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Long-term performance of 'Gala', Fuji' and 'Honeycrisp' apple trees grafted on Geneva® rootstocks and trained to four production systems under New York State climatic conditions

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ABSTRACT

In 2006, two 1-ha orchard trials were established at each of two sites (Dressel farm in Southeastern New York State and VandeWalle farm in Western New York State) to compare seven Geneva® rootstocks ('CG.4210', 'G.11', 'G.16', 'G.41', 'G.30', 'G.210', and 'G.935') with one Budagovsky ('B.9') and three Malling rootstocks ('M.9T337', 'M.26EMLA' and 'M.7EMLA') as controls. 'Gala' and 'Fuji' were used as scion cultivars at Dressel farm and 'Gala' and 'Honeycrisp' as the scion cultivars at VandeWalle farm. At each location trees were trained to four high-density systems: Slender Pyramid (SP) (840 trees ha^{-1}), Vertical Axis (VA) (1284 trees ha^{-1}), Slender Axis (SA) (2244 trees ha^{-1}), and Tall Spindle (TS) (3262 trees ha^{-1}). Location, rootstock, and training system, interacted to affect growth, production and fruit quality of each scion cultivar. 'Gala' trees from VandeWalle farm were smaller but more productive than those from Dressel farm. In general, the largest trees (in trunk cross sectional area: TCSA) were SP on 'M.7' rootstock and the smallest were TS on 'B.9' and 'G.11'. Cumulatively, yield was lowest for trees on SP with 'M.7'. However, the highest values were on TS with 'G.11' for 'Fuji', TS with 'G.41' for 'Gala', and TS with 'G.16' and 'M.9' for 'Honeycrisp'. Independent of the cultivar, trees on SP with 'M.7' had the highest number of root suckers. When comparing systems which had the same rootstocks, TS trees were the least vigorous ones, but much more productive although, fruit red color was slightly reduced compared to the lower density systems. When comparing dwarfing rootstocks common across several systems, generally, 'G.16' trees were the largest, however 'G.11', 'G.41' and 'M.9' were the most productive for 'Fuji', 'Gala' and 'Honeycrisp', respectively.

1. Introduction

With the adoption of dwarfing and precocious rootstocks over the past 50 years, apple orchard systems have transitioned from the traditional with large trees in wide spacing arrangements (70–100 trees ha^{-1}) to high-density with smaller closely spaced trees (1,000–6,000 trees ha^{-1}) in order to increase early yields to pay back the high initial investment cost and to improve early and lifetime orchard profitability. Such orchards also have high sustained yields, smaller tree size to facilitate tree management, excellent fruit quality (Robinson, 2007), and better light interception and absorption in the different parts of the crown (Gandev et al., 2016).

With the development of high density orchard systems, several researchers have studied alternative approaches to tree management that involved less pruning and the use of feathered trees. Dominguez (2015) has shown that bending lateral branches below horizontal instead of pruning them back in high density Tall Spindle orchards resulted in greater early yield of 'Gala', whereas had no effect on 'Honeycrisp'. Wertheim and Joosse (1972) showed that both the thickness of the trunk and the number of lateral branches (feathers) of the maiden tree

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Table 1
Apple rootstocks evaluated and their descriptions.

Rootstock	Type	Parentage	Tree size	Origin
B.9	Dwarf	M.8 x Red Standard	'M.9'	Michurinsk State Agrarian, Russia
CG.4210	Dwarf	Ottawa 3 × Robusta 5	'M.7'	Cornell University-USDA (USA)
G.11	Dwarf	M.26 x Robusta 5	'M.9'	Cornell University-USDA (USA)
G.16	Dwarf	Ottawa 3 × Malus floribunda	'M.9' to 'M.26'	Cornell University-USDA (USA)
G.30	Semi dwarf	Robusta 5 x M.9	'M.7' to 'MM.106'	Cornell University-USDA (USA)
G.41	Dwarf	M.27 x Robusta 5	'M.9'	Cornell University-USDA (USA)
G.210	Semi dwarf	Ottawa 3 × Robusta 5	'M.7'	Cornell University-USDA (USA)
G.935	Dwarf	Ottawa 3 × Robusta 5	'M.26' to 'M.7'	Cornell University-USDA (USA)
M.7EMLA	Semi dwarf	Unknown	'M.7'	East Malling (UK)
M.9T337	Dwarf	Unknown	'M.9'	East Malling (UK)
M.26EMLA	Dwarf	M.16 x M.9	'M.26'	HRI-East Malling (UK)

had a large influence on early yield. The greater the number of feathers at planting, the greater was the yield, especially in the second and third year. Thus, for very high-density systems that depend on significant 2nd and 3rd year yields, feathered trees have become an essential part of the success of these systems (Robinson, 2007). Currently, the ideal tree for high density plantings should have a minimum diameter of 15 mm, and 10–15 well positioned feathers with a maximum length of 40 cm and starting at a minimum height of 80 cm (Balkhoven-Baart et al., 2000; Robinson, 2007; Weiss, 2004).

One of the most critical elements of any apple orchard is the rootstock, particularly in high-density systems where the economic risks and potential returns are the highest (Autio et al., 2017). Most successful high-density apple orchards are planted with dwarfing rootstocks such as 'M.9', 'M.26' or 'B.9' rootstocks, although it is possible to plant high density orchards on semi-dwarf rootstocks such as 'M.7'. 'M.9' is the most frequently used apple dwarfing rootstock in both commercial and home orchards (Webster, 1995). However, in general, some or all of these rootstocks lack winter hardiness, are susceptible to *Phytophthora* spp. root rot or fire blight bacterial disease (*Erwinia amylovora* Burill), have burrknots, poor anchorage or root suckers, are sensitive to apple replant disease or have brittle graft unions, which limits the establishment of new high-density plantings (Norelli et al., 2003; Robinson, 2007; Russo et al., 2007). To overcome these challenges and provide sufficient growth control, enhanced precocity, higher yield, improved adaptability to environmental conditions, and better fruit quality, several breeding programs worldwide, such as the Bugadovsky and the Cornell-Geneva breeding programs have been established (Autio et al., 2017; Robinson, 2007).

Besides the rootstock, intensive apple orchard systems must also include the optimization of management for each combination of cultivars, planting density and location to obtain high yields and quality every year (D'Abrosca et al., 2017). The specific combination of management strategies has been termed as the training system (Hampson et al., 2002; Robinson, 2003). The training of fruit trees to a certain system aims at shaping canopy architecture to improve light interception and distribution for the purpose of optimizing fruit quality and yield. Thus, the choice of the training system is critical for orchard profitability. Over the past two or three decades many new systems for high-density apple orchards have been developed worldwide (Tall Spindle, Central Leader, Fruiting Wall, Palmette, Slender Pyramid, Slender Axis, Slender Spindle, Solaxe, Super Spindle, Vertical Axis, V-shaped, Y-trellis) (Robinson, 2003). Research on planting and training systems using dwarf and semidwarf rootstocks, especially those from East Malling breeding program, has been conducted around the world (Hampson et al., 2002; Harper et al., 2013; Hassan et al., 2010; Kapel and Quamme, 1992; Kucuker et al., 2015; Ozkan et al., 2016; Platon, 2007; Robinson et al., 1991). Since there are many different factors which affect orchard profitability (Badiu et al., 2015; Bradshaw et al., 2016; Lordan et al., 2017, 2018b; Sojkova and Adamickova, 2011; Weber, 2001) it is necessary to conduct exhaustive studies to find the best training system for each particular scenario: cultivar, rootstock, climate and economics.

Very few studies offer direct long-term comparisons of systems with different rootstocks (released and not yet released), cultivars (the preferred by the consumers), and locations (different growing conditions) due to the expense and time commitment required. Therefore, the aim of this trial was to investigate the effectiveness of four of the most promising high-density systems (Slender Pyramid, Vertical Axis, Slender Axis and Tall Spindle) and seven of the most promising Geneva® rootstocks ('G.11', 'G.16', 'G.210', 'G.30', 'G.41', 'G.935', and 'CG.4210') along with 'B.9', 'M.9', 'M.26' and 'M7' as controls using 3 important apple cultivars ('Gala', 'Fuji' and 'Honeycrisp') by assessing agronomic performance and physico-chemical fruit traits at different locations. Currently, 'Gala', 'Fuji' and 'Honeycrisp' belong to the top ten apple varieties produced in the USA (usapple.org).

2. Material and methods

2.1. Plant material, site description and experimental design

In the spring of 2006, two 1-ha orchard trials of eleven apple rootstocks and four training systems were established at two locations in New York State, USA (Dressel farm and VandeWalle farm). 'Gala' and 'Fuji' apple cultivars were used at the Dressel farm site and 'Gala' and 'Honeycrisp' were used as scion cultivars at the VandeWalle farm site. Rootstocks included six named Cornell-Geneva rootstocks [(Geneva® 11 ('G.11'), Geneva® 16 ('G.16'), Geneva® 41 ('G.41'), Geneva® 30 ('G.30'), Geneva® 210 ('G.210') and Geneva® 935 ('G.935')], one unreleased Cornell-Geneva clone ('CG.4210'), one Budagovsky series clone ('B.9'), and three Malling series clones ('M7EMLA', 'M.9T337' and 'M.26EMLA') to serve as controls (Table 1). The four planting systems were: Slender Pyramid (SP) (trees spaced at 2.44 m × 4.88 m, 840 trees ha^{-1}), Vertical Axis (VA) (trees spaced 1.83 m × 4.27 m, 1282 trees ha^{-1}), Slender Axis (SA) (trees spaced 1.22 m × 3.66 m, 2244 trees ha^{-1}), and Tall Spindle (TS) (trees spaced 0.91 m × 3.35 m, 3262 trees ha^{-1}). Fully feathered nursery trees (2 years in the nursery with 7–10 feathers), were used in this study and were propagated by Adams County Nursery, Aspers PA, USA. Virus free scion wood and rootstocks were used.

The trial at Dressel farm was planted in Southeast New York State, Town of New Paltz, Ulster County, USA (lat. 41°42′53.15″N, long. 74°06′39.78″W) on a Hoosic gravelly loam soil. The trial at VandeWalle farm was planted in Western New York State, Village of Alton in the Town of Sodus, Wayne County, USA (lat. 43°13′12.58″N, long. 76°58′17.11″W) on a Williamson silt loam soil (USDA, 2018). In both trials, row orientation was north-south. The Dressel site had previously been planted to apple trees on seedling rootstock for 40 years and was not fumigated. The VandeWalle site had previously been planted to an apple tree nursery and was not fumigated before planting. The replant disease severity at both trial sites was not evaluated before planting but field fumigation trials in the same counties by Merwin et al. (2001) showed low replant disease pressure for similar soils. Trees at both sites