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Horticultural performance and elemental nutrient concentrations on 'Fuji' grafted on apple rootstocks under New York State climatic conditions

Gemma Reig[a,*], Jaume Lordan[b], Gennaro Fazio[b,c], Michael A. Grusak[d], Stephen Hoying[a], Lailang Cheng[e], Poliana Francescatto[b], Terence Robinson[b]

[a] School of Integrative Plant Science – Department of Horticulture, Hudson Valley Research Laboratory, Cornell University, Highland, NY, United States
[b] School of Integrative Plant Science – Department of Horticulture, New York State Agricultural Experiment Station, Cornell University, Geneva, NY, United States
[c] USDA ARS Plant Genetic Resources Unit, New York State Agricultural Experiment Station, Geneva, NY, United States
[d] USDA-ARS Children's Nutrition Research Center, Baylor College of Medicine, Houston, TX , United States
[e] School of Integrative Plant Science – Horticulture Section, Cornell University, Ithaca, NY, United States

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ABSTRACT

A study was carried out to determine the horticultural performance and leaf and fruit elemental nutrient concentrations of 48 apple rootstocks grafted on 'Fuji' apple cultivar, and grown on a commercial farm in the Hudson Valley (Milton) New York State, USA from 2005 to 2015. Tree circumference was measured at the end of each year, and fruit yield data were collected from the third year (2007) to the eleventh year (2015). Leaf and fruit macro- and microelements were evaluated at the tenth year of the study. Most of the rootstocks evaluated survived well in the Hudson Valley conditions, with the exception of the Geneva® (G or CG) rootstocks CG.4002 and CG.5030. The smallest trees were on CG.2034, M.27 and JM.4 and had the lowest cumulative yield and the lowest cumulative number of fruits, and medium to low fruit size, but the highest cumulative yield efficiency (kg cm^{-2}). Other rootstocks, such as the dwarfing CG.2002, CG.2426, CG.4008, CG.5757, M.9 and the semi-dwarfing rootstock CG.6006, also had higher yield efficiencies. On the other hand, the medium vigor CG rootstocks such as CG.6001, CG.6253, CG.6976, and CG.8189 had high cumulative yield and high cumulative fruit number, and medium to high yield efficiency. Rootstocks had a significant influence on most of the fruit and leaf mineral concentration (dry weight basis). G.935, G.222 and CG.5257 conferred some of the highest values of fruit boron whereas M.9, M.27 and PiAu51.11 had the lowest. Fruit phosphorous values were closely associated with leaf boron, leaf potassium, and leaf sodium. Fruit calcium was highest in G.214, CG.2406, G.969, JM.4 and CG.5757, while the lowest values were with JM.1, PiAu51.11, and JTE-C. Fruit nitrogen values were lowest in M.7, PiAu51.4, B.54-118, and CG.8534 and the highest values were in the dwarfing rootstock CG.2034 and semi-dwarfing rootstock CG.4011. Weak but significant positive correlations were found between fruit size and leaf and fruit Mg, and leaf C. Significant correlations were found between nutrients: leaf B, P and K were highly positively correlated, and leaf Zn with leaf Mn and leaf Na. A strong positive correlation was found between fruit P and fruit K, fruit P and fruit B, and moderate positive correlation between fruit S and fruit K suggesting similar mechanisms of rootstock induction for these nutrients. These nutrient data are being utilized to customize scion nutrient requirements to rootstock-induced nutrient profiles.

1. Introduction

Apple [*Malus* × *domestica* Borkh.] is an important deciduous fruit tree grown throughout the world. The United States is the second leading apple producer in the world behind China, with an average production of 4.5 million tons each year (usapple.org), followed by Poland, Italy, India and France, respectively (FAOSTAT, 2015). New York State is the second largest producer in the United States, after Washington, which averages around 0.6 million tons of production annually (www.nyapplecountry.com). The Hudson Valley is the second major production district in New York State.

Advancements in rootstock breeding and selection have revolutionized the manner in which apples are grown throughout the world (Fazio, 2014; Fazio et al., 2015a; Russo et al., 2007). With the adoption of dwarfing and precocious rootstocks over the past 60 years, apple orchard systems have transitioned from traditional production

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[*] Corresponding author.
E-mail address: reiggemma@gmail.com (G. Reig).

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systems established with large trees in wide spacing arrangements (70–100 trees/ha) to high-density orchards with smaller closely spaced trees (1000–6000 trees/ha) (Robinson, 2004). Planting densities of this magnitude require dwarfing rootstocks and dwarf trees with reduced yield on a per-tree basis but significantly increased yield per unit area (Hampson et al., 2002) as a result of enhanced annual and lifetime light interception and maximized light partitioning within the canopy (Robinson and Lakso, 1991; Webster et al., 2000). Research on apple rootstocks has also shown that they can affect the alternate bearing habit of grafted scions (Kviklys et al., 2016; Racsko and Miller, 2011; Rackso, 2007), modify the nutritional status of scions (Kucukyumuk and Erdal, 2011; Fallahi et al., 2013; Fazio et al., 2013, 2015b), and influence flower development and fruit quality (Kucukyumuk and Erdal, 2011; Fallahi et al., 1994, 2002). Specific rootstocks can also protect the scion from soil borne diseases like *Phytothpthora* crown rot and crown gall disease, from whole tree bacterial diseases such as fire blight caused by *Erwinia amylovora*, from insects such as woolly apple aphid (*Eriosoma lanigerum* Hausmann) (Beers et al., 2006), and from abiotic stresses such as drought (Tworkoski et al., 2016), water excess, spring frost and winter cold tolerance (Robinson, 2004).

A paradigm shift in fruit production was achieved when the dwarfing ‘Malling 9’ (M.9), a fully dwarfing and highly productive rootstock (Russo et al., 2007), was adopted as the dominant rootstock worldwide (Marini et al., 2014). Notwithstanding its many favorable characteristics, M.9 also has several weaknesses, such as poor anchorage in the soil, propagation difficulty, winter injury, brittle roots, presence of burr knots, susceptibility to replant disease (Auvil et al., 2011; Laurent et al., 2010), and most importantly its susceptibility to fire blight (Crassweller et al., 2001; Marini et al., 2014; Norelli et al., 2003). For these reasons, new rootstocks without the shortcomings of M.9 are desirable.

In modern production systems, selection of an appropriate rootstock is as important to the viability and success of a new planting as the choice of fruiting cultivar. However, the selection of the most appropriate rootstock for new apple plantings has become increasingly complicated with the introduction of new rootstocks potentially with 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 and higher planting densities (Autio et al., 2008). For that reason in the last 20 years, several studies have compared the horticultural performance of scion-rootstock interaction on apples (Autio et al., 1996, 2011; Schupp, 1995; Russo et al., 2007), but few studies have been done analyzing the different capacities of rootstocks to absorb mineral nutrients from the soil and transfer them to the grafted apple scion variety (Cheng and Raba, 2009; Fazio et al., 2015b; Neilsen and Hampson, 2014). However, relative performance among rootstocks has not always been consistent from study to study. Part of the variability may be attributable to scion cultivar differences (Autio et al., 2011), but also to the agro-climatic conditions.

The Geneva® rootstock series, originating from the Geneva NY Breeding Program, a joint venture between the USDA-ARS and Cornell University, are the leading fire blight resistant rootstocks commercially available (Fazio et al., 2015a; Johnson et al., 2001; Norelli et al., 2003). Geneva® rootstocks also exhibit high cumulative yield efficiency in multiple size classes combined with enhanced disease and, in some cases, insect tolerance (Autio et al., 2005a,b; Cummins and Aldwinckle, 1983; Robinson et al., 2006a). Therefore, the aims of this long-term study were: (1) assess horticultural performance of 48 rootstocks from the leading breeding programs; (2) evaluate the concentration (dry weight basis) of mineral nutrients in mature leaf and immature fruit tissue; (3) assess how rootstock performance and nutrient uptake interact; and (4) study the correlation among all traits evaluated.

2. Material and methods

2.1. Plant material and trial characteristics

In the spring of 2005, a 0.8 ha orchard trial of apple rootstocks was planted at a Hudson Valley farm (Southeast New York State, USA). ‘Fuji’ was used as the scion cultivar for a set of rootstocks that included 33 Geneva® rootstocks (Cornell-Geneva Apple Rootstock Breeding Program, Geneva, New York, USA), four Japan rootstocks (Apple Research Center, Morioka, Japan), three German rootstocks (Institut fur Obstforschung Dresden-Pillnitz, Germany), two Czech rootstocks (Czech Republic), one Russian rootstock (Michurinsk College of Agriculture, Soviet Union) and five English rootstocks (East Malling Research Station, Maidstone, Kent, England). Rootstock, type (dwarf or semi-dwarf), parentage and tree size are listed in Table 1. The maiden trees were produced in a common nursery in Geneva (New York) in 2003–2004.

The orchard trial was planted on a bath gravel silt loam soil, with pH of 6.3. 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. ‘Fuji’ trees grafted on dwarf rootstocks were planted at 1.5 m × 5 m, while ‘Fuji’ trees grafted on semi-dwarf rootstocks were planted at 2.4 m × 5 m, with the bud union height 10 cm above the soil in mid May 2005.

Trees were minimally pruned at planting. The leader was not headed, but large lateral branches (larger than 2/3 diameter of leader) were removed and smaller lateral branches, if present, were shortened by one-third. Trees were trained into a vertical axis system (Robinson, 2003), which included leaving the leader unheaded and removing only one to two large vigorous lateral branches each year beginning in year 3. Branches were removed at the point of origin on the trunk using an angle cut. Trees were irrigated from rain fed ponds through drip lines, and the orchard was sprinkler irrigated every 10–12 days in July and August. All water used was tested and approved by New York State every year. Trees received Sulpomag product ($K_2SO_4 \cdot 2MgSO_4$, 22% S, 18% MgO and 22% K2O) as fertilizer at 224 kg ha^{-1} each November, and ammonium nitrate (NH_4NO_3, 30%N) at 40 kg ha^{-1} in early April each year. Weeds were controlled by annual applications of contact and residual herbicides in a 2 m wide band under the trees.

Trees were defruited chemically in the first 2 years (2005 and 2006) by spraying carbaryl (Sevin XLR; Bayer Crop Science, Research Triangle Park, NC) at 3.8 L per 380 L of water, based on a full dilute tree row volume application, and then allowed to crop from 2007 to 2015. In 2007 and 2008, trees were hand-thinned to a single fruit per cluster, whereas from 2009 to 2015, trees were chemically thinned by spraying them with 0.5 L Sevin tank mixed with 1.5 L NAA (Fruitone-L, AMVAC Chemical Corp., Los Angeles, CA) using 380 L of water based on a full dilute tree row volume application at 10–12 mm fruit size. Chemical thinning was effective most of the years, and additional hand thinning was done when it was necessary. These trees were evaluated through the eleventh years (season 2015) after planting.

2.2. 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.

2.3. Growth measurements and yield characteristics

At harvest, all fruit from each tree were counted and weighed to determine total yield per tree (kg/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, yield efficiency (YE) and crop load (CL) of each