Rootstocks for Organic Apple Orchards

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ew organic apple orchards, like conventional orchards, depend on rapidly filling the allotted space with canopy to achieve early fruiting, to pay back the initial investment of planting the orchard (Gonzalez et al., 2023). Using a planting density of ~1300 trees/acre and a rootstock that performs well in an organic system will result in the trees filling the allocated space by the end of the third year (Lordan et al., 2019). Such intensive orchards are not common among organic growers, which limits their profitability. In addition, almost all previous organic apple management research in the Eastern US has been done with more traditionally spaced orchards (Garcia et al., 2013).

One of the major challenges faced by organic orchardists is to provide proper nutrition to apple trees to achieve high productivity, particularly with greater weed competition and the use of organic fertilizers. Apple rootstocks have been shown to influence the mineral nutrient composition of leaf and fruit tissue in orchards under conventional management; however, there is little information about their nutrient use efficiency under organic management.

Conventional dwarfing apple rootstock genotypes are susceptible to fire blight bacterial disease and apple replant disease and are vulnerable to cold injury which are major problems in organic systems. This has limited their use in organic apple production in the Eastern US. The new Geneva® apple rootstocks have high potential to improve orchard performance by impacting soil health and nutrient status, plant-associated soil microbial communities, tree growth, and fruit yields (Fazio, 2014; Robinson et al., 2014).

The first U.S. organic field trial with the Geneva® rootstocks was performed in Chelan, WA (Auvil et al., 2011) and showed how impactful the new rootstocks could be by increasing yields by 20-65% when compared to traditional rootstocks M.9, M.26 or B.9. Similar results have been observed with similar Geneva® rootstocks in Europe where they are providing novel solutions to organic apple growers (Spornberger et al., 2020; Wurm, 2018). In addition to improvement in productivity and tree survival, some Geneva® rootstocks impact mineral nutrient uptake and utilization in apple in diverse ways that are linked to improved fruit quality, tree growth, and perhaps return bloom (Fazio et al., 2018a; Fazio et al., 2018c; Robinson and Fazio, 2022). Traditional rootstocks have shown drastic deficiencies with regards to nutrient uptake which are then translated into poor tree growth followed by lower yields of lower quality fruit (Garcia et al., 2013; Lanauskas et al., 2014; Racsko et al., 2008; Weibel et al., 2008). Given the paucity of information on how some of the newer rootstocks perform under organic management with regards to nutrient uptake we set a goal to understand this subject by interrogating nutrient content in several field trials under organic management.

Material and methods

<u>Plant Materials:</u> The research featured two dedicated organic apple research plots at Cornell's Experimental fields in Geneva, NY

in three organic orchards. Based on overall productivity and nutrient use efficiency, G.890, G.484, G.222, G.41 and perhaps

The experiments at the GEN and ITH locations are

(GEN) and Ithaca, NY (ITH) and another one established on a grower field in Albion, NY (ALB).

a 0.5 acre plots, planted in May 2015 and compare 11 Geneva® disease resistant rootstocks with one conventional rootstock. Stocks include M.9T-337, G.16, G.222, G.214, G.969, G.30, G.11, G.935, G.41 G.202 and G.890. The scion variety was 'Modi' which is resistant to apple scab and perhaps cedar apple rust cultivar (Agnello et al., 2017). The trees were spaced at 3' x 12', giving a planting density of 1210 trees/acre. Trees were trained to the Tall Spindle system, creating a slender fruiting wall. The field was under organic management 5 years prior to planting. The experiment utilized a randomized complete block experimental design with 10 single-tree replications.

The experiment on the organic grower farm at the ALB location features a 0.7 acre plot planted in 2012 on the shores of Lake Ontario and combines 20 commercial and experimental rootstocks including B.9, CG.2006, CG.3001, CG.4003, CG.4013, G.213, G.214, CG.4288, CG.4294, CG.5030, CG.5202, G.484, G.257, G.890 G.202TC, G.41, G.41TC, G.935, G.935TC, and M9-T337. Trees were grafted with 'Autumn Crisp' scion cultivar. The field was under certified USDA Organic management since planting. There were three replications with each elemental plot composed of three to five trees per rootstock.

Nutrient analysis Nutrient levels were measured by two methods targeting both fruit and leaves. Ten randomly selected fruits and fully developed mid-position leaves distributed throughout the tree canopy were harvested 120 days after bloom on three replicates of each rootstock genotype from each of the 3 field trials (GEN, ITH and ALB). Fruit and leaves from the same trees in ALB were collected in 2014, 2016, 2022 and 2023 where the samples from 2014 and 2016 were oven dried, ground into powder and shipped a third party (A&L Great Lakes Laboratories, Inc. Fort Wayne, IN) for mineral analysis of several macro- and micro-mineral nutrients via inductively coupled plasma optical emission spectrometry. Samples from GEN, ITH and ALB collected in 2022 and 2023 were collected in the same way but nutrient levels (Ca, Cu, K, P, S, Mn, Ni and Fe) were measured using a hand-held X-ray nutrient analyzer instrument (Bruker Tracer 5) where intact fruit where subjected to two reading on opposite sides similar to what has been described in the literature (Kalcsits, 2016) and leaves were ground, pelletized and analyzed in a similar way. Leaf and fruit nutrient levels were tabulated and analyzed with SAS and JMP Pro 17 statistical software packages (Cary, NC); rootstock genotype was treated as the main effect in a randomized complete block analysis. Rootstock genotype means for all nutrients tested were used in a multivariate analysis to gener-

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performance and nutrient profiles

G.935 seem to be well suited for

organically managed orchards.

ate correlation matrices and two-way similarity cluster diagrams (WARD) based on genotype and variable similarities.

Results

Tree size (Trunk Cross-sectional Area, TCSA) after 9 years reflected 5 groups of vigor: with G.16 and G.222 being the most dwarfing stocks; G.969, G.11, G.214, and G.935 slightly more vigorous; G.41 and M.9 were more vigorous; a semi-dwarfing group of G.202 and G.30; and finally, a semi-vigorous stock of G.890. The greatest cumulative yield was with G.890 followed by G.41, G.30 and G.214. The lowest cumulative yield was with G.222 and G.16. Cumulative yield efficiency was higher with G.16 followed by G.214, G.11, G.935, and G.41 (> 2.0 kg/cm² TCSA).

The organic 'Modi' trials replicated in GEN and ITH provided a good comparison between different sites/soils and rootstock po-

tential to absorb and translocate nutrients under organic management. Unfortunately, rootstocks like G.969 and G.16 which displayed stunted growth in both trials may have been affected by a combination of latent viruses (Apple Stem Grooving and Apple Stem Pitting viruses - data not shown) which in turn may have modified the uptake potential and productivity of those trees. Dual hierarchical clustering of leaf nutrient means (XRF) for ITH and GEN locations for 2022 and 2023 (Figure 1) revealed that G.890 consistently displayed higher levels of S, P, K for both locations and both years, whereas G.11 displayed lowest levels suggesting that it may not be well adapted for organic production. M.9T337 displayed higher levels of Mn and Fe in both locations and years. G.202 displayed higher levels of P and K in both GEN and ITH in 2022 and 2023 whereas G.41 was inconsistent in the higher values suggesting an interaction with climate/soil management for the two locations. G.222 displayed higher Ca in GEN and ITH in 2023 whereas G.30 and G.214 displayed higher Ca in GEN in 2022. Such seasonal variation for Ca level rankings has been observed and may have its origins in water availability and year to year climatic differences. G.202 was however consistent in displaying lower levels of Ca in both locations and years. Leaf Ca plays an important role in influencing fruit quality where the K/ Ca ratio has been implicated in bitter pit development therefore in these conditions, G.202 might not provide the best fruit quality in scion varieties sensitive to bitter pit (Fazio et al., 2018b).

Genotypic means for leaf nutrients at the ALB site were used to measure stability of the nutrient traits over the years. There was some revealing some consistency in mean values over nine years and over instruments (ICP and XRF) and some variation according to seasons (Figure 2). Strong correlations over years for the same nutrients were found for K (2016 ICP, 2022XRF and 2023XRF), Ca (2014ICP, 2022XRF and 2023XRF), Fe (2016ICP and 2022XRF). Leaf B, K, P, Cu and S, for 2014 displayed a lot of similarity, possibly because these were young trees that were beginning production and had not quite adjusted to the organic nutrient regimen from the nursery stage which was under conventional management. Similarities in genotypic means have been described for the relationships among B, P and K in other

similar works in conventional apple rootstock trials (Fazio et al., 2020; Reig et al., 2018). The genotypic similarity and consistency observed between Ca and Na for 2014ICP, 2016ICP, 2022XRF, 2023XRF has not been observed in other nutrient datasets where Ca levels seem to vary according to season (Fazio et al., 2020; Reig et al., 2018). Yet, the negative correlation relationship between K and Ca levels is evident for this experiment and is consistent with other rootstock experiments.

Discussion

In Geneva, rootstocks G.969, G.41, G.935 and G.222 displayed higher levels of leaf S which has been shown to have a correlation with leaf N concentration. In Ithaca G.890 had consistently higher S, P, and K levels. G.11 and G.214 displayed lower levels of S in both locations and both years. Other nutrient levels were

Table 1. Nine-year cumulative production of 'Modi' apple with 11 rootstocks under organic management at Geneva, NY. Av Biennial Bearing Index was calculated with the average of 7 last years.

Stock*	TCSA 2023	Sucker No. 2023	Survival (%) 2023	Cum Fruit No.	Cum Yield (kg/ tree)	Cum. Yield Eff.	Av Crop Load	Av Fruit Size (g)	Av Biennial Bearing Index
G.16	11.9	4.8	70	183.8	23.8	2.1	3.0	136	0.38
G.222	12.5	1.0	90	162.7	21.2	1.9	2.8	133	0.37
G.969	14.5	1.4	90	206.9	27.0	1.9	2.9	131	0.39
G.11	14.9	0.1	90	217.3	28.8	2.0	2.8	134	0.40
G.214	15.3	1.7	90	230.5	30.0	2.1	3.2	134	0.38
G.935	15.5	4.0	80	230.4	29.3	2.0	3.1	130	0.38
G.41	20.0	0.3	100	265.7	39.2	2.0	2.8	148	0.42
M.9T337	22.5	2.0	100	202.6	28.7	1.5	2.2	139	0.48
G.202	24.2	2.0	100	205.7	27.7	1.2	1.7	138	0.42
G.30	26.7	2.2	100	277.8	37.7	1.6	2.4	131	0.43
G.890	38.5	4.6	90	294.0	41.0	1.1	1.7	140	0.43
Significance	<0.01	0.02	0.43	<0.01	<0.01	<0.01	<0.01	<0.01	0.31
LSD P≤0.05	6.0	3.0	23	51.9	7.4	0.6	0.7	9.8	0.1
*Stocks ordered by increasing TCSA.									

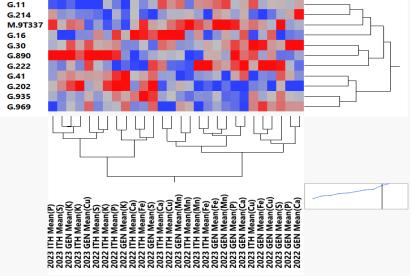


Figure 1. Dual hierarchical clustering (WARD) of 2022-2023 genotypic means for leaf XRF data collected from the GEN and ITH locations. Red corresponds to high values; blue corresponds to low values and gray to average values.

somewhat inconsistent between locations and years in the NC-140 trials. In the Albion organic trial G.484, G.890, G.222, and CG.5030 displayed higher levels of leaf P and S. CG.4003 displayed consistently higher levels of Ca in leaves and fruit.

After 9 growing seasons, G.41, G.484 G.222 and G.935 and are promising rootstocks for organic production in a highdensity system. For a medium density system, G.890 has shown good promise. G.484 was not included in the Geneva or Ithaca trials but has shown outstanding performance in other trials (Fazio and Robinson, 2023) (Figure 4). Based on nutrient uptake efficiency, G.890, G.484, G.222, and perhaps G.935 seem to be well suited for organically managed orchards, however, the susceptibility of G.935 to Wooly Apple Aphid make it less desirable in a system with limited insecticides to control this insect.

The knowledge of nutrient uptake potential of apple rootstocks under organic management gained in these experiments combined with other knowledge of productivity, disease and insect resistance can guide the decisions on rootstock choice and fertilizer

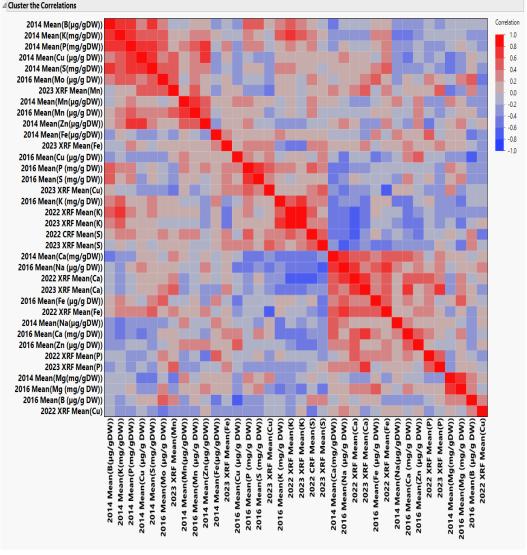


Figure 2. Clustered correlations for ALB 2014, 2016, 2022-23 leaf ICP and XRF data.

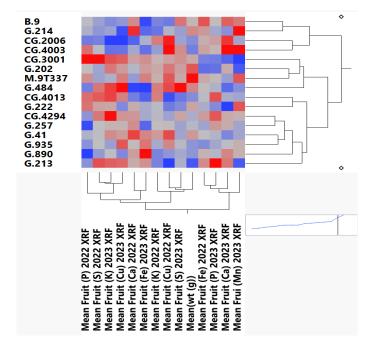


Figure 3. Dual hierarchical clustering (WARD) of 2022-2023 genotypic means for fruit XRF data collected from the ALB location. Red corresponds to high values; blue corresponds to low values and gray to average values.



Figure 4. Four year old apple trees of 'Autumn Crisp' on G.935 (left), G.484 (center) and G.890 (right) rootstocks at the Albion organic rootstock trial.

applications. This is one of the first sets of experiments that has examined rootstock effect on nutrients under organic management. Further, long term research is needed correlate productivity and fruit quality to these rootstock traits.

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