Unique Characteristics of Geneva® Apple Rootstocks

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> **"The high field performance of the Geneva® rootstocks has generated an increasing demand in the U.S. markets possibly trending to replace current commercial rootstocks in the next two decades. Over the last 3 years we have seen a boom of stoolbed plantings of Geneva rootstocks. This past winter (2012/2013) licensed nurseries harvested ~2 million Geneva rootstock liners. These liners will result in finished trees for growers in the spring of 2015. The new stoolbeds will now provide a steady supply of improved rootstocks for North American apple growers."**

The Geneva® apple rootstock breeding program has been operating since the early 1970's. It is a unique program in that it had access to important germplasm resources that later became the USDA ARS apple collection in Geneva, NY (Aldwinckle et al., 1976). This genetic diversity allowed for the achievement of one of the project goals: breeding disease resistant apple rootstocks while achieving gains in productivity. A visionary Cornell University plant breeder (Dr. Cummins) and plant pathologist (Dr. Aldwinckle) are the scientists who decades ago pioneered the utilization of wild germplasm to provide the apple industry with dwarfing disease resistant rootstocks (Cummins and Aldwinckle, 1974). The USDA ARS joined the effort in the late 1990's to maintain the momentum of the breeding program. The ultimate purpose of the Geneva® apple rootstock breeding program matches the ultimate goal of apple growers: to maximize efficient production of high quality apples by grafted apple scions in a commercial orchard setting. Many factors influence fruit yield and quality, but there are a few choices that a grower can make only once in the lifetime of an orchard – the choice of an apple rootstock compatible with a productive orchard system is one of those major decisions that can enhance or shatter the yield potential of an orchard. The expectation of the Geneva® rootstock breeding program is to provide better choices and alternatives relative to the currently available population of apple rootstocks. In this article we describe some of our findings and discuss the benefits of utilizing certain Geneva® apple rootstocks.

The Geneva® Apple Rootstock Breeding Process

The program owes some of its uniqueness to the multi stage 20-30 year breeding process that starts with a large number of seeds from multiple parents and cross combinations; these are germinated and inoculated with fire blight bacteria *(Erwinia amylovora)* and crown rot oomycete (*Phytophthora* spp) within the first month after germination. This first inoculation stage generally eliminates 50-80% of the seedlings and the survivors are established as single plant stool tree populations. In the second and third stages the focus is on evaluation of propagation properties as well as generating initial evaluation trees which are planted in a replicated orchard experiment to allow for important traits like precocity and dwarfing to be measured. In these orchards, data are collected annually for yield, yield efficiency, tree vigor, suckering, nutrient uptake efficiency and response to any other unique stress events. In stages four and five, rootstocks that have performed well in previous stages are increased in numbers to be able to run highly replicated tests and produce a reliable estimate of how resistant or tolerant a selection is to different biotic and abiotic stresses that these new plants will be faced with in the life of an orchard. These tests could include exposure to extreme soil temperatures, replant soils, multiple strains of fire blight, wooly apple aphids, crown rot, viruses, and graft union strength with multiple scion varieties. During stages six and seven the new selected rootstocks are observed in highly replicated trials with different training systems that match vigor potential and characteristics of each rootstock, the same rootstocks are also distributed to cooperating commercial nurseries to bulk up production and evaluate propagation potential. During stage eight the rootstocks are disseminated throughout the U.S. and the world for cooperator testing through the NC-140 system and a network of international scientists. During stage nine and ten a select few apple rootstocks are increased in production for commercial level tests (large orchards, few rootstocks), intellectual property protection is filed followed by final release of these rootstocks to nurseries and orchard growers. For most Geneva® apple rootstocks released so far this multistage process has taken on average more than 30 years.

Unique Genetic Sources

When compared with commercial and experimental rootstocks from other breeding programs, most of the Geneva elite rootstocks stand out from other apple rootstock germplasm (Fazio et al., 2011). Currently in the Geneva breeding pipeline, thanks to multiple crosses between elite rootstocks and wild germplasm, there is a tremendous amount of genetic variation which can be utilized for breeding, selection and characterization of new traits, including disease resistance, vigor, precocity, and productivity. While only a small portion of that variation is visible or experienced in the many different flavors, colors, leaf and branch shapes, and growth habits, the remaining genetic variation is concealed from the naked eye and can only be identified through experiments, conditions and analysis designed to unveil that variation. Such is the case with what was observed in regard to resistance to Rosellinia (although temporary) in some of the Geneva rootstock material, which was not part of the initial disease screen but showed itself once exposed to the Brazilian inocula. The wide genetic base of the breeding program should allow a prompt (in rootstock terms) response to new challenges and goals.

Resistance to Wooly Apple Aphids (WAA)

Wooly apple aphids, are not just a nuisance to growers but can have a significant negative effect on fruit production in certain climates. Most commercial dwarfing rootstocks including M.9, B.9, M.26, M.7, Ottawa 3 are severely susceptible (Beers et al., 2010). Resistant apple rootstocks may contribute in the eradication of this pest in the orchard by preventing the overwintering stage that occurs in the soil while the insects feed on root systems, and the escape from aerial pesticide treatments during the growing season. The Geneva® breeding program has been the first to release several dwarfing apple rootstocks (G.41, G.969, G.214, G.210, G.202) that possess a different and more effective type of resistance than the MM.106, MM.111 type.

Modification of Tree Branching and Root Architecture

In addition to dwarfing the scion, a number of Geneva rootstocks have shown the ability to: 1) increase the number of feathers in the nursery stage of the tree and 2) flatten the branch angles of grafted scions. The flattening of branches seems to be well correlated with an increase in productivity of these apple rootstocks when compared to others that do not have this trait (Fazio and Robinson, 2008). How can a rootstock accomplish this? In the past several years we have learned that apple rootstocks have the innate ability to modify the basic physiology of the tree by modulating the expression of genes in the scion (Jensen et al., 2010) therefore it is possible that the apple rootstocks are sending a signal that modifies wood properties/growth in the scion and shifts resources to fruit production. Another unique trait in several rootstocks in our breeding program is the ability to produce root systems that have more fine roots than thick roots (high fine/thick root ratio) which is heritable (Fazio et al., 2009b) and might be involved in making this set of apple rootstocks more productive than other commercial counterparts.

Resistance to Fire Blight

Resistance to *E. amylovora* bacteria which causes fire blight has been a major goal since the inception of the Geneva breeding program (Cummins and Aldwinckle 1974). All released rootstocks today are tolerant or immune to this disease and allow the survival of susceptible scion varieties even under high disease pressure (Norelli et al., 2002; Russo et al., 2007). Breeding with new sources of fire blight resistance continues in the Geneva® program in an effort to prevent new strains from overcoming the resistance genes that have already been deployed (Fazio et al., 2009a).

Tolerance to Apple Replant Disease

Apple Replant Disease (ARD) is a major problem in the apple production areas of the world as less fumigants are available to sterilize the soil prior to replanting an orchard. Tolerance to ARD is one of the hidden traits that was not on the priority list in the initial stages of the breeding program, but has been discovered in the elite germplasm developed in Geneva. ARD causes stunting of young trees and substantial losses in production over the lifetime of the orchard. It is a complex disease and several causative agents have been implicated in the development of ARD symptoms including *Cylindrocarpon destructans*, *Phytophthora cactorum*, *Pythium spp.*, and *Rhizoctonia solani* (Mazzola, 1998). Not all orchard sites may be affected by all these pathogens, and some may have only one or two that are a factor. Several studies in many different locations in the U.S. and the world have demonstrated that certain Geneva rootstocks are very tolerant to replant disease when compared to existing commercial stocks (Auvil et al., 2011; Fazio et al., 2012; Rumberger et al., 2004). Some of these experiments show that while fumigation was successful in promoting growth for 2-3 years at an otherwise poor site, the rootstock's inherent genetic tolerance or resistance lasts as long as the orchard, well after the effects of fumigation have vanished.

Increase in Tree Productivity

Many Geneva® apple rootstocks have been the subject of numerous multi-state and international field trials that have taken place for the past 20 years. The best Geneva rootstocks have been top performers with regards to cumulative yield, yield efficiency and survival, several of them have consistently outperformed the standard commercial varieties (M.9 clones, B.9, M.26, M.7, MM.106, B.118, etc.) at many locations (Autio et al., 2011a; Autio et al., 2011b; Czynczyk et al., 2010; Kviklys, 2011; Marini et al., 2006a; Robinson et at., 2003; Robinson et al., 2006; Russo et al., 2007). An example of the high yield efficiency of the best Geneva rootsocks if presented in Fig. 1 from a trial done in Wayne County, NY State.

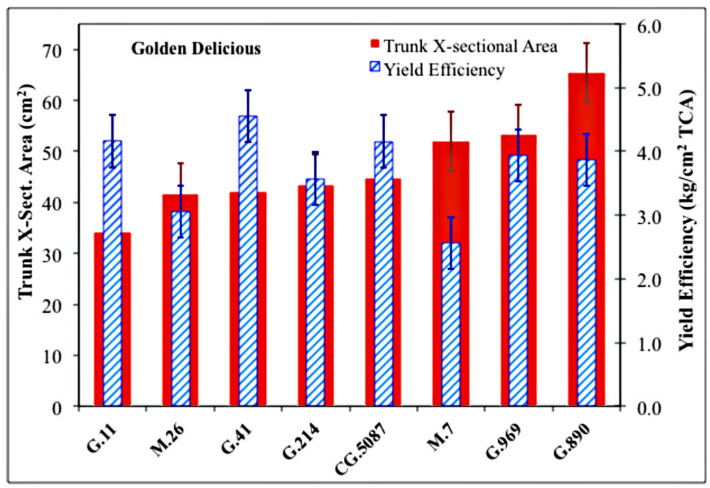

Figure 1. Tree size and yield efficiency of 'Golden Delicious' apple trees on several Geneva® rootstocks over 10 years at Wolcott, NY.

Geneva® Rootstock Releases

Eleven Geneva® rootstocks have been released in the U.S. of which seven are being supported for further commercial application. Several of these rootstocks are also being commercialized in countries other than the U.S. Many more genotypes are in the process of being tested and commercialized in these countries.

Geneva® 11 is similar in size to B.9 in some trials and similar to M.9T337 in others. It is very precocious, has very high yield efficiency (Fig. 1) and reduces bienniality with Honeycrisp (Robinson et al., 2011). It is fire blight resistant and has good resistance to Phytophthora root rot, but it is not resistant to wooly apple aphids or apple replant disease. G.11 has good layerbed and nursery characteristics and produces high quality nursery trees. It is proving to be an excellent replacement for M.9 in North America and Europe. Its stool bed production in the USA in 2012 was about 800,000 liners and production should increase to 1,000,000 liners in 2013 (Figs. 2 and 3).

Geneva® 41 is similar in size to vigorous clones on M.9 such as Nic29 or Pajam 2. It is usually the most efficient dwarf root-

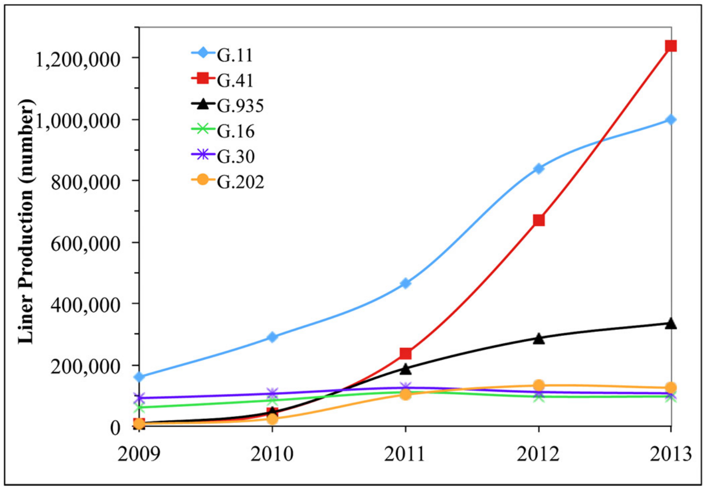

Figure 2. Production of rootstock liners of 6 Geneva rootstocks over the last 4 years and projected production in 2013.

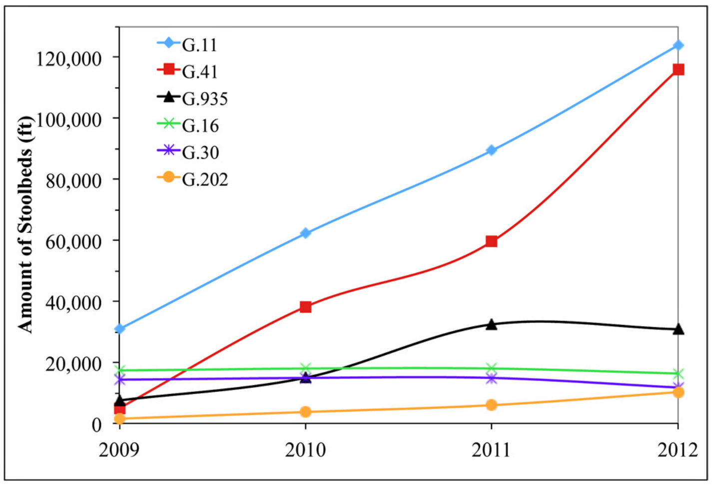

Figure 3. Amount of stoolbeds of 6 Geneva rootstocks existing in each of the last 4 years and projected amount in 2013.

stock in our trials (Fig. 1) and reduces bienniality with Honeycrisp (Robinson et al., 2011). It has excellent fruit size and induces wide branch angles. It is highly resistant to fire blight and is also resistant to Phytophthora and wooly apple aphids. It has some tolerance to apple replant disease and has good winter hardiness. In the stoolbed, G.41 is a shy rooter and requires specialized rooting techniques including tissue cultured stoolbed mother plants to improve its rooting. It has brittle roots and a brittle graft union similar in strength to M.9 and must be handled with care. Its stellar orchard performance in both eastern and western North America indicate that it will be a good alternative to M.9 in high fire blight prone areas, in replant disease areas and in woolly aphid prone areas. Its stoolbed production in the USA in 2012 was only 600,000 liners. Substantial new stoolbeds have been planted which should increase production to 1,200,000 liners in 2013 (Figs. 2 and 3).

Geneva® 935 is similar in size to M.26 in some trials and similar to the vigorous clones of M.9 in other trials. It is highly precocious has very high yield efficiency. It induces wide branch angles, is highly resistant to fire blight and Phytophthora, and appears to have some tolerance to apple replant disease. It also appears to be very winter hardy, but it is not resistant to wooly apple aphid. Fruit size has been slightly smaller than with M.9. It is an excellent new rootstock for weak growing cultivars like spur-type 'Delicious', 'Honeycrisp', 'Sweet Tango' or 'Snapdragon'. Its stoolbed production in the USA in 2012 was only 300,000 liners and production should increase to 400,000 liners in 2013 (Figs. 2 and 3).

Geneva® 202 produces a tree slightly larger than M.26. It has high yield efficiency and is precocious. It is resistant to fire blight, Phytophthora, apple replant disease and to wooly apple aphid. It is a useful with weak growing cultivars and as an alternative to M.26 in climates that have problems with woolly apple aphid. It has become a popular dwarfing rootstock in New Zealand. Its stoolbed production in the USA in 2012 was 150,000 liners with substantial new stoolbeds in Mexico (Figs. 2 and 3).

Geneva® 214 is similar in size to M.9 in some trials and similar in size to the vigorous clones of M.9 in other trials. Due to the outstanding performance of G.214 in the trials reported in this article and other trials done in Washington State it was released in 2010. It is slightly less yield efficient than G.41 but has better stoolbed propagation characteristics, which may make it easier to be introduced quickly. The first commercial stoolbeds of this stock will be planted in 2013.

Geneva® 969 is similar in size to M.26 in some trials and similar to M.7 in others. It is highly yield efficient and was released in 2010 as a free standing semi-dwarf tree for processing orchards. It is resistant to fire blight, Phytophthora, and wooly apple aphid. It has excellent stoolbed propagation characteristics, which may make it easier to be introduced quickly. It performs well in northern climates. It may be an excellent stock for weak growing cultivars in northern climates like Honeycrisp, Sweetango or Snapdragon when planted at high densities. The first commercial stoolbeds of this stock will be planted in 2013.

Geneva® 890 is similar in size to M.7 or MM.106. It is more yield efficient than either M.7 or MM.106 and was released in 2010 as a free standing semi-dwarf tree for processing orchards. It has excellent stoolbed propagation characteristic and is resistant to fire blight, Phytophthora and wooly apple aphid. The first commercial stoolbeds of this stock will be planted in 2013.

Four other Geneva rootstocks (G.65, 16, 30 and 210) have also been released but have limited commercial propagation. G.65 is too dwarfing in many locations while G.16 is susceptible latent virus infections when grafted with infected budwood. G.30 very productive in the orchard and is proving to be useful in northern growing areas where it shows wide soil adaptation, good winter hardiness and high yields. However, it is difficult to handle in the stoolbed and nursery due to excessive production of sharp spines. This has limited its production for the last 5 years to about 100,000 liners per year (Figs. 2 and 3). G.210 is newly released with similar characteristics as G.30 but with less spines.

Conclusions

Thanks to many years of investment into breeding and evaluation of apple rootstocks the Geneva® breeding program has produced a series of unique apple rootstocks that consistently outperform the current commercial standards in both productivity and disease resistance. Their high field performance has generated an increasing demand in the U.S. markets possibly trending to replace current commercial rootstocks in the next two decades. While some may be slightly harder to propagate than traditional rootstocks, experienced nurseries have been able to maximize production. Over the last 3 years we have seen a boom of stoolbed plantings of Geneva rootstocks. This past winter (2012/2013) licensed nurseries harvested ~2 million Geneva rootstock liners. These liners will result in finished trees for growers in the spring of 2015. It has been a long effort to get the stoolbeds planted but they will now provide a steady supply of improved rootstocks for North American apple growers.

Acknowledgements

We give special thanks to international collaborators and testers of Geneva rootstocks, Todd Holleran and Sarah Bauer of the USDA ARS apple rootstock breeding program.

Mention of a trade name, proprietary product or specific equipment does not constitute a guarantee or warranty by USDA and does not imply its approval to the exclusion of other products that may be suitable.

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