Horticultural performance of Geneva® rootstocks grafted with 'Fuji' in the Hudson Valley, NY

Gemma Reig[1], Jaume Lordan[1], Gennaro Fazio[2], Michael A. Grusak[3], Stephen Hoying[1], Lailiang Cheng[1], Poliana Francescatto[1], and Terence Robinson[1]

[1] School of Integrative Plant Science, Horticulture Section, Cornell University, Hudson Valley Lab, Geneva and Ithaca, NY

[2] USDA ARS Plant Genetic Resources Unit, NYSAES, Geneva, NY 14456

[3] USDA-ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Houston, Texas 77030

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

In modern apple production systems, selection of an appropriate rootstock is as important to the viability and success of a new planting as the choice of fruiting variety. However, the selection of the most appropriate rootstock for new apple plantings has become increasingly complicated with the introduction of new rootstocks with potentially better yield performance, size control, and pest resistance, with different capacities to absorb mineral nutrients from soil and transfer them to the grafted scion variety, and with the continual movement toward higher high-density plantings. For that reason in the last 20 years, several studies have compared the horticultural performance of scion-rootstock interaction on apples. However, relative performance among rootstocks has not always been consistent from study to study. Part of the variability may be attributable to scion differences, but also to the agro-climatic conditions.

"A long-term study in the Hudson Valley showed considerable promise for alternative rootstocks to M.9 in future plantings, These included CG.6006, CG.8189 in the semi-dwarfing class; CG.4004 and CG.5087 in the dwarfing class, and confirmed the good performance of already released rootstocks like G.969, G.935, and G.890 within this setting. G.214 had high levels of calcium in the leaves, which could make it a good stock for 'Honeycrisp'."

The Geneva® rootstock series, originating from the Geneva, NY Breeding Program, are the leading fire blight-resistant rootstocks commercially available. Geneva® rootstocks also exhibit high cumulative yield efficiency in multiple size classes, combined with enhanced disease and, in some cases, insect tolerance. Therefore, one of the aims of this long-term study was to assess horticultural performance of 16 rootstocks from the Geneva, NY Breeding Program compared with the standard apple rootstocks, M.9 and M.26.

Materials and Methods

Plant material and trial characteristics. In the spring of 2005, a 1.98-acre orchard trial of apple rootstocks was planted at a Hudson Valley farm (in southeastern New York State). 'Fuji' was used as the scion variety for a set of rootstocks that included 16 Geneva rootstocks (Cornell-Geneva Apple Rootstock Breeding Program, Geneva, NY), and two English rootstocks (East Malling Research Station, Maidstone, Kent, England). Rootstock, type (dwarf or semi-dwarf), parentage, tree size and the suggested planting space are shown in Table 1.

The orchard trial was located in the Hudson Valley, on a bath gravel silt loam soil, with a pH of 6.2. This trial was established on a non-fumigated replant site, one year after uprooting an old apple orchard. The planting included five replications (one or two trees per replication) in a randomized complete block experimental design. Trees were trained into a vertical axis system, irrigated from ponds through drip lines, and the orchard was sprinkler irrigated every 10–12 days.

Tree survival and suckering. Tree health and survival were monitored throughout the trial. Dead trees were recorded each year at the time when growth measurements were taken. The incidence of rootstock suckering (root and collar suckers) was also recorded during this study.

Growth measurements and yield characteristics. At harvest, all fruit from each tree were counted and weighed to determine total yield per tree (lb/tree). Fruit weight (FW) was calculated considering the total number of fruits and total yield per tree. Average fruit size from 2007 to 2015 was also calculated. Cumulative yield (CY) per tree, cumulative yield per acre, yield efficiency (YE) and crop load (CL) of each scion-rootstock combination were computed from the harvest data. At the end of the experiment (Oct. 2015), tree circumference was recorded at 30 cm above the graft union, and the trunk cross-sectional area (TCSA) was then calculated. Cumulative yield efficiency (CYE) was calculated as the ratio between the cumulative yield in pounds per tree (from 2007 to 2015) per final TCSA (cm^2).

An alternate bearing index (AI) was calculated using the

NYSHS

New York State Horticultural Society

Check out our website's new design!

NYSHS.org

One Bushel Crates

Well built and reliable, these boxes will protect your produce. In bulk, $7.50 each

Hamlin Sawmill
1873 Redman Rd. Hamlin, NY 14464
585-964-3561
art@rochester.rr.com
www.OneBushelCrate.com

THE PICKIN' IS EASY WITH THESE MACHINES

MUNCKHOF The Munckhof Pluk-O-Trak

Increase Fruit Quality up to 60%
Bin filler ensures that large bins are filled evenly, without bruising fruit

Sort the Fruit
Presort bin for culls

Removable Conveyers
Remove to use for pruning

Automatic Sensor Steering

Leveling & Stability
Hydraulic leveling suspension

Increase Efficiency
Four hydraulic adjustable platforms - pick at all levels

Compressor
Onboard air compressor for pneumatic tools

Bin Trailer
Trailer holds up to 16 bins.

Two Sizes of Pluk-O-Trak!
Senior *(shown)* and Junior models available.

Scan to see the Pluk-O-Trak in action!

Call OESCO, Inc. for a demonstration
800-634-5557
www.oescoinc.com

REVO The REVO Piuma 4WD Harvester

- For apple & pear high-density fruit orchards
- Compact 12'-6" footprint
- Independent front & rear steering
- 4-wheel drive system
- Self-contained power and mobility; no tractor needed
- Auto-drive, auto-levelling, auto-steering
- Whisper-quiet fuel efficient diesel engine
- Onboard compressor for air-driven tools
- Flow-thru bin design

Scan to see the Piuma in action!

63 YEARS since 1954

Supplying Growers, Gardeners and Groundskeeping Professionals. Since 1954.

OESCO INC™

P.O. Box 540, 8 Ashfield Road / Rt. 116, Conway, MA 01341

Table 1. Apple rootstocks grown for 11 years with 'Fuji' as the scion at Milton, NY.

Rootstock	Type	Origin	Parentage	Tree size	Suggested in-row spacing (ft.)	Suggested between row spacing (ft.)
CG.2034	Super dwarf	Geneva Research Station, NY, USA	Dolgo crab x Malling 27	M.27	2	10
CG.4004	Semi dwarf	Geneva Research Station, NY, USA	722506-004 x OP	M.26 to M.7	5	13
CG.5087	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26 to M.7	4	12
CG.5257	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26 to M.7	5	13
CG.5757	Dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26	2	10
CG.6006	Semi dwarf	Geneva Research Station, NY, USA	PK-14 x Robusta 5	M.26 to M.7	4	12
CG.6976	Semi dwarf	Geneva Research Station, NY, USA	Robusta 5 x M.9	M.7-MM.106	6	14
CG.8189	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.7-MM.106	6	14
G.202	Dwarf	Geneva Research Station, NY, USA	M.27 × Robusta 5	M.26	3	11
G.210	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.7	6	13
G.214	Dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26	4	12
G.222	Semi dwarf	Geneva Research Station, NY, USA	M.27 × Robusta 5	M.26 to M.7	5	13
G.814	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26 to M.7	4	12
G.890	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.7	6	13
G.935	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26 to M.7	4	12
G.969	Semi dwarf	Geneva Research Station, NY, USA	Ottawa 3 × Robusta 5	M.26 to M.7	5	13
M.26	Dwarf	HRI-East Malling, UK	M.16 x M.9	M.26	4	12
M.9	Dwarf	Reselected at HRI-East Malling, UK	Unknown	M.9	3	11

following formula from the fifth year after planting (2009) to the eleventh year after planting (2015):

$AI = 1/(n-1) \times \{|(a_2-a_1)| / (a_2+a_1) + |(a_3-a_2)| / (a_3+a_2) \ldots + |(a_{(n)}-a_{(n-1)})| / (a_{(n)} + a_{(n-1)})\}$

where n: number of years, and a_1, a_2,..., $a_{(n-1)}$, a_n: yield (lb tree^{-1}). An average alternate bearing index was then calculated. This index ranges from 0 to 1, with 0 = no alternation and 1= complete yield alternation.

Leaf elemental analysis. Leaf mineral concentrations were determined in 2014. Ten mid-shoot leaves on new extension growth distributed throughout the tree canopy were harvested 90 days after bloom on all tree replicates. Leaves were oven-dried, ground into powder and shipped to the USDA ARS Children's Nutrition Research Center (Houston, TX) for mineral analysis of several macro- and micro-mineral nutrients, via inductively coupled plasma-optical emission spectroscopy (CIROS ICP Model FCE12; Spectro, Kleve, Germany). Concentrations of B, Cu, Fe, Mn, Na, and Zn were expressed as μg g^{-1} on a dry weight basis, and Ca, K, Mg, P and S were expressed as mg g^{-1}, also on a dry weight basis. Carbon (C) and nitrogen (N) values for leaf samples were measured with a LECO TruMac CN analyzer (Leco Corporation, St. Joseph, Missouri) at the Cornell University Drinkwater Horticulture Laboratory (Ithaca, NY), and both were expressed as percentage on a dry weight basis.

Statistical analyses. Statistical data analyses were performed with one-way ANOVA with rootstock genotype as the main effect and replicate as a random effect in a completely randomized plot analysis. Rootstock genotype means were used in a multivariate analysis to generate two-way similarity cluster diagrams based on genotype similarity and variable similarity. The Ward's minimum variance criterion was used. Data were analyzed using the JMP statistical software package (Version 12; SAS Institute Inc., Cary, North Carolina).

Results and Discussion

Survival. After 11 growing seasons, tree survival differed significantly among rootstocks. Tree survival was lower than 100% for trees on CG.2034, CG.5087, CG.5757, CG.6006, CG.6976, G.814, G.890, M.26 and M.9 (Figure 1). The rest of the rootstocks studied showed good survival in the soil conditions of the trial. The causes of tree death were not determined.

Tree vigor and suckering. Among the 18 rootstocks evaluated in this study, 'Fuji' trees with the smallest trunk

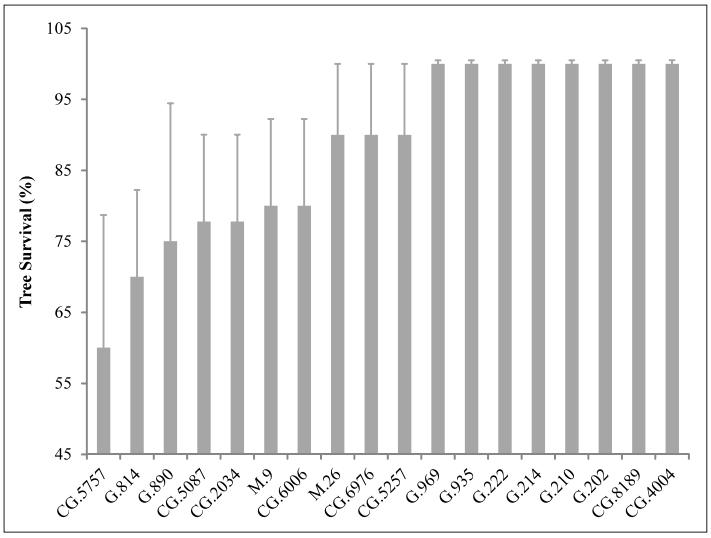


Figure 1. Tree survival rate (%) (plus standard error) in the 11th year after budding (2015).

cross-sectional area (TCSA) were on CG.2034 and CG.5757, followed by M.9, G.202, M.26 and G.214 (Figure 2). M.26 is usually considered to be in a different size class than M.9 (Table 1). CG.5087, CG.5257, CG.6006, G.214, G.814 and G.935 were similar to M.26, whereas CG.5757, G.202 and G.214 were between M.9 and M.26.

The greatest cumulative root suckering was with CG.8189, followed by G.890 and CG.6976, although the mean value was less than 5 suckers per tree, which we consider a minimal amount (Figure 2). CG.5087, CG.5757, M.9 and M.27 had no suckers. Sucker production is a genetic predisposition of the rootstock, but it is influenced by climate. In some trials, M.9 produces suckers, but in this trial it had none. Suckers can be a source of infection of fire blight. Currently, there is no technique for eliminating suckers except to cut them out every year. Therefore, breeding rootstocks with no or low suckering predisposition is one of the breeding objectives of the Geneva program (Fazio et al. 2015).

Yield, fruit size, & yield efficiency. 'Fuji' scions grafted on the super dwarf rootstock CG.2034 and the semi-dwarf rootstock G.202 had the lowest cumulative yield values, followed by trees on G.814, G.214, M.26, M.9 and CG.5757. The greatest cumulative yield was with trees on CG.6976, followed by CG.8189, CG.6006, and G.969 (Figure 3). M.9 performed well in this trial, which is one of the reasons it has persisted as the standard dwarfing rootstocks for over 50 years. Some new dwarfing rootstocks in this study exceeded significantly the cumulative yield of M.9. Therefore, high-density orchards with these rootstocks should produce greater yields, thus reducing production costs per unit of fruit (Robinson and Lakso 1991).

In contrast, trees on CG.2034, CG.5757 and M.9 had higher yield efficiency (yield adjusted for tree size) compared with the rest of the rootstocks evaluated (data not shown). Based on these results and other studies, it was not unexpected that the most dwarfing rootstocks would have the highest yield efficiency. The preference for grafting cultivars on dwarf rootstocks is aimed at the production of more flowers and fruit per unit area of land, and at the greater efficiency of conversion of light energy into fruit dry matter. In addition, scions grafted onto clonal dwarfing rootstocks produce fruits approximately in the second year, which is 4 or 5 years earlier than scions grafted on seedling rootstocks.

Mean fruit size was largest with the semi-vigorous rootstocks CG.8189, and CG.6976 (217.9 g and 215.7 g, respectively), and the semi-dwarf rootstock G.890 (215.8 g), whereas the dwarfing CG.2034, G.814 and G.969 had the smallest fruit size (183.1 g, 184.3 g and 185.7 g, respectively) (Figure 3). 'Fuji' on M.9 and M.26 had similar fruit size (around 200 g). Despite these differences in fruit sizes among rootstocks, most rootstocks had average fruit sizes greater than 180 g and can be classified as large fruits.

Based on the suggested planting space for each rootstock (Table 1) and the cumulative yield per tree (Figure 3), the estimated cumulative yield per acre after 11 years of study was calculated (Figure 4). The dwarf CG.5757 had the highest estimated cumulative yield per acre, followed by the dwarf rootstocks CG.6006, M.9, CG.5087 and G.935, and the super dwarf CG.2034. In contrast, the lowest values were for the semi-dwarf rootstocks CG.5257, G.814 and G.210.

Crop load and bearing index. The highest cumulative crop

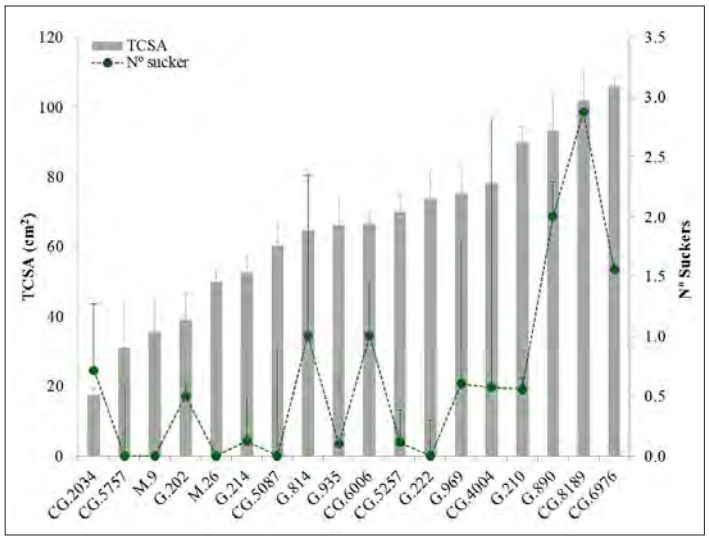


Figure 2. Final trunk cross sectional area (TCSA), and average number of suckers (plus standard errors) of 18 apple rootstocks budded on 'Fuji' after 11 years of study.

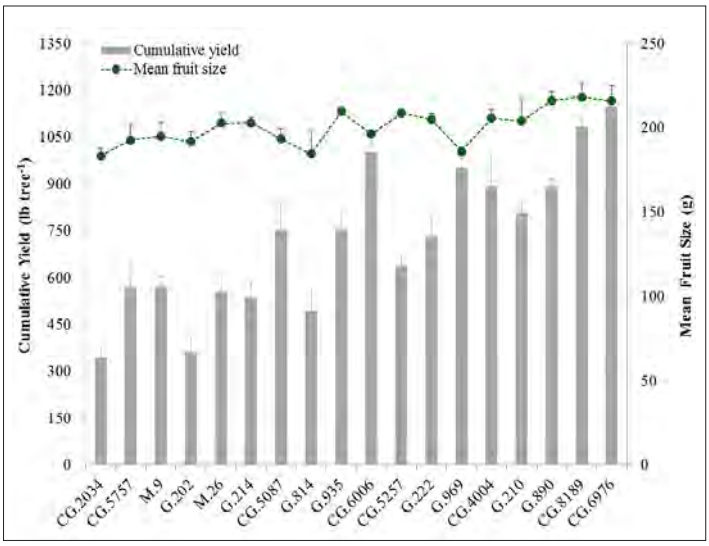


Figure 3. Cumulative yield and mean fruit size (plus standard errors) of 18 apple rootstocks budded on 'Fuji' after 11 years of study.

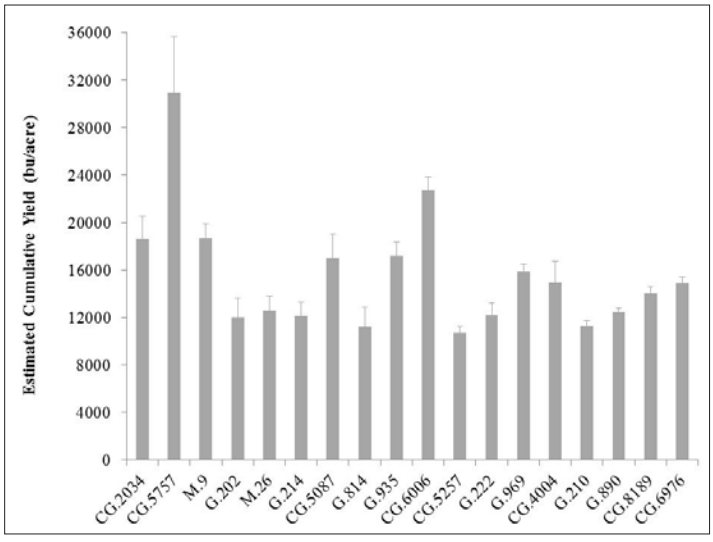


Figure 4. Estimated cumulative yield per acre (plus standard errors) of 18 apple rootstocks budded on 'Fuji' after 11 years of study.

load was on CG.2034, followed by CG.5757, M.9 and CG.6006, whereas G.814, G.202, and G.210 had the lowest values (Figure 5). During the course of the trial, crop load was generally good and there was a highly significant correlation between cumulative yield efficiency and cumulative crop load.

All rootstocks evaluated in this study had a mean biennial bearing index value lower than 0.5, which means there was low alternation of cropping (Figure 4). G.214 had the lowest biennial bearing index, while G.202, followed by CG.5757 and G.814, had the highest biennial bearing index value. Alternate bearing is a physiological condition that occurs in apples. It refers to the tendency of an entire tree to produce a greater than average crop one year, and a lower than average crop the following year. Gibberellins are considered to be the main cause of alternate bearing due to their role in preventing the formation of flowers buds. 'Fuji,' as expected, was biennially bearing during the course of this trial. However, since annual cropping is essential for orchard profitability, it is important to know which rootstock induces more annual bearing with this type of variety. Generally, weak or dwarfing rootstocks have been reported to reduce biennial bearing in apples.

The effect of rootstock on leaf mineral concentration was evaluated for each rootstock. To simplify the interpretation of this data, a hierarchical agglomerative cluster analysis was used to divide the rootstocks into groups of increasing dissimilarity. Three clusters were identified from similar nutrient profiles (Figure 6). This division did not correspond to rootstocks groupings based on type, parentage or tree size. The first group, which included CG.2034 through G.935 (in red in Fig. 6), was characterized by rootstocks with low to medium P, K, and Fe values. The dwarf CG.2034 and the semi-dwarfs G.969 and CG.6006 resulted in higher Mn concentrations in leaves. The second group, which included CG.4004 through M.9 (in green), showed low to medium B, Ca, Cu and Na values. The last group, CG.5257 through G.214 (in blue), had medium to high B, P, and K values. In this group, G.890 conferred some of the highest values of B, P, K, Cu, Fe and Mg, while G.214 had the highest Ca value, which is consistent with data from similar experiments in Washington State (Musacchi, pers. comm.). The high Ca values for G.214 could make it a good rootstock for bitter pit-susceptible varieties like 'Honeycrisp'. All of the rootstocks had optimum leaf Fe, Mn, P, compared with reference values (Stiles and Reid 1991), optimum Ca values with the exception of M.26, which had lower than the optimum, optimum leaf K values except CG.5757 and CG.6006, which had lower values compared with the optimum, and lower leaf B, Cu, Mg and Zn values than the optimum reference values. Unfortunately, no reference values have been found for Na, S and C. Therefore, results cannot be compared.

Conclusions

It is likely that the rootstock-induced changes in the concentrations of mineral nutrients can have subtle or dramatic effects on the physiological machinery of the tree, resulting in changes in fruit production and quality. Several Geneva® rootstocks evaluated during the course of this study showed considerable promise as alternatives to M.9 in future plantings, such as CG.6006, CG.8189 in the semi-dwarfing class; CG.4004 and CG.5087 in the dwarfing class, and confirmed the good performance of already released rootstocks like G.969, G.935, and G.890 within this setting. This study, for the first time, has generated a comprehensive horticultural and elemental data set for 'Fuji' grafted on several rootstocks, mostly Geneva®, trained in vertical axis system.

Acknowledgements

The authors wish to thank Jeff Crist and his family for all the help and resources invested in all these years, and Rick Schoonmaker and Joe Whalen for plant material management in the orchard. This research was funded by a grant from the NY Apple Research and Development Program, and in part with federal funds from the U.S. Department of Agriculture, Agricultural Research Service under Co-operative Agreement

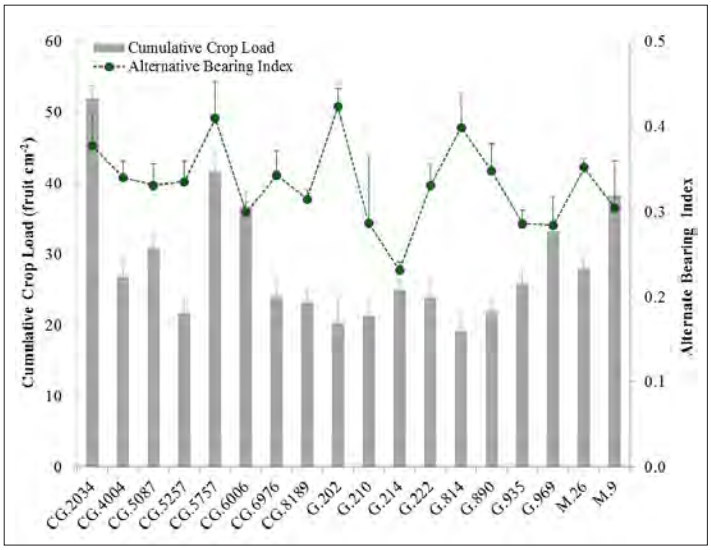


Figure 5. Cumulative crop load and mean alternative bearing index (plus standard errors) of 18 apple rootstocks budded on 'Fuji' after 11 years of study.

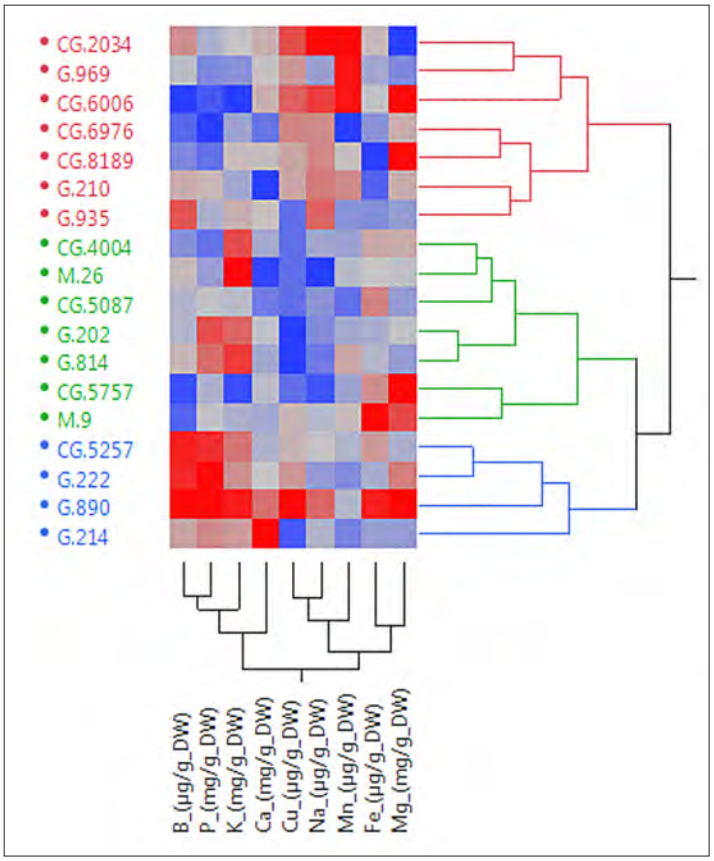


Figure 6. Rootstocks and leaf nutrients grouped by similarities in mineral nutrient concentration mean values (Gradrient from low (blue), medium (gray), and high (red)).

number 58-6250-0-008 to MAG. The contents of this publication do not necessarily reflect the views or policies of the U.S. Department of Agriculture, nor does mention of trade names, commercial products, or organizations imply endorsement by the U.S. Government.

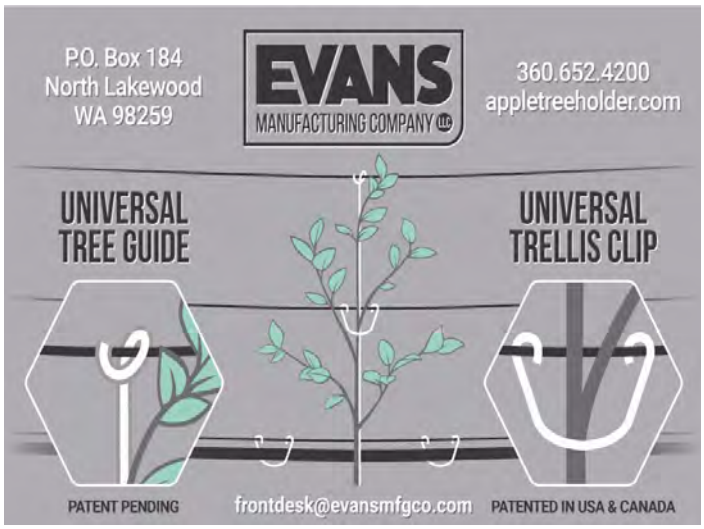
References

Fazio, G., Robinson, T. L., Aldwinckle, H. S. 2015. The Geneva Apple Rootstock Breeding Program, in: Wiley, M.F. (Ed.), Plant Breeding Reviews, vol. 39, pp. 379–423.

Robinson, T. L., Lakso, A. N. 1991. Bases of yield and production efficiency in apple orchard systems. J. Am. Soc. Hort. Sci. 116: 188–194.

Stiles, W. C., Reid, W. S. 1991. Orchard nutrition management. Cornell Univ. Coop. Ext., Ithaca, N.Y. Info. Bull. no. 219.

Gemma Reig was a Postdoctoral Research Associate in the Horticulture department at Cornell University's Hudson Valley Research Laboratory. Currently, she is working at the Experimental Station of Aula Dei (Zaragoza, Spain). **Jaume Lordan** and **Poliana Francescatto** are Postdoctoral Associates at Cornell's Geneva Experiment Station in Dr. Robinson's program. **Gennaro Fazio** is a research scientist who leads the Cornell/USDA apple rootstock breeding and evaluation program. **Michael A. Grusak** is a research scientist at the USDA-ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Houston, Texas. **Steve Hoying** is a retired senior extension associate who was located at Cornell's Hudson Valley Lab who specializes in orchard management. **Lailiang Cheng** is a research and extension professor at Cornell's Ithaca campus who leads Cornell's mineral nutrition program for fruit crops. **Terence Robinson** is a research and extension professor at Cornell's Geneva Experiment Station who leads Cornell's program in high-density orchard systems, irrigation and plant growth regulators.



Columbia Tractor, Inc.

Serving the Hudson Valley & Western New England
with these quality lines of tractors & equipment:

— Case IH — Kubota — Bush Hog — Woods — Kinze —
— Unverferth — Brillion — Monosem — Unverferth —
— Ag-Tec Sprayers — Aerway Aerators — Husqvarna —
— Kawasaki Mule — Befco — Echo — Great Plains Drills —

Call us for Parts - Service - New & Used Tractors & Equipment

PO Box 660, 841 Route 9H, Claverack, NY 12513
Approx. 40 miles south of Albany, NY, in the Hudson Valley
Phone: 518-828-1781 • 800-352-3621 • Fax: 518-828-2173
Email: Skinne@columbiatractor.com Web: www@columbiatractor.com