).

Testing of G.257 with extreme cold treatments in fall and spring seasons in Maine indicated normal acclimation and good tolerance to cold in the fall but a potential sensitivity of cambial tissues in the springtime (Moran et al. 2018; Moran et al. 2021).

Testing of nutrient and micronutrient content of leaves and fruit at multiple sites and with multiple grafted scions revealed superior absorption and translocation of boron, potassium and nitrogen (depending on soil type and scion) and medium levels of calcium (Fazio et al. 2015a; Reig et al. 2018).

In preparation for release, clonal material of G.257 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of High Throughput Sequencing (HTS) which showed negative results (Bettoni et al. 2022). G.257 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

Certified clonal material of G.257 was placed in a sterile micro-propagation regime which showed good properties of propagation, cycling and acclimation per-

centages. Media recipes and protocols for micropropagation of G.257 are available upon request.

A recently completed 10-year trial with G.257 using NY1 as the scion variety showed that G.257 produces a tall spindle tree that fills the space by the end of the 3rd years while trees on M.9 did not fill the space ever (Table 1). Production on G.257 was higher, fruit size was larger and biennial bearing was lower than with M.9. Estimates of the planting density required to equal the production of G.257 planted at 1157 trees/acre (3'X12') indicated that M.9 would need to be planted at almost double the density (2178 trees per acre 2'X11'). In the Geneva trial, G.257 was the best rootstock for NY1 and its release and commercialization will be a great benefit to growers of this variety.

Apple Rootstock Geneva® 484 (G.484)

Geneva®484 (G.484) apple rootstock is a semi-dwarfing rootstock that is being released because it induces early bearing on grafted scions, is highly productive, yield efficient and resistant to fire blight (*Erwinia amylovora*). When fully developed, this rootstock produces trees that are 35-45% the size of a standard apple seedling tree (Figure 2). G.484 has been tested in the breeding program in NY since the late 1980's and has entered national



Figure 2. Honeycrisp on G.484 in a farm trial in upstate NY.

Table 1. Performance of G.257 rootstock compared to other named rootstocks with 'NY1' (Snapdragon) as the scion at Geneva, NY from 2013-2022.

Rootstock	Trunk Cross-Sectional Area (cm ²)	Cum. Fruit Number per Tree	Cum. Yield (kg/tree)	Cum. Yield Efficiency (kg/cm ² TCA)	Average Fruit Size (g)	Fruit Size adjusted for Crop Load (g)	Average Crop Load (no/cm ² TCA)	Cum. Suckers (no.)	Biennial Bearing Index (0-1)	Projected Optimum Planting Density based on TCA (trees/acre)	Projected Cum. Yield at Optimum Density (bu/acre)
M.9T337	19.6	629	87	4.9	173	177	5.9	20	0.47	2,178	10,421
M.26	20.7	614	89	4.4	176	179	5.4	5	0.44	2,062	10,140
G.11	22.5	788	121	5.5	185	189	5.8	1	0.45	1,897	12,725
G.214	26.4	763	112	4.3	174	173	4.9	34	0.37	1,617	10,006
G.814	29.4	874	126	4.5	181	181	5.2	12	0.46	1,452	10,068
G.935	33.3	997	138	4.2	177	178	5.4	5	0.47	1,282	9,767
G.222	36.0	674	107	3.0	178	172	3.5	42	0.41	1,186	7,036
G.874	36.6	936	139	3.9	186	184	4.8	20	0.45	1,166	8,925
G.257	36.9	968	159	4.4	189	188	4.7	16	0.35	1,157	10,188
LSD P≤0.05	5.7	132	21	0.7	7	7	0.8	16	0.06		
*Rootstocks ranked by increasing trunk cross-sectional area.											

and international tests as selection CG.4004. The initial stages of selection for G.484 began with inoculation with fire blight (*Erwinia amylovora*) and a challenge with organisms that cause phytophthora crown rot in apple rootstocks where it displayed its inherited resistance to the pathogens used in the inoculation procedures. This initial selection was followed by decades long research which included multiple plantings in New York as a finished tree grafted with different scions including Gala, Fuji, Golden Delicious, and Mutsu where productivity, yield efficiency and disease resistance were examined and deemed to fall in the superior category among the rootstocks tested (Robinson et al. 2011b; Russo et al. 2007).

G.484 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties, minor production of spines and straight upright liners. Layer beds of G.484 are at least as productive as M.9 layerbeds. G.484 was subjected to bench grafting and budding with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing no major issues with healing and production of finished trees.

Additional testing in the nation-wide rootstock testing network NC-140 confirmed the desirable horticultural performance of G.484 as one of the most yield efficient rootstocks in its size category (Autio et al. 2020a; Autio et al. 2020b) and revealed that in certain sites it may produce a limited number of root suckers. This rootstock was also tested independently on apple grower farms that featured organic and conventional management practices, revealing similar superior performance in both.

Testing of nutrient and micronutrient content of leaves and fruit at multiple sites and with multiple grafted scions revealed superior absorption and translocation of potassium and medium levels of calcium which makes this rootstock more suitable for scion varieties that are not sensitive to bitter pit caused by

an unbalanced K/Ca ratio (Fazio et al. 2020), however, in orchards under organic management this rootstock seemed to have higher uptake of nitrogen and potassium which propelled the trees into a high level of productivity.

In preparation for release clonal material of G.484 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of

Table 2. Performance of G.484 rootstock in comparison with other named rootstocks with 'Honeycrisp' as the scion at 8 locations in North America (BC, MA, MI, MN, NS, NY, OH, WI) from 2010-2017. (Extracted from Autio et al., 2020b).

Rootstock	Trunk Cross-sectional Area 2017 (cm ²)	Survival 2010-17 (%)	Cum. Root Suckers 2010-17 (no/tree)	Cum. Yield/tree 2011-17 (kg)	Biennial Bearing Index (0-1)	Cum. Yield Efficiency 2011-17 (kg/cm ² TCA)	Average Fruit Size 2012-17 (g)	Projected Optimum Planting Density based on TCA (trees/acre)	Projected Cum. Yield at Optimum Planting Density 2011-17 (bu/acre)
B.9	10.2	99	9.8	44	0.55	4.37	204	3,224	7,838
G.11	13.6	89	5.1	69.9	0.56	5.08	208	2,418	9,339
M.9T337	15.1	95	11.4	62.6	0.56	4.3	209	2,178	7,533
B.10	15.6	95	2.4	69	0.54	4.57	208	2,108	8,037
M.9Pajam2	16.7	92	21.3	62.1	0.56	3.81	204	1,969	6,757
G.41	17.1	88	1.8	75.5	0.55	4.51	216	1,923	8,022
G.202	17.5	89	13.9	66.3	0.57	3.88	199	1,879	6,884
G.214	17.7	93	32	82	0.53	4.85	202	1,858	8,418
G.935	18.7	84	16.7	82.5	0.58	4.47	204	1,759	8,016
M.26EMLA	18.8	87	7.7	61.5	0.59	3.37	212	1,749	5,944
G.814	19.5	76	17.4	79.3	0.53	4.12	185	1,687	7,389
G.222	22.9	83	23.4	76.6	0.55	3.6	207	1,436	6,078
G.484	28.9	98	11.6	105.7	0.57	3.81	215	1,138	6,646
Estimated HSD	4.6	17	8.5	12.8	0.1	0.67	18	205	1,712
*Rootstocks ranked by increasing trunk cross-sectional area.									

Table 3. Performance of G.484 rootstocks in comparison with other named rootstocks with 'Aztec Fuji' as the scion at 6 locations in North America (ID, KY, NC, NY and UT) from 2010-2017. (Extracted from Autio et al., 2020a).

Rootstock	Trunk Cross-sectional Area 2017 (cm ²)	Survival 2010-17 (%)	Cum. Root Suckers 2010-17 (no/tree)	Cum. Yield/tree 2011-17 (kg)	Biennial Bearing Index (0-1)	Cum. Yield Efficiency 2011-17 (kg/cm ² TCA)	Average Fruit Size 2012-17 (g)	Projected Optimum Planting Density based on TCA (trees/ha)	Projected Cum. Yield at Optimum Planting Density 2011-17 (MT/ha)
B.9	17.9	97	14	59	0.58	3.23	167	2,905	9,022
G.214	32.5	100	14.1	93	0.6	3.16	193	1,600	7,833
G.202	36.9	100	17.8	98	0.63	2.82	180	1,409	7,270
B.10	37.6	91	2.8	94	0.62	2.66	199	1,383	6,843
M.9T337	39.4	79	15.2	100	0.65	2.88	195	1,320	6,947
G.11	41.6	97	4.1	105	0.63	2.83	205	1,250	6,909
M.9Pajam2	46.4	81	29.6	108	0.62	2.48	196	1,121	6,371
G.935	47.1	94	11.2	143	0.59	3.35	198	1,104	8,311
G.814	47.8	95	20.1	111	0.61	2.61	187	1,088	6,356
G.41	48.3	100	3.4	123	0.62	2.49	211	1,077	6,971
G.484	59.9	100	13.4	149	0.65	2.63	214	868	6,809
G.222	60.6	100	19.5	124	0.64	2.14	201	858	5,601
M.26EMLA	72.6	84	1.9	113	0.66	1.68	210	716	4,260
Estimated HSD	13	20	15.7	23	0.12	0.65	17	2,905	9,022
*Rootstocks ranked by increasing trunk cross-sectional area.									

High Throughput Sequencing (HTS) which showed negative results. G.484 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

Certified clonal material of G.484 was placed in a sterile micro-propagation regime which showed good properties of propagation cycling and acclimation percentages. Media recipes and protocols for micro-propagation of G.484 are available upon request.

G.484 was included in two nationwide trials of rootstocks conducted from 2010-2017. One trial used Honeycrisp as the scion at 8 locations and the other trial used Fuji as the scion at 5 locations. With Honeycrisp, G.484 had good survival and produced a tree larger than M.26 and had the highest yield per tree among the stocks evaluated (Table 2). The optimum planting density for G.484 was estimated to be 1157 trees/acre (3'X12') while more dwarfing stocks such as M.9 would require 2178 trees/acre (2'X10') and B.9 would require 3224 trees/acre (1.3'X10'). With Fuji as the scion, G.484 was smaller than M.26 but produced the highest yield per tree among all the rootstocks evaluated in the trial (Table 3). The optimum planting density for G.484 with Fuji was estimated to be 868 trees/acre (3.9'X13') while M.9 would require 1320 trees/acre (3'X11') to produce the same yield.

G.484 appears to be a good choice on weak soils or under organic management due to its good uptake of N and K. Although the good uptake of K with this stock would make a poor choice with Honeycrisp, its good growth on weak soils or under organic management would make it an excellent choice with other weak cultivars since it will fill the allotted space rapidly and will produce high yields.

Apple Rootstock Geneva® 66 (G.66)

Geneva® 66 (G.66) is a semi-dwarfing (35-40% of seedling), red leafed, precocious and productive rootstock which is resistant

to fire blight (Figure 3). G.66 has been in testing in the breeding program since the late 1970's and appeared in national and international trials as CG.6006. G.66 underwent greenhouse and field resistance testing for fire blight (*Erwinia amylovora*) and crown and root rot caused by *Phytophthora* species. The process of selection



Figure 3. Torres Fuji on G.66 rootstock in a trial in Washington State.

Table 4. Performance of G.66 rootstock in comparison with other named rootstocks with 'Fuji' at Milton NY from 2005-2015. (Extracted from Reig et al., 2018).

Rootstock	Trunk Cross-sectional Area (cm ²)	Tree Survival (%)	Cum. Fruit Number	Cum. Yield (kg/tree)	Cum. yield efficiency (kg/cm ² TCSA)	Average fruit size (g)	Cum. Crop Load (fruit/cm ² TCSA)	Cum. No. Root Suckers	Biennial Bearing Index (0-1)	Projected Optimum Planting Density (trees/acre)	Projected Cum. Yield at Optimum Planting Density (bu/acre)
M.9	36	80	1346	262	7.4	200	38	0.0	0.3	1,320	18,223
G.202	39	100	792	165	4.2	192	20	0.5	0.4	1,218	10,588
M.26	47	90	1239	241	5.5	201	28	0.0	0.4	1,005	12,727
G.214	56	100	1281	256	5.0	202	25	0.1	0.2	850	11,458
G.66	64	80	2369	446	7.1	195	38	1.0	0.3	743	17,441
G.935	66	100	1667	343	5.3	209	26	0.1	0.3	720	13,005
G.814	68	70	1158	219	3.3	187	18	1.0	0.4	701	8,090
G.484	72	100	1929	386	5.5	203	28	0.6	0.3	659	13,386
G.257	73	90	1447	296	4.2	209	21	0.1	0.3	654	10,166
G.222	74	100	1663	331	4.7	205	24	0.0	0.3	647	11,260
G.969	75	100	2379	431	6.0	186	33	0.6	0.3	632	14,328
G.210	89	100	1845	360	4.1	204	21	0.6	0.3	535	10,139
G.890	89	75	1971	400	4.6	214	23	2.0	0.4	533	11,221
MM.106	94	90	2317	460	5.0	204	26	0.4	0.3	506	12,239
M.7	100	100	1619	344	3.7	220	17	19.2	0.4	475	8,595
LSD P < 0.05	22	22	308	62	0.9	15	5	1.9	0.1		

*Rootstocks ranked by increasing trunk cross-sectional area.

of G.66 included more than 30 years of field testing that featured multiple locations/environments and scion varieties which included Empire, Gala, Fuji, Golden Delicious, and Honeycrisp (Robinson et al. 2011b; Russo et al. 2007). G.66 was consistently rated high in horticultural performance and productivity where in a trial with Fuji scion in the Hudson valley it displayed the highest cumulative production in its size category (Reig et al. 2017).

Graft unions with G.66 are generally strong. G.66 has displayed a good potassium to calcium balance in several experiment with scion varieties like Fuji and Honeycrisp, making it less prone to bitter pit induction than other rootstocks (Fazio et al. 2015a; Reig et al. 2018).

In the rootstock layer bed nursery, G.66 displays mostly straight shanks with low-medium spine production. The layer bed of G.66 is at least as productive as a M.26 layer bed. G.66 was also evaluated for liner production in a rootstock nursery for more than 10 years in Geneva, NY and displayed acceptable rooting properties which can be improved by the application of prohexadione calcium after the first mounding. G.66 was subjected to bench grafting and budding with different scion varieties to evaluate success rate and healing of buds in several finished tree nurseries showing good healing and production of finished trees.

Certified clonal material of G.66 was placed in a sterile micro-propagation regime which showed good properties of propagation, cycling and acclimation percentages. Media recipes and protocols for micro-propagation of G.66 are available upon request.

In preparation for release, clonal material of G.66 was tested for common latent apple viruses (ASPV, ASGV, ACLSV, ToRSV, etc.) and other viral or viroid particles using multiple rounds of High Throughput Sequencing (HTS) which showed negative results (Bettoni et al. 2022). G.66 when grafted with virus laden wood might display sensitivity and stunting depending on viral load and type, therefore it is highly recommended that only certified graft wood and bud wood be used in the nursery and orchard establishment stages.

G.66 was included in rootstock conducted in the Hudson Valley of NY from 2005-2015 with Fuji as the scion variety. G.66 had excellent survival and produced a tree larger than M.26 but smaller than M.7 and MM.106. It had the highest yield per tree among the stocks evaluated (Table 4). The optimum planting density for G.66 with Fuji was estimated to be 743 trees/acre (4.2'X12') while M.9 would require 1320 trees/acre (3'X11') to produce the same yield.

G.66 appears to be a good choice for weak cultivars like Honeycrisp because it has a good K/Ca ratio. It also would be a good stock for multi-leader trees since its vigor level will allow the trees to rapidly grow several leaders on each tree and thus fill the allotted space rapidly resulting in high yields.

Conclusions

The three newly released rootstocks from the Geneva rootstock program have performed well in local and national trials. Virus free budwood has been sent to licensed nurseries and commercial quantities of these rootstocks should be available in 1-2 years. They expand the list of released Geneva® rootstocks to 18 varieties and give apple growers new options for conventional and organic production. Each of the three new rootstocks has unique advantages in specific situations of climate, soil type, cultivar and management system. As they are planted more widely and in commercial quantities, their niche in the apple industry will become more clear.

Literature Cited

- Autio W, Robinson T, Black B, Crassweller R, Fallahi E, Hoying S, Parker M, Quezada RP, Reig G, Wolfe D. 2020a. Budagovsky, Geneva, Pillnitz, and Malling apple rootstocks affect 'Fuji' performance over eight years in the 2010 NC-140 'Fuji' apple rootstock trial. *Journal of the American Pomological Society*. 74(4):196-209.
- Autio W, Robinson T, Blatt S, Cochran D, Francescato P, Hoover E, Kushad M, Lang G, Lordan J, Miller D et al. 2020b. Budagovsky, Geneva, Pillnitz, and Malling apple rootstocks affect 'Honeycrisp' performance over eight years in the 2010 NC-140 'Honeycrisp' apple rootstock trial. *Journal of the American Pomological Society*. 74(4):182-195.
- Auvil TD, Schmidt TR, Hanrahan I, Castillo F, McFerson JR, Fazio G. 2011. Evaluation of dwarfing rootstocks in Washington apple replant sites. *Acta Hort*. 903(903):265-271.
- Bettoni JC, Fazio G, Costa LC, Hurtado-Gonzales OPP, Al Rwahnih M, Nedrow A, Volk GMM. 2022. Thermotherapy followed by shoot tip cryotherapy eradicates latent viruses and apple hammerhead viroid from in vitro apple rootstocks. *Plants-Basel*. 11(5):18.
- Fazio G, Aldwinckle HS, Robinson TL. 2022. Selection of apple rootstock breeding families for phytophthora crown rot resistance. *Acta Horticulturae*. 1346:717-722.
- Fazio G, Cheng L, Grusak MA, Robinson TL. 2015a. Apple rootstocks influence mineral nutrient concentration of leaves and fruit. *New York Fruit Quarterly*. 25:11-15.
- Fazio G, Cheng L, Lordan J, Francescato P, Grusak MA, Robinson TL. 2018a. Breeding apple rootstocks for modulation of mineral nutrients in scions. *Acta Hort*. 1217:29-37.
- Fazio G, Lordan J, Francescato P, Robinson TL. 2018b. Breeding apple rootstocks to match cultural and nutrient requirements of scion varieties. *Fruit Quarterly*. 26(2):25-30.
- Fazio G, Lordan J, Grusak MA, Francescato P, Robinson TL. 2020. I. Mineral nutrient profiles and relationships of 'Honeycrisp' grown on a genetically diverse set of rootstocks under western new york climatic conditions. *Scientia Horticulturae* 266:108477.
- Fazio G, Robinson TL. 2021. Designer rootstocks: The basis for precision management of apple orchards. *Acta Horticulturae*. 1314:275-286.
- Fazio G, Robinson TL, Aldwinckle HS. 2015b. The Geneva apple rootstock breeding program. *Plant Breeding Reviews*. 39:379-424.
- Moran RE, Peterson BJ, Fazio G, Cline J. 2018. Genotypic variation in apple rootstock low temperature tolerance during spring and fall. *Journal of the American Society for Horticultural Science*. 143(5):319-332.
- Moran RE, Peterson BJ, Fazio G, Cline JA. 2021. Low temperature tolerance of apple shoots following exposure to warm temperatures in late winter. *Hortscience*. 56(6):642-+.
- Reig G, Lordan J, Fazio G, Grusak MA, Hoying S, Cheng LL, Francescato P, Robinson T. 2017. Horticultural performance of Geneva® rootstocks grafted with 'Fuji' in the Hudson valley, NY. *New York Fruit Quarterly*. 25(3):3-8.
- Reig G, Lordan J, Fazio G, Grusak MA, Hoying S, Cheng LL, Francescato P, Robinson T. 2018. Horticultural performance and elemental nutrient concentrations on 'Fuji' grafted on apple rootstocks under New York state climatic conditions. *Scientia Horticulturae*. 227:22-37.
- Robinson TL, Fazio G, Hoying S, Miranda M, Iurgerman K. 2011a. . Geneva® rootstocks for weak growing scion cultivars like 'Honeycrisp'. *New York Fruit Quarterly*. 19(2):10-16.
- Robinson TL, Hoying SA, Fazio G. 2011b. Performance of Geneva rootstocks in on-farm trials in New York state. *Acta Hort*. 903(903):249-255.
- Russo NL, Robinson TL, Fazio G, Aldwinckle HS. 2007. Field evaluation of 64 apple rootstocks for orchard performance and fire blight resistance. *Hortscience*. 42(7):1517-1525.

Gennaro Fazio is a research scientist with the USDA-ARS who leads the Geneva apple rootstock breeding program. **Terence Robinson** is a research and extension professor at Cornell University who is the co-leader of the Geneva apple rootstock breeding program.