

Apple Rootstocks Influence Mineral Nutrient Concentration of Leaves and Fruit

Gennaro Fazio^{1,2}, Lailiang Chang², Michael A. Grusak³ and Terence L. Robinson²

¹ USDA ARS Plant Genetic Resources Unit, Geneva, NY

² Horticulture Section, School of Integrative Plant Sciences, Cornell University, Ithaca, NY

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

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The basic functions of tree root systems are to absorb water and nutrients from the soil and provide anchorage to the tree. Root systems accomplish these through a variety of biological systems powered by energy captured from the sun, and transported down to the roots as sugars or other energy-rich molecules. We can compare the basic function of taking up nutrients to mining operations, where certain nutrients require little energy and are easily available whereas others require quite a bit more work because they are either tightly held by the chemistry of the soil particles or because they are rare in the soil. It makes sense that trees have developed several min-

“Apple rootstocks show considerable variability in their nutrient acquisition and distribution properties. This project seeks to study the ability of new Geneva rootstocks to first absorb nutrients and secondly to partition nutrients into fruit and/or leaves. In the long-term this project will result in new rootstocks with increased ability to overcome nutrient deficiencies in scion, reduce postharvest nutrient related problems such as bitter pit, increase efficiency of fertilizer applications and decrease effluent waste.”

ing strategies to get what they need from different soil profiles. For example, for a relatively abundant nutrient like sodium (ions), apple trees in general, allow it to be absorbed into the roots and transported through the xylem in the transpirational stream. For other nutrients that may not be so readily available, apple roots may employ a combination of energy dependent mining and transport systems. These include processes like soil acidification achieved by exuding organic acids, active transport of specific ions by using specialized transmembrane proteins called “ion channels”, or the deployment of chelators or protectants that prevent reactive ions like zinc or iron from indiscriminately binding to cell walls. One can imagine that given the genetic diversity of apples that we readily observe above ground in apple scions (taste, color, fruit shape, leaf shape, and tree architecture), the same concept of diversity would apply to the “hidden” below ground systems associated with root functions. It was this concept that led our breeding team to investigate the degree to which apple root systems varied in their ability to 1) absorb nutrients from the soil and 2) transport them to the above ground portions of the trees (leaves and fruit). Another phenomenon that has been described in the literature and perhaps discussed by packers and producers is the effect of rootstock on fruit quality and storage. It makes sense that if rootstocks have a significant effect on nutrient concentration in fruit, they may also be playing a role in the block-to-block variability that packers see in their fruit. In an

Table 1. Soil analysis results for the HUDSON and CHAMPLAIN rootstock research blocks. The HUDSON site in general possessed optimal levels of phosphorus, potassium and calcium but was low in magnesium. The CHAMPLAIN site had optimal levels of phosphorus and potassium and had very high levels of calcium and magnesium. Nutrients were extracted using the modified Morgan method.

Field Name	Organic Matter %	pH	Al ppm	Ca ppm	Fe ppm	K ppm	Mg ppm	Mn ppm	P ppm	Zn ppm
HUDSON CG NW	3.54	5.52	47.5	953.4	2.3	111.5	47.7	10.3	1.8	0.9
HUDSON CG SW	2.91	6.67	29	1134.4	1.2	99.8	60.1	8.3	2.9	0.4
HUDSON CG MID N	4.06	6.32	30.3	1342.4	1.3	97.8	45.6	8.1	5.3	0.6
HUDSON CG MID S	3.31	6.4	35.9	1285.9	1.4	116.5	42.8	7	6.2	0.5
HUDSON CG NE	3.19	5.99	38.8	832.2	1.7	101.1	32.9	8.3	2.6	0.5
HUDSON CG SE	3.1	7.06	19.3	1611	1	100.7	40.3	7.9	5.8	0.3
CHAMPLAIN NORTH	3.47	7.76	6.5	10147.7	1.7	103.7	422.8	30.2	1.9	0.5
CHAMPLAIN CENTRAL	2.69	7.78	12.9	6330.6	2.3	100.6	361.1	18.2	1.3	0.2
CHAMPLAIN SOUTH	3.01	7.67	6.2	2478.2	0.8	112.4	313.6	9.4	1.5	0.5

effort to understand the role of rootstocks on fruit production and quality, preliminary experiments followed which showed that the genetic makeup of apple rootstocks interacted with soil type, replant condition and pH to produce different concentrations of nutrients in the leaves and fruit of apple scions (Fazio et al., 2012b). Furthermore, in another first of its kind experiment in tree fruits, we found that there were strong inherited genetic components in breeding populations of Geneva rootstocks for absorption and translocation of several mineral nutrients (potassium, sodium, calcium, etc.) (Fazio et al., 2012a; Fazio et al., 2013). These findings were obtained by a series of potted plant or field experiments performed in Geneva, NY; therefore, the next logical step was to verify if the findings in Geneva, NY were applicable to other apple growing regions of NY State. Through this work we hope to understand

which rootstocks work better in certain NY soil types, elucidating the role of a rootstock in the absorption of nutrients in different soil types, and how this affects growth and productivity. Finally, we will build a rootstock/soil recommendation table based on nutrition data. In this publication, we report on the findings from two of the six field experiments in this project.

Materials and Methods

Mature apple rootstock field trials in the Champlain Valley (Honeycrisp scion, CHAMPLAIN), Hudson Valley (Fuji scion, HUDSON), Lake Ontario (Enterprise scion, ONTARIO) apple growing regions and research plots at the New York State Agricultural Experiment Station in Geneva, NY were chosen as the source of plant material for these studies. Some of these trials have been described in previous publications (Robinson et al., 2011). Ten mid position leaves on new extension growth and ten fruit randomly distributed throughout the tree canopy were harvested 80-90 days after bloom on all tree replicates of each field trial. Fruit was cored and portion of the flesh was sampled consisting of a 0.5 cm thick horizontal doughnut shaped section obtained two cm from the calyx end of fruit. Tissue samples from 10 fruits were bulked for each sample. Leaves and fruit tissue samples were oven dried, ground into powder and analyzed for several macro- and micro-mineral nutrients via inductively coupled plasma mass spectrometry. Carbon and nitrogen concentration of the fruit and leaf samples from the Hudson and Champlain experiments were measured with a C/N analyzer. Soil samples were collected from 3-6 locations on the Champlain and Hudson research plots and were analyzed for nutrients after modified Morgan extraction. Rootstock genotype means were used in multivariate analysis to generate two-way similarity cluster diagrams based on genotype similarity and variable similarity.

Results and Discussion

Soil Analyses. Soil analysis results for the HUDSON research site showed an optimal levels of P, K and Ca but was low in Mg (Table 1). The CHAMPLAIN site had optimal levels of P and K and very high levels of Ca and Mg. The pH values were different between the two sites (5.5-7 HUDSON, 7.7 CHAMPLAIN) making the spectrum of bioavailability of nutrients quite different between the sites and for the HUDSON site, across the research plot.

Mineral Nutrient Analyses. Leaf and fruit mineral data and carbon/nitrogen data were combined in a single dataset to contrast site, cultivar and rootstock differences. A comparison between the overall values (average of all rootstocks) between CHAMPLAIN (Honeycrisp) and HUDSON (Fuji) shows that there were significant differences between sites/cultivars (Figure 1). Concentration of fruit calcium, boron, copper, iron, potassium, sodium, and phosphorous in the CHAMPLAIN planting was significantly lower than in HUDSON. However, fruit concentrations of magnesium, manganese, sulfur and zinc were significantly

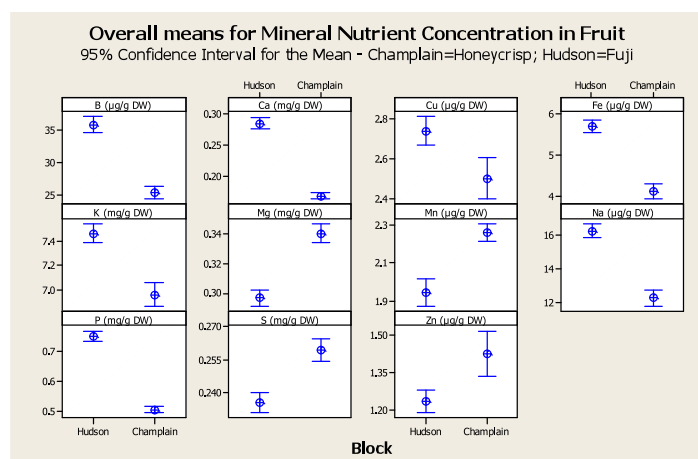


Figure 1. Overall nutrient concentration differences (average of all rootstocks) between CHAMPLAIN (Honeycrisp) and HUDSON (Fuji). Note that fruit calcium in the CHAMPLAIN planting is much lower than in HUDSON. The available calcium in the soil analysis for CHAMPLAIN is quite high, suggesting that the Honeycrisp variety itself (its genetics) may be a poor calcium transporter overall. The high pH in CHAMPLAIN might also explain the low iron values overall. Mineral abbreviations in all figures and tables: boron (B), calcium (Ca), copper (Cu), iron (Fe), potassium (K), magnesium (Mg), manganese (Mn), sodium (Na), phosphorous (P), sulfur (S), zinc (Zn), and aluminum (Al).

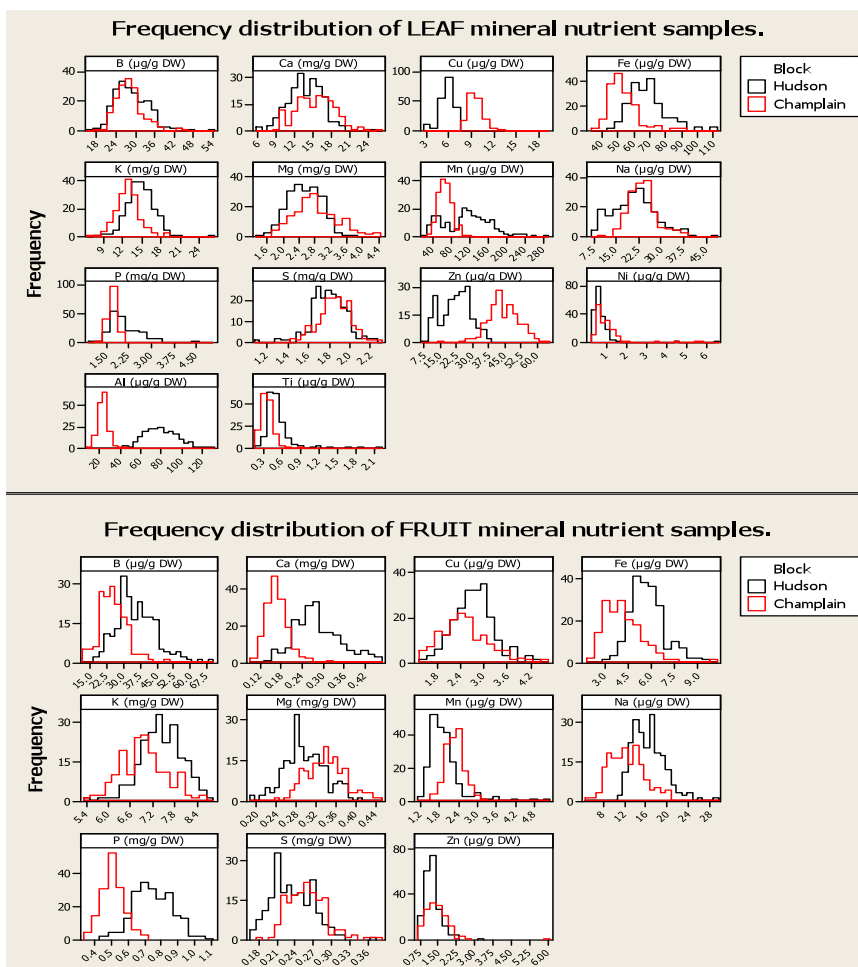


Figure 2. A&B. Leaf and Fruit mineral nutrient distributions for all rootstocks at two sites: HUDSON (Fuji) and CHAMPLAIN (Honeycrisp). Evident from these graphs is the fact that while leaf calcium is similar in both plantings, the fruit calcium is very different, confirming a variety specific (not site) inability to partition calcium to the fruit. Other nutrients are performing according to soil analyses and are similar for leaf and fruit: magnesium is lower in HUDSON as indicated by analysis and the availability of iron is negatively affected by higher pH in CHAMPLAIN.

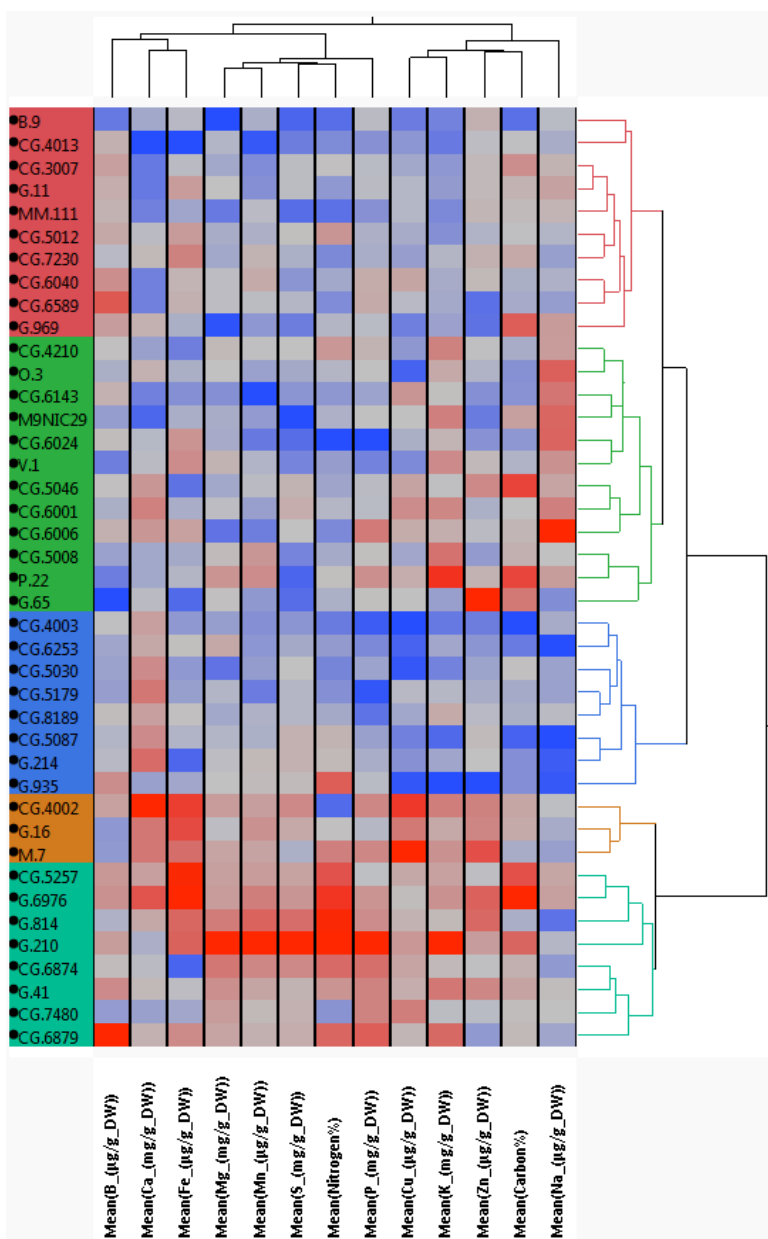


Figure 3. CHAMPLAIN Honeycrisp: Fruit mineral nutrient concentration values clustered by similarities (Red=high, Gray=Medium, Blue=Low) of how each rootstock performed and how similar each mineral nutrient behaved. Evident in this graph is the fact that some rootstocks (CG.6976, CG.4002, CG.4814, G.16, G.214 and M.7) delivered significantly higher amounts of calcium to the Honeycrisp scion in these growing conditions. M.9 was very poor for fruit calcium while G.41 (CG.3041) was middle of the pack.

higher in CHAMPLAIN. It is not clear to us if some of the differences detected are associated with a varietal source (Fuji vs. Honeycrisp) or a site source. For example, the available calcium in the soil analysis for CHAMPLAIN was quite high; however, the concentration in fruit was much lower than HUDSON, suggesting that the Honeycrisp variety itself (its genetics) might be a poor calcium transporter overall. The high pH in CHAMPLAIN might also explain the overall low iron (Fe) values. Soil magnesium and manganese were on average lower in HUDSON, which might explain why their concentrations in fruit were also lower.

A comparison between leaf and fruit nutrient averages and distributions (Figure 2 A&B) revealed some interesting patterns that may be attributed to the genetics and physiology of the scion variety rather

than site. The means and distribution of zinc and copper values in fruit were similar for the two sites; however, it was quite different in leaves indicating that the flow of zinc into the fruit is more tightly controlled. While leaf calcium was similar in both plantings, the fruit calcium was very different, confirming a variety-specific (not site) inability to partition calcium to the fruit. This observation is also true for boron, phosphorous, and sodium.

Within each field trial, rootstocks had significant effects on the concentration of mineral nutrients and nitrogen in leaves and fruit. To compare and contrast rootstock effects, we color coded (Blue=Low, Gray=Medium, Red=High) the means for each rootstock and grouped the rootstocks and the nutrients based on their similarity (Figures 3 and 4). Grouping by rootstock reveals which rootstocks might perform similarly in a particular environment. Grouping the nutrient values revealed which nutrients are physiologically connected (similar pathways, absorption and transport systems). Fruit nutrient concentrations for the CHAMPLAIN Honeycrisp planting (Figure 3) showed how B.9 seemed to confer the lowest overall values for the nutrients tested, while G.210 and CG.4002 seemed to confer the highest (balanced values) for all nutrients tested; G.41 was in this group of rootstocks. In this trial, calcium values were associated (correlated) with iron and boron values, indicating some rootstock-specific ability to overcome the pH induced low availability of iron and the likelihood of rootstock-specific increases in foraging and transport of calcium. Several associations were discovered between values of calcium, zinc, magnesium and manganese in fruit (Figure 5). Fruit sodium was highest in CG.6006, CG.6001, CG.6024, M.9 (Nic29), O.3 and CG.6143 while CG.5087, C.214, G.814 and G.935 conferred the lowest values on the Honeycrisp fruit. When fruit quality parameters are measured, it will be interesting to see if these mineral differences might be associated with any changes in fruit size, crispness, or storability.

The HUDSON Fuji planting (Figure 4) featured significant effects of rootstocks on fruit values of mineral nutrients. G.935, G.222 and CG.5257 conferred some of the highest values of boron in the fruit whereas M.9, M.27 and PiAu51.11 had the lowest. Phosphorous values were closely associated with potassium, boron and sodium. Fruit calcium was highest in G.214, CG.2406, G.969, JM.4 and CG.5757, while the lowest values were conferred by JM.1, PiAu51.11, and JTE-C. In this planting, fruit calcium was associated with iron, copper, zinc and manganese. Fruit nitrogen values were lowest in M.7, PiAu51-4, B.118, and CG.8534 and highest values were in super-dwarfing rootstock CG.2034 and semi-dwarfing rootstock CG.4011. Soil magnesium at this site is lower than Cornell's recommended level, however a few dwarfing rootstocks (CG.4011, CG.5257) and semi-dwarfing (CG.6589, CG.6024, G.890 and G.210) were able to transfer higher than average amounts to the fruit.

Honeycrisp is among the most difficult scions to manage nutritionally as nutrient imbalance can cause storage disorders and off flavors that make the fruit less desirable. The relationships among rootstock-induced nutrient con-

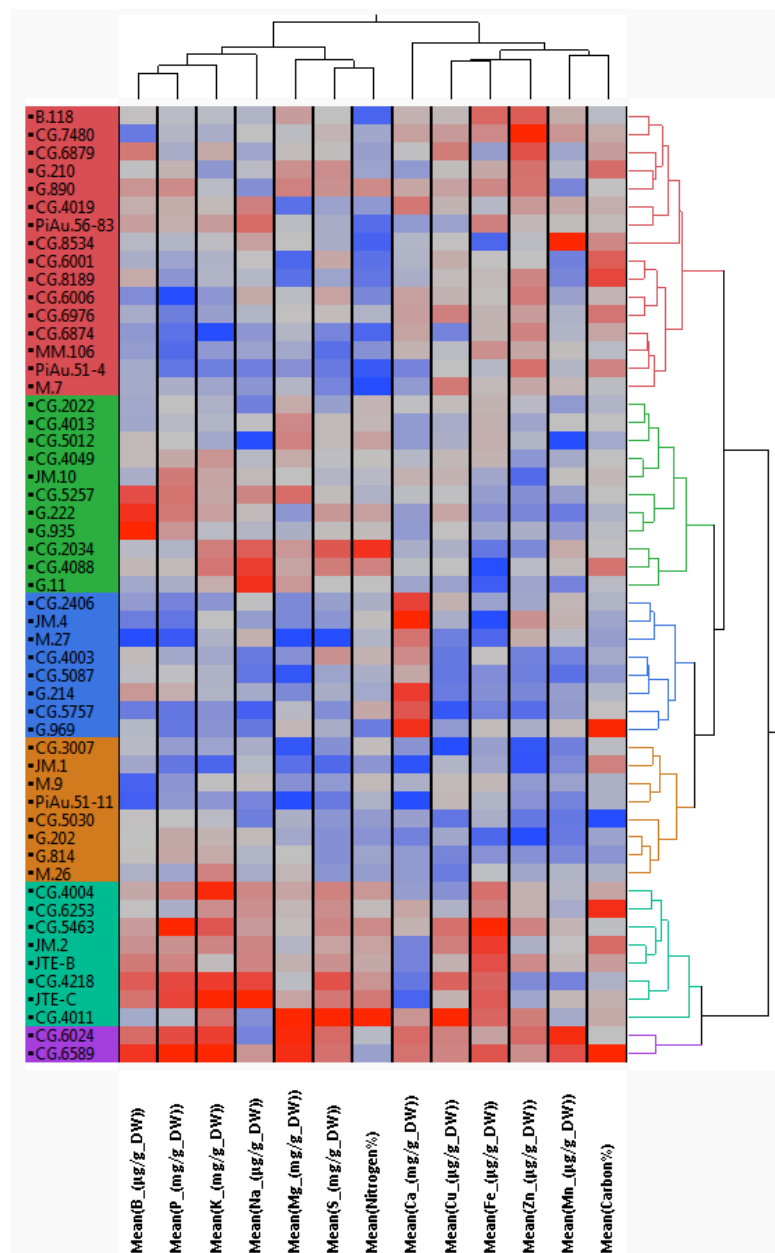


Figure 4. Rootstocks and nutrients grouped by similarities in mineral nutrient concentration values (Gradient from low (blue)->medium (gray)->high (Red) for Fuji fruit in the HUDSON research block. In this field experiment, higher fruit calcium values were observed in G.214, G.969, CG.2406, JM.4, CG.5757, and CG.6024. Calcium values were correlated with other metal ions including copper, iron, and zinc. Values of boron and phosphorous were correlated. Also a strong correlation between sulfur and nitrogen values was observed. This newly reported correlation is consistent with other experiments performed by our lab.

centrations (Figure 5-7) may reveal limitations in how effective fertilizer applications may be in curbing these issues. When fruit and leaf values for calcium, magnesium, zinc, and manganese were compared, a positive relationship between the four nutrients was found, indicating that rootstocks inducing higher values in one also have positive effects on the rest. Rootstock-induced leaf calcium values are negatively correlated with leaf potassium values and positively correlated with the concentration of fruit nitrogen, phosphorous and magnesium (Figure 6). A new set of relationships for Honeycrisp calcium values is described in Figure 7 where sulfur concentration is positively correlated with calcium values. Sulfur has a role in acidification of vacuoles and rootstocks that are able to take

up more sulfur, or that can benefit from sulfur fertilizer applications, might increase transport of calcium to the fruit.

Conclusions

As the availability and knowledge of diverse rootstocks increases, it will increase the potential to impact fruit productivity, quality and ultimately profitability of our apple orchards. The choice of the best rootstock for the site, scion and orchard system is going to become more important than ever. Nutrient uptake and transport characteristics will be added to the current requirements of disease resistance (fire blight, replant), cold hardiness, dwarfing and productivity that the Geneva® breeding program has delivered to the industry. The ability to match the nutritional requirements of a scion cultivar to a specially tuned rootstock will enhance orchard management in the future by allowing healthier trees and more efficient use of fertilizers. This study, first of its kind, lays the foundation for this scenario and hopefully will provide better choices to our apple growers in terms of rootstock technologies.

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Gennaro Fazio is a research scientist who leads the Cornell/USDA apple rootstock breeding program at Geneva, NY. **Dr. Lailiang Cheng** is a research and extension professor at Cornell's Ithaca campus who leads Cornell's mineral nutrition program for fruit crops. **Dr. Michael Grusak** is a research scientist at the USDA-ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Houston, Texas. **Terence Robinson** is a research and extension professor at Cornell's Geneva Experiment Station who leads Cornell's program in high-density orchard systems, rootstocks and plant growth regulators.

Figure 5. Rootstock induced relationships between FRUIT (left panel) and LEAF (right panel) for calcium, magnesium and manganese values in the Honeycrisp CHAMPLAIN planting. What is interesting to note is how the relationships are maintained in both tissues, indicating a biological relationship in the conferring of these nutrients by the rootstocks (perhaps similar pathways).

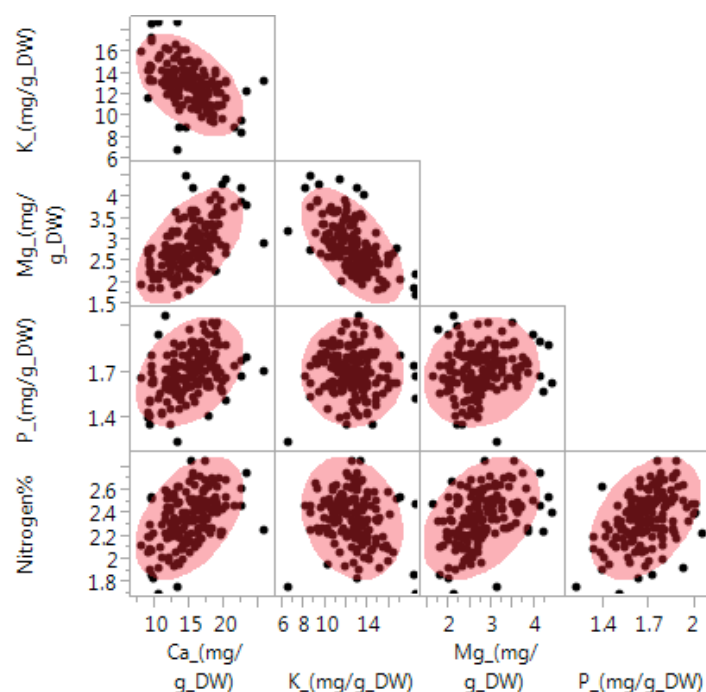
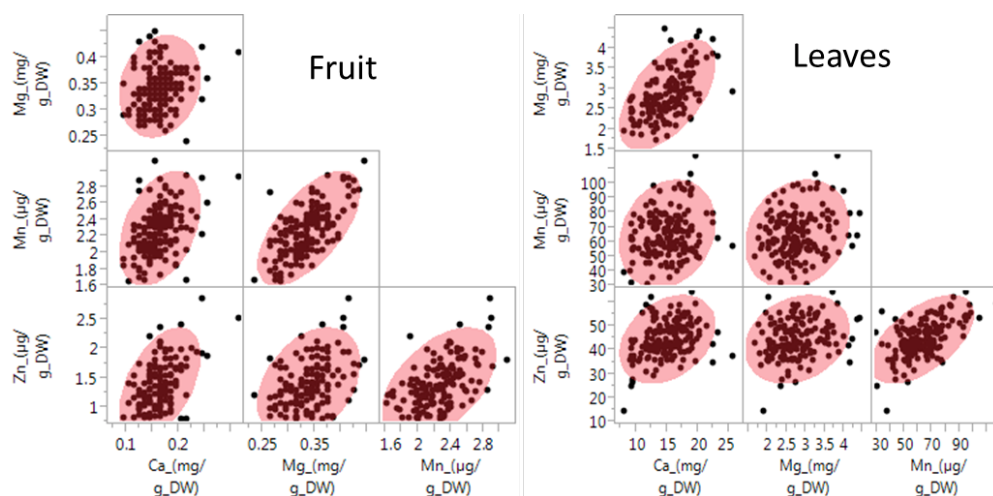


Figure 6. Relationships between rootstock conferred LEAF nutrient values in CHAMPLAIN Honeycrisp planting. Calcium concentration in leaves seems to be positively correlated with leaf magnesium, nitrogen and phosphorous and negatively correlated with leaf potassium. Leaf magnesium is also negatively correlated with leaf potassium. These correlations are somewhat different than what is observed in fruFigure 7. This figure features the means by rootstock of some leaf and fruit nutrient variables in the CHAMPLAIN Honeycrisp trial. Evidenced by the density ellipses is the relationship between rootstock conferred mean values of fruit calcium, zinc, sulfur and leaf calcium and zinc. This is the first time that we have observed a loose but clear relationship between rootstock conferred leaf calcium and fruit calcium values, meaning that it should be possible in some cases to select for high leaf calcium promoting rootstocks and obtain a positive effect on fruit calcium. Of importance is also a positive correlation between fruit sulfur and calcium. While rootstocks that promoted higher zinc in leaves seemed to have less fruit calcium in general – this is opposite to what was observed with fruit zinc, which is positively correlated with fruit calcium (Figure 5, left panel).

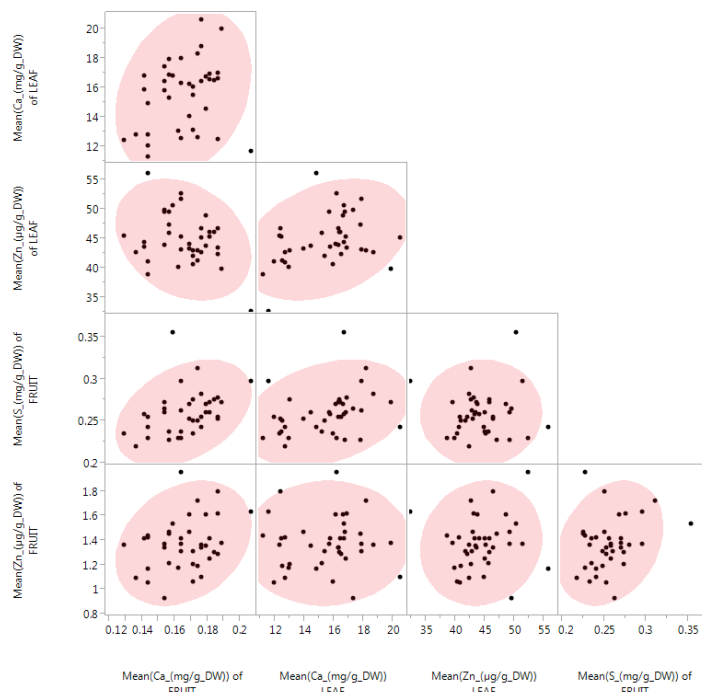


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