Soil pH, Soil Type and Replant Disease Affect Growth and Nutrient Absorption of Apple Rootstocks

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Rootstocks are the foundation of a healthy and productive orchard. They are the interface between the scion and the soil, providing anchorage, water, nutrients, and disease protection that ultimately affect the productivity and sustainability of the orchard. Recent advances in the science of genetics and genomics of apple rootstocks show that at the molecular level different rootstocks have the ability to turn on or off and/or increase or decrease the production of proteins in the scion (trunk, leaves and even fruit). So, for example the tissues of a Gala scion grafted on M.9 will behave differently at the molecular level than the same tissues grafted on B.9. The mechanisms by which apple rootstocks accomplish this feat are still not very well understood. We can hypothesize that signals transmitted by the rootstock machinery are detected and interpreted by the scion machinery to give visible effects on photosynthesis, growth, and productivity. Among these root signals we may find different levels of water, inorganic macro and micro-nutrients, plant hormones, and organic molecules such as sugars and micro-RNAs that may have capacity to change the behavior of the scion. Different rootstocks therefore are similar to different TV stations broadcasting different signals (shows) to the same audience and the audience reacting accordingly. In order to better understand this relationship we decided to investigate one set of signals that the rootstock absorbs from the soil and transmit to the scion: macro and micro nutrients such as phosphorous (P), potassium (K), magnesium (Mg), calcium (Ca), sodium (Na), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), sulfur (S), molybdenum (Mo), and, nickel (Ni).

"Our recent studies have shown that rootstock genotype affects not only dwarfing and precocity of the scion but also tolerance to replant disease and the efficiency of uptake of various macro and micro nutrients. Choosing which rootstock matches your orchard environment is going to leverage the natural positive traits in each rootstock to increase productivity and quality of fruit. As we learn more about this in the future we should be able to make more informed decisions based on soil variables."

Materials and Methods

We designed two experiments to answer four questions: 1. How well do different rootstocks absorb and transmit macro and micronutrients? 2. Is this capacity influenced by soil type? 3. Is this capacity influenced by replant disease? and 4. Is this capacity influenced by soil pH levels?

The first experiment tested the effect of two apple replant soils (Clay Loam, and Sandy Loam) pasteurized and unpasteur-

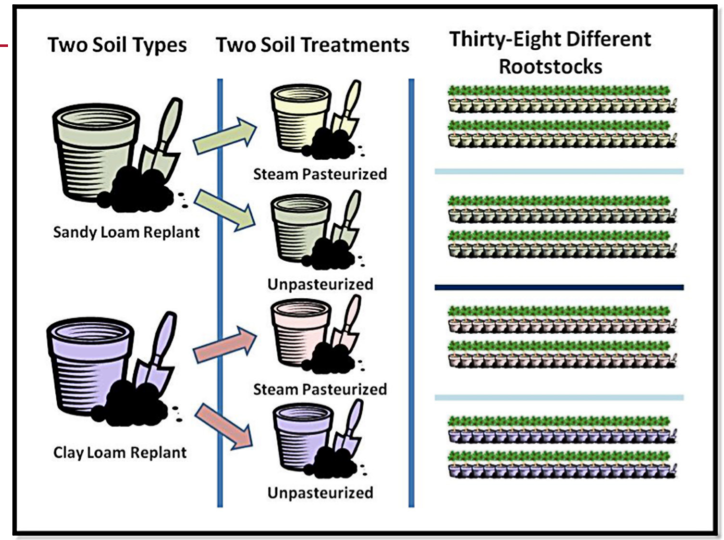

Figure 1. Diagram of the experiment testing the effect replant disease in two soil types (sandy loam and clay loam) on growth and nutrient uptake parameters of potted nursery trees grafted onto 38 different apple rootstocks.

Table 1. Rootstocks used in the Apple Replant Disease (ARD) and soil pH (pH) experiments and their origins.

Rootstock	Origin	ARD	pH	Rootstock	Origin	ARD	pH
B.9	Budagovsky	X	X	CG.6143	Geneva	X	
B.10 (396)	Budagovsky	X		CG.6253	Geneva	X	
B.118	Budagovsky	X	X	CG.6589	Geneva	X	X
B.491	Budagovsky	X	X	CG.6874	Geneva	X	X
CG.2006	Geneva		X	CG.6879	Geneva	X	
CG.2406	Geneva	X	X	CG.7707	Geneva	X	
CG.3007	Geneva	X	X	CG.8534	Geneva	X	
CG.4002	Geneva	X	X	CG.9778	Geneva	X	
CG.4011	Geneva	X	X	G.11	Geneva	X	X
CG.4019	Geneva		X	G.16	Geneva	X	X
CG.4094	Geneva		X	G.30	Geneva	X	X
CG.4113	Geneva		X	G.41	Geneva	X	X
CG.4172	Geneva	X	X	G.65	Geneva	X	X
CG.4814	Geneva	X	X	G.202	Geneva	X	X
CG.5012	Geneva	X	X	G.214	Geneva	X	X
CG.5030	Geneva	X		G.890	Geneva	X	X
CG.5179	Geneva	X		G.935	Geneva	X	X
CG.5257	Geneva	X	X	G.969	Geneva	X	X
CG.5757	Geneva		X	M.26EMLA	Malling	X	X
CG.6001	Geneva	X	X	M.9T337	Malling	X	X
CG.6024	Geneva	X		MM.111	Malling		X
CG.6025	Geneva	X		Marubakaido	Japan		X
CG.6040	Geneva	X					

ized, on the growth of 1 year Golden Delicious Smoothee trees grafted on 38 different experimental and commercial apple rootstocks (Figure 1, Table 1). These apple trees were grown in pots, with standard fertigation and integrated pest management. Tree growth parameters (trunk size and height) were collected in bi-weekly intervals until dormancy. Final fresh and dry weight of leaves, trunks, and roots were collected at the end of the experiment. Fully developed leaves from the top of the plant were collected at the beginning of August for mineral concentration analysis.

The second experiment tested the effect of 5 different pH levels derived from amending one soil type, on the growth of 1 year Golden trees grafted on 33 different experimental and commercial apple rootstocks (Figure 2, Table 1). These apple trees were grown in pots, with standard fertigation and integrated pest management. Tree growth parameters (trunk size and height) were collected in bi-weekly intervals until dormancy. Final fresh and dry weight of leaves, trunks, and roots were collected at the end of the experiment. Fully developed leaves from the top of the plant were collected at the beginning of August for mineral content analysis.

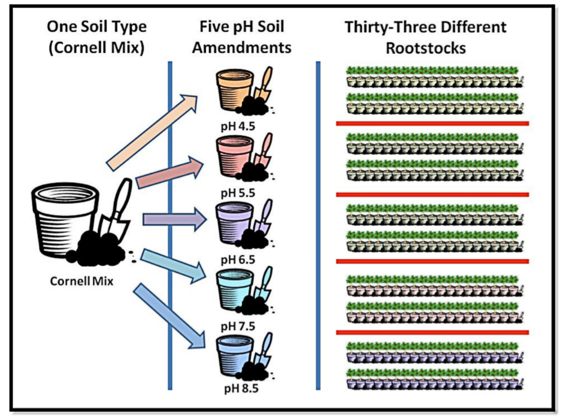

Figure 2. Diagram of the experiment testing the effect of soil pH on growth parameters and nutrient uptake of potted nursery apple trees grafted on 33 different rootstocks.

Leaf mineral concentration for both experiments was measured on two subsamples (~0.25 g dry weight) of each field leaf sample. Samples were ground, digested and processed for elemental analysis. Elemental analysis was performed using inductively coupled plasma–optical emission spectroscopy (CIROS ICP Model FCE12; Spectro, Kleve, Germany); the instrument was calibrated daily with certified standards. We measured concentrations of Ca, Cu, Fe, K, Mg, Mn, Mo, Na, P, S, and Zn. Tissue mineral concentrations were determined on a dry mass basis (μg g^{-1} or mg g^{-1}), using an average value derived from the two subsamples of each field replicate.

Results and Discussion of the Replant Experiment

One of the best ways to diagnose if a soil has a replant problem is to compare apple tree growth in a pasteurized sample of the soil (enough to kill soil borne diseases) to tree growth in an unpasteurized sample of the soil. If a scion/rootstock combination shows an increase in growth in the pasteurized sample compared to the unpasteurized soil, then there was a replant disease component (Phytophthora, Rizhoctonia, Pythium, Cylindocapon etc. species) in the unpasteurized sample. Overall our replant experiment indicated that both the clay soil and the sandy soil showed increases in the final growth of the trees due to pasteurization, indicating that

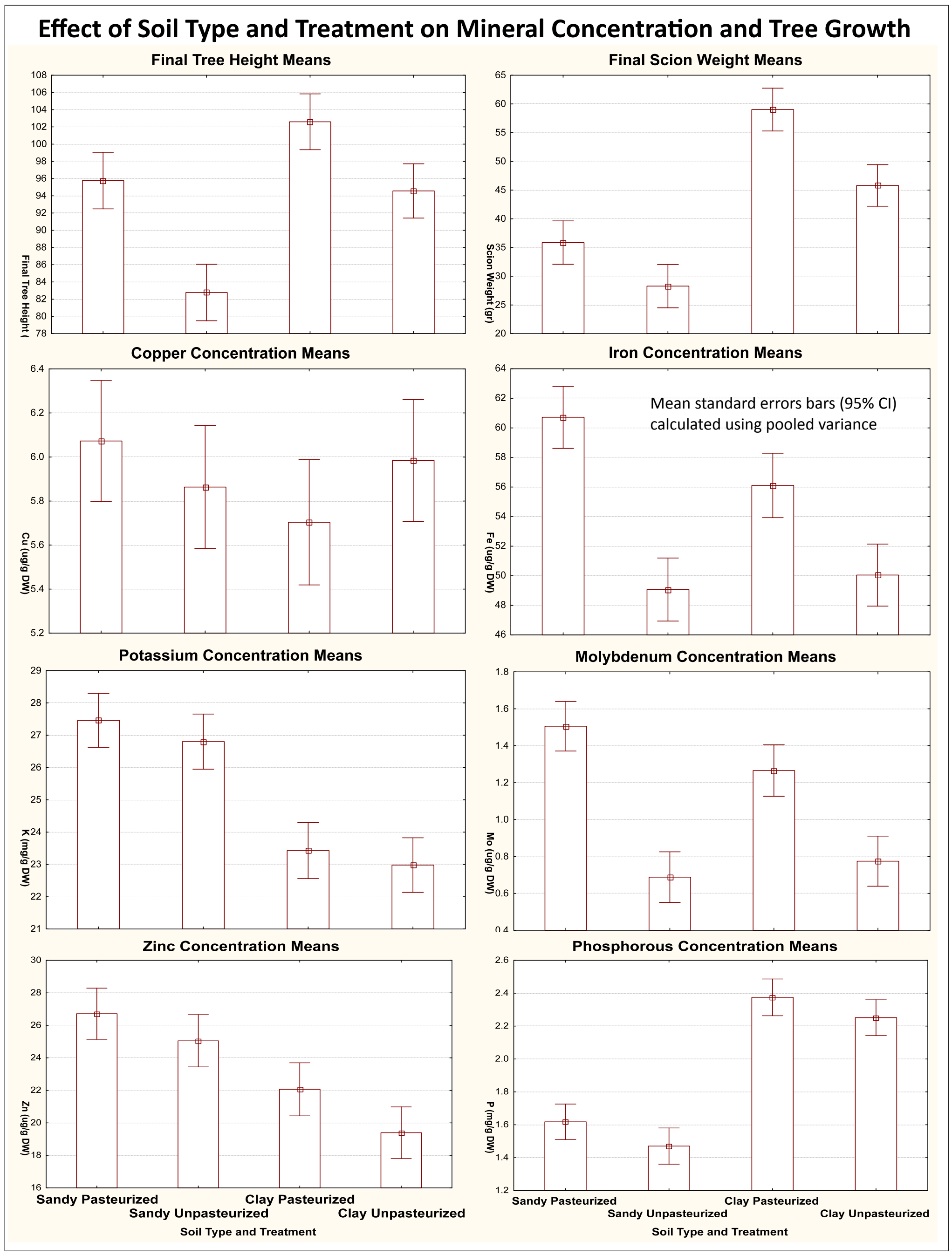

Figure 3. Effects of soil type (Clay loam and Sandy Loam) and pasteurization treatment on growth and nutrient uptake of potted Golden Delicious Smoothee trees grafted onto 38 different rootstocks.

there was a biological effect stunting tree growth in the unpasteurized soil (Figure 3, top panels). Leaf iron and molybdenum concentrations also showed a significant affect of pasteurization that paralleled tree growth, indicating that they were correlated to replant disease in some manner. Leaf zinc, sodium, potassium, manganese, calcium, magnesium and phosphorous concentrations showed significant differences between soil types but very small differences (non significant) between the pasteurized and non-pasteurized treatments.

Overall, vegetative tree growth was much stronger in the clay soil than the sandy soil. However, some rootstocks (B.9, G.214, G.890) appear to have similar growth in both soils (Figure 4). Some rootstocks appeared in this experiment to be ARD tolerant in the clay soil, but appeared sensitive to ARD in the sandy soil. Such rootstocks were: CG.4011, B.9, B.396. Other rootstocks (G.16, CG.6143, CG.6001) appeared to have the opposite relationship with soil type and ARD where they were more sensitive in the clay soil and tolerant in the sandy soil. Leaf P concentration was lower than optimum in the sandy replant soil while Zn concentration was lower in the clay replant soil. Leaf K concentrations differed significantly between soil types, but were high in all treatments (Figure3).

Results and Discussion for the pH Experiment

As a general trend, absorption of molybdenum (Mo), calcium (Ca) and phosphorous (P) increased with higher pH levels while absorption of iron (Fe), manganese (Mn) and nickel (Ni) decreased with increasing pH (Figure. 5-6). Absorption of potassium (K), copper (Cu), sodium (Na), zinc (Zn), magnesium (Mg) and sulfur (S) did not seem to be greatly affected by soil pH (Figure. 5-7). Over all the rootstocks, plant growth was affected adversely by low or high pH treatments and displayed optimum growth around pH 7.5 (Figure 8). However when plant growth was examined in different rootstocks, each rootstock exhibited a different pattern of growth as influenced by soil pH. CG.3007 and CG.5257 did not seem greatly affected by soil pH (almost flat curve), while CG.6589 had optimum growth at pH of 5.5 and G.41 and MM.111 had optimum growth at pH 7.5 (Figure 9). This indicates that G.41 may be well adapted to higher pH soils.

Scion leaf concentration of different micro- and macro-nutrients also exhibited different curves for different rootstocks. G.41 displayed unusually high levels of iron at high pH while MM.111 and CG.4172 had lower levels of iron over all pHs tested (Figure 10). Most of the rootstocks we tested reached optimal iron concentration in acid soil from 4.5 up to 6.5. When soil pH reached 7.5 or 8.5 uptake of Fe was suppressed in leaves of CG.3007, CG.2406 and G.969. Leaf molybdenum concentrations were significantly affected by pH where lower pH was correlated with lower concentrations and higher pH was correlated with higher concentrations, however different rootstocks exhibited different slopes: CG.4113 was characterized by a flatter slope and CG.2406, CG.3007 and MM.111 had steeper slopes (Figure 11). G.41 seemed to have higher phosphorous concentrations than most rootstocks at the various pH levels (Figure 12). Lower than optimum leaf P content was recorded for CG.3007 CG.4113 and CG.5257 at all pHs. MM.111, CG.4172, CG.2406 reached optimal values in more alkaline conditions, while leaf P content of G.969 was the highest at pH 4.5. The effect of soil pH on leaf calcium concentration also followed very different patterns among rootstocks: G.41 and CG.5257 had similar patterns with a low concentration in the mid range pH and higher concentration in the extremes (Figure 13), while MM.111 showed an increasing level of calcium with increasing pH, maintaining a similar trend as overall rootstocks (Figure 6). High calcium concentration is very important to prevent different fruit physiological disorders like bitter pit, scald, etc. The highest Ca concentration was found in apple leaves grown on G.969 in the wide range of pH 5.5 – 8.5. CG.5257 accumulated more Ca at pH 7.5 and 8.5; CG.4172 at pH 7.5 (Figure 13). G.41 had high leaf Ca a pH8.5 but lower Ca at

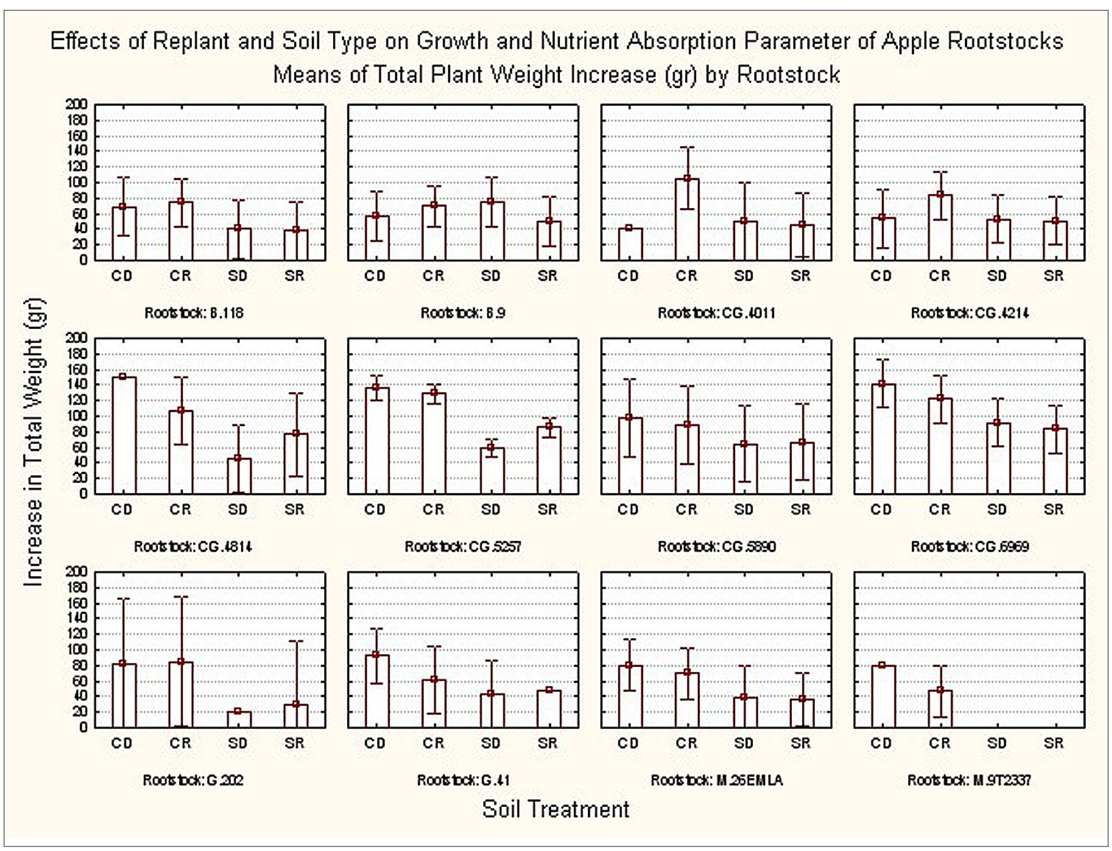

Figure 4. Interaction of soil type, pasteurization treatment (CD= Clay soil Disinfected, CR=Clay soil Replant, SD=Sandy soil Disinfected, SR=Sandy soil Replant) and rootstock genotype on total plant weight increase (initial fresh weight-final fresh weight for one season) of potted Golden Delicious Smoothee trees grafted onto 12 different rootstocks.

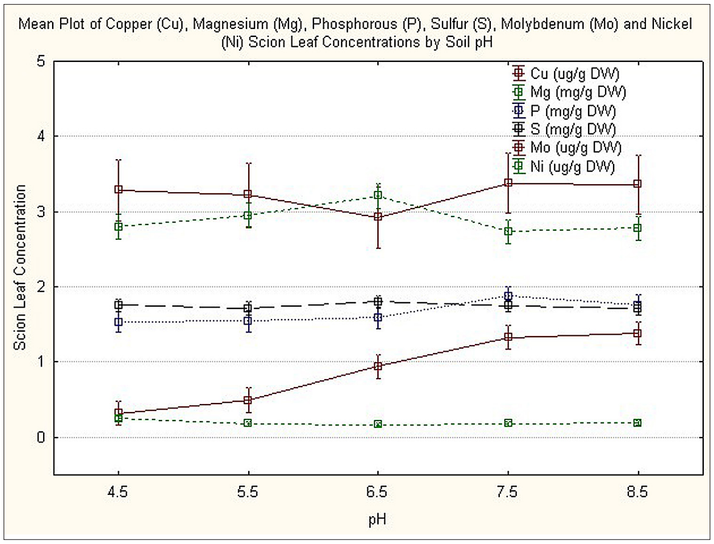

Figure 5. Effect of soil pH on leaf concentrations of copper, magnesium, phosphorous, sulfur, molybdenum, and nickel of potted Golden Delicious Smoothee trees grafted onto 33 different rootstocks.

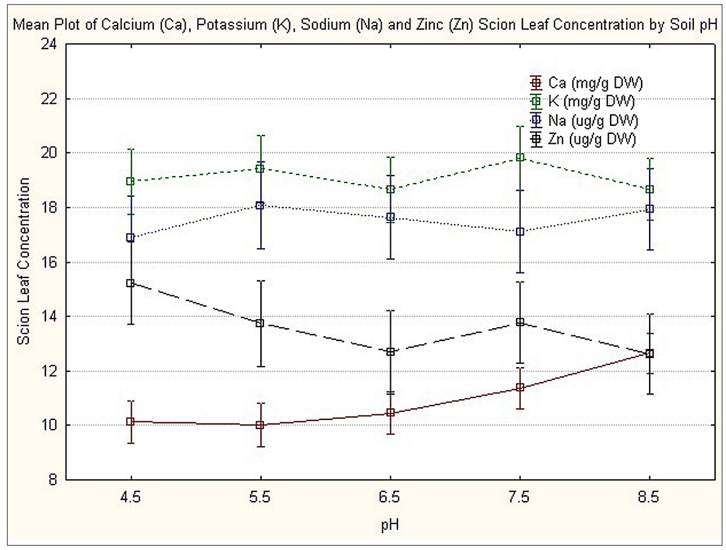

Figure 6. Effect of soil pH on leaf concentrations of calcium, potassium, sodium, and zinc of potted Golden Delicious Smoothee trees grafted onto 33 different rootstocks.

the more neutral pH of 6.5. Ca content of CG.3007 and MM.11 was very low at low pH and increased linearly to a high level at pH 8.5.

The interaction of soil pH and rootstock genotype means that the same rootstock will not be the best for different soil pHs. It appears that certain rootstocks genotypes will perform better in high pH soils while other rootstocks will perform better in low or neutral pH soils. As we develop more information on rootstock uptake of nutrients in different pH soils it will allow fruit growers to select a rootstock that is adapted to their soil pH to improve Ca and Fe uptake to reduce bitter pit and chlorosis problems in the field.

Conclusions

The preliminary studies described above have been valuable to confirm or understand several major points about apple rootstocks:

1. Rootstocks don't behave the same way in different soil environments (pH, soil type and disease).
2. The effect of replant disease can be observed at the micronutrient level.
3. The rootstocks tested showed genetic variation that allows them to absorb and transfer to the scion micro and macro-nutrients more or less efficiently. More efficient ones should grow better.
4. Choosing which rootstock matches your orchard environment is going to leverage the natural positive traits in each rootstock to increase productivity and quality of fruit. As we learn more about this in the future we should be able to make more informed decisions based on soil variables.

We have just scratched the surface with the results of these experiments – the absorption of soil nutrients once thought to follow similar trends in all apple rootstocks does

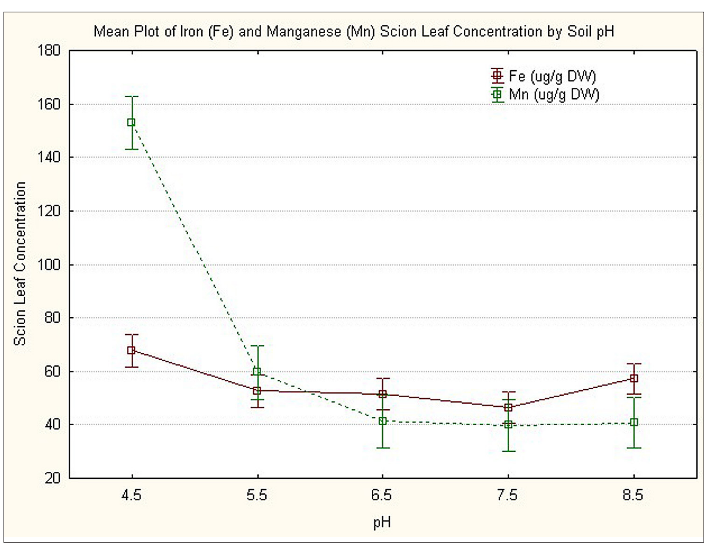

Figure 7. Effect of soil pH on leaf concentrations of iron and manganese of potted Golden Delicious Smoothee trees grafted onto 33 different rootstocks.

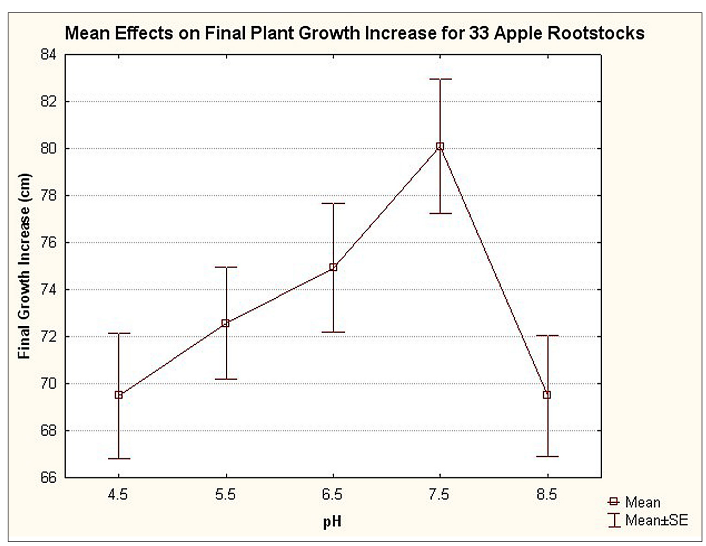

Figure 8. Effect of soil pH on total tree growth (final height-initial height) for one season (June-October) of potted Golden Delicious Smoothee trees grafted onto 33 different rootstocks.

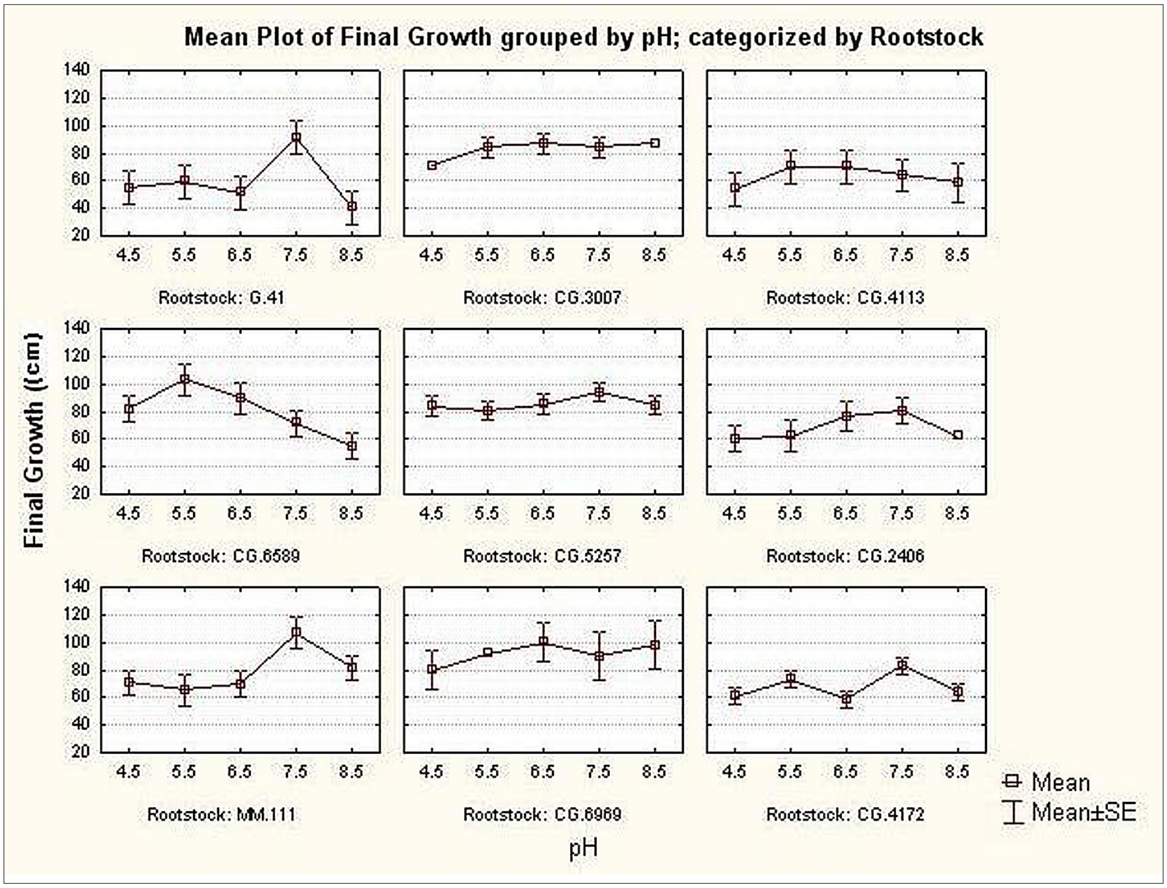

Figure 9. Interaction of soil pH and rootstock genotype on total tree growth (final height-initial height) for one season (June-October) of potted Golden Delicious Smoothee trees grafted onto 9 different rootstocks.

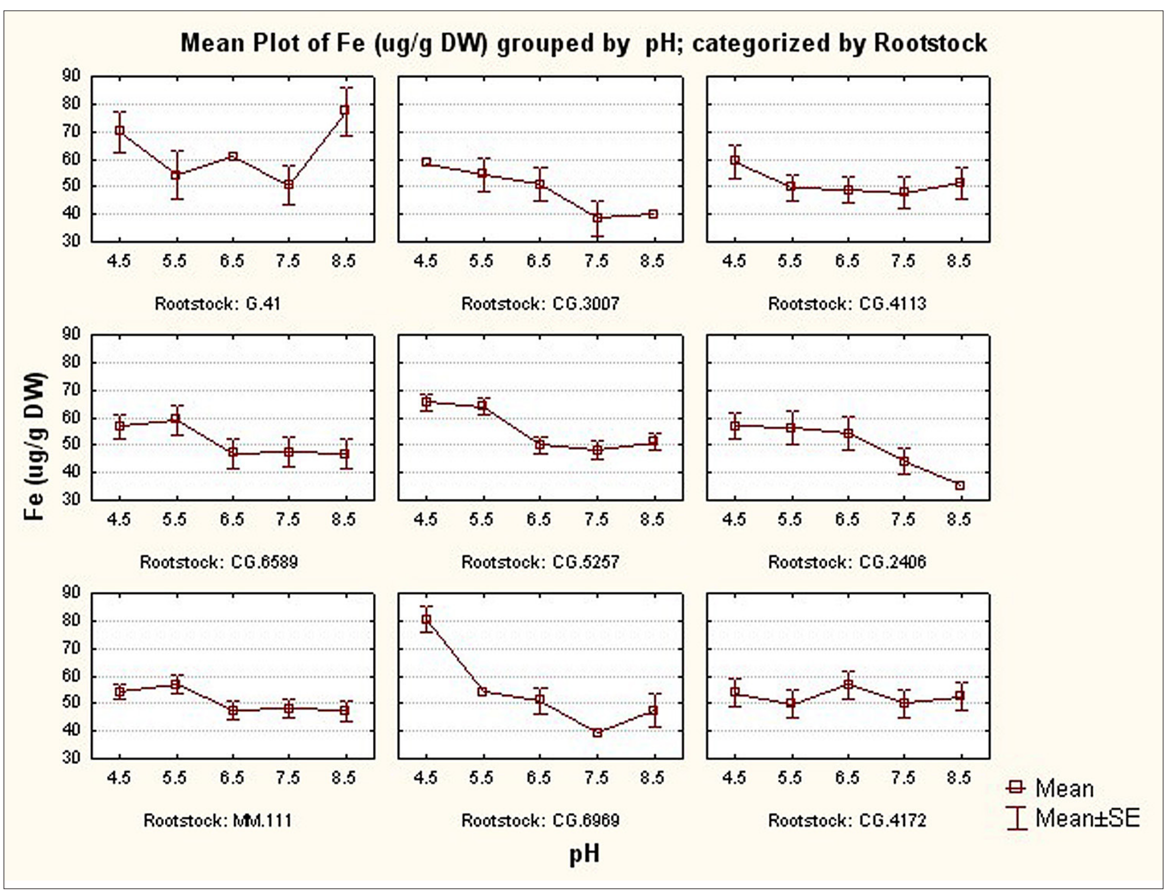

Figure 10. Interaction of soil pH and rootstock genotype on leaf iron concentration of potted Golden Delicious Smoothee trees grafted onto 9 different rootstocks.

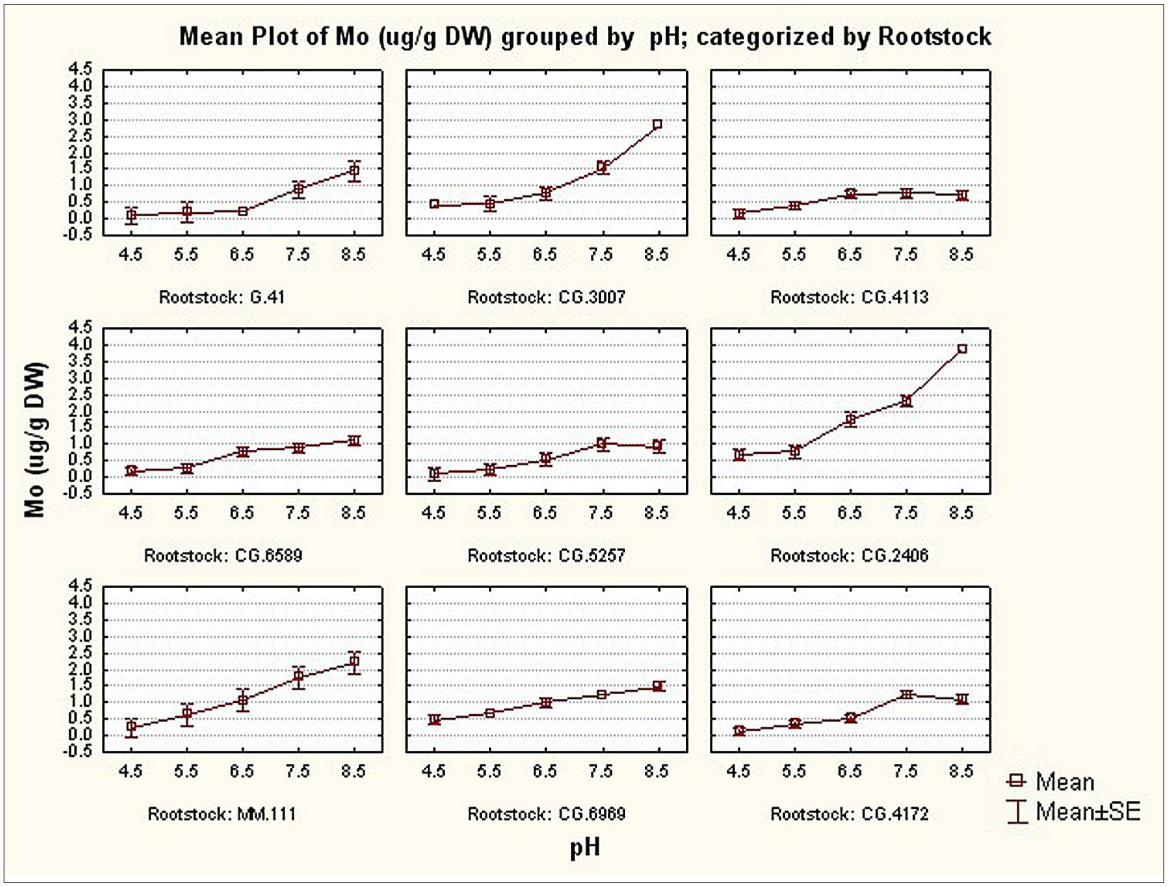

Figure 11. **Interaction of soil pH and rootstock genotype on leaf molybdenum concentration of potted Golden Delicious Smoothee trees grafted onto 9 different rootstocks.**

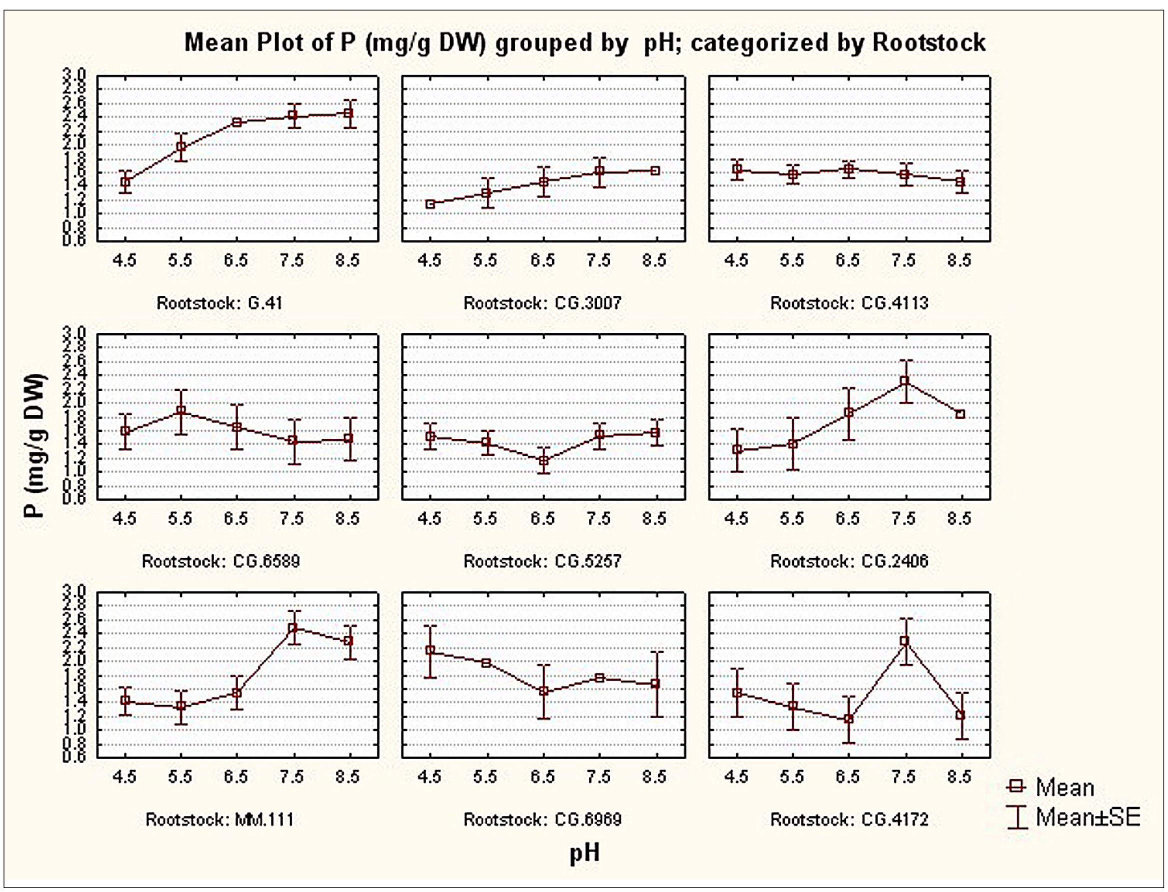

Figure 12. **Interaction of soil pH and rootstock genotype on leaf phosphorous concentration of potted Golden Delicious Smoothee trees grafted onto 9 different rootstocks.**

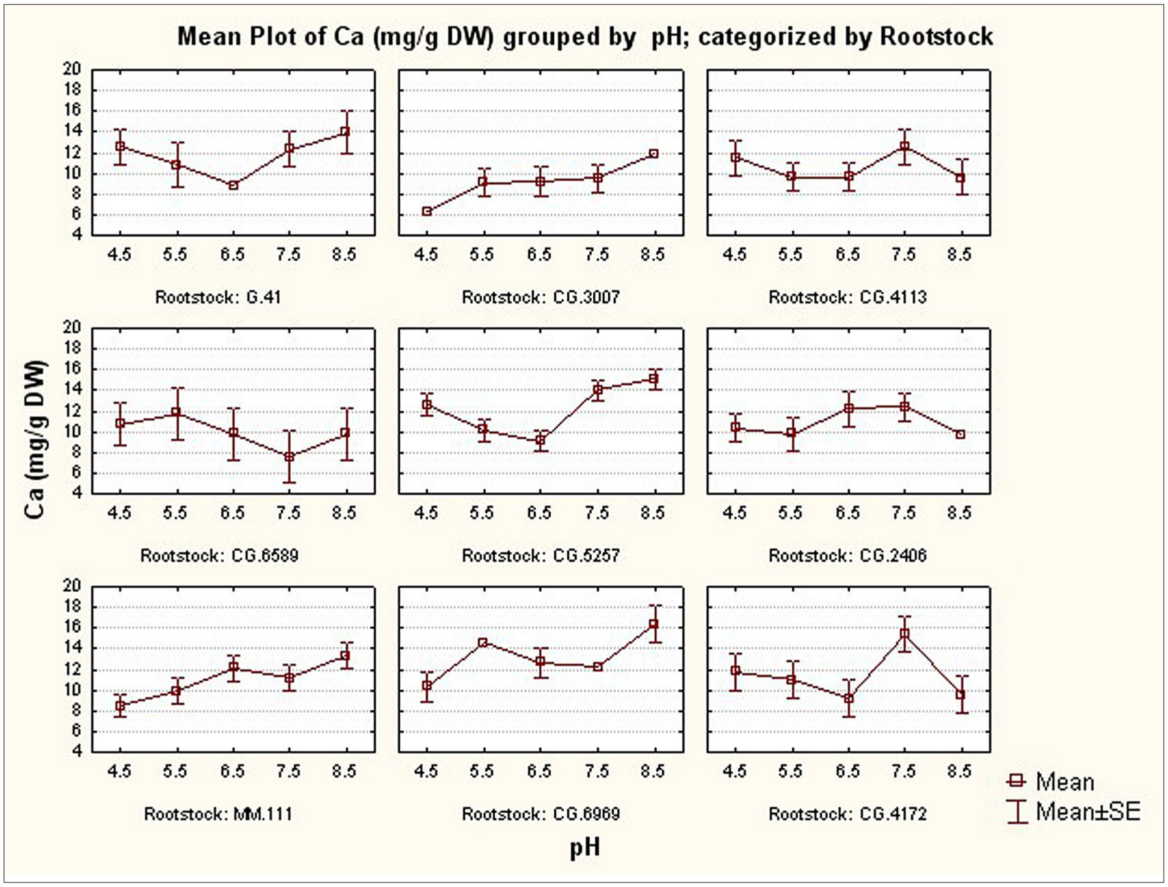

Figure 13. Interaction of soil pH and rootstock genotype on leaf calcium concentration of potted Golden Delicious Smoothee trees grafted onto 9 different rootstocks.

not behave the same way in newer rootstocks. Rootstocks such as G.87 that behave very well in the sandy soils of Northern Michigan might have the right combination of genetic factors that make it very well adapted to the soil type and pH levels in that region. What we thought might work for M.26 might not be optimal for G.935 or G.41, furthermore as we understand more about how individual rootstocks have more efficient machinery to absorb and translocate nutrients we can avoid waste and runoff (especially with phosphorous products). We can also breed for nutrient efficiency in new apple rootstocks and make the orchard more productive in the long term. While this set of experiments has proven very useful to understand some of the dynamics of apple tree nutrition, it represents an exploration that needs to be greatly expanded to permit a better understanding of rootstock specific interactions with the parameters tested and permit a knowledge based recommendation of apple rootstocks tailored to specific growing sites.

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