Time analysis of rootstock mediated nutrient transport in 'Honeycrisp'

G. Fazio[1,2] and T.L. Robinson[2]

[1]Plant Genetic Resources Unit USDA ARS, Geneva, NY, USA; [2]Horticulture Section, School of Integrative Plant Sciences, Cornell University, Geneva, NY, USA.

Abstract

An experiment aimed at understanding the genotypic potential of certain rootstocks to influence the nutrient concentration of 'Honeycrisp' fruit was conducted over two years (2016 and 2017) on trees that had reached production maturity. Four or five replications of trees grafted on B.9, G.11, G.214, G.30, G.41, G.210, G.814, G.935, M.26, M.9 Pajam2 rootstocks were used as the source of tissues for this experiment. The nutrient concentration of leaves, pedicels, and fruit was monitored 8-10 times in two-week intervals from the time fruit reached 10 mm in diameter to harvest. Nutrients like boron, potassium, sulfur, phosphorous and calcium showed good correlation among rootstock/tissue combinations. Overall, nutrient concentration changed in tissues over time with some nutrients like boron and potassium displaying higher concentration early in the season then decreasing over time in a similar way for all tissues. Other nutrients like calcium displayed discordance between tissue types as all tissues started from the same concentration, with leaves increasing concentration, pedicels remaining constant and fruit decreasing in concentration with time. Nutrient ratios like K/Ca and (K+Mg)/Ca showed starkly different trends in fruit tissues (increasing with time) compared to pedicel and leaves where the ratios remained relatively constant. These ratios were slightly influenced by rootstocks genotype over time, indicating effects that could be tied to rootstock specific influence on fruit quality parameters like bitter pit. While Ca increased in leaves, it was constant over time in the pedicel and slightly decreased in fruit. K in the pedicel and the fruit decreased over time in a similar way, however leaf K displayed a different rate of decline and was more variable during the season. Rootstock genotype significantly affected the overall concentration of certain nutrients and as previously observed in a previous experiment, M.9 Pajam 2 displayed the lowest levels of boron in all tissues compared to other rootstocks. This work is part of a larger project aimed at understanding the connection between rootstocks and fruit quality being studied in the USDA NIFA Specialty Crop Project "AppleRoot2Fruit".

Keywords: nutrient uptake, rootstock, breeding, yield components, fruit quality

INTRODUCTION

Apple rootstocks perform the important function of mining mineral nutrients from the soil and shuttling them to grafted scion varieties thus allowing proper whole tree growth and production of fruit (Fallahi et al., 1984). Recent experiments have outlined the influence of rootstock genotype on this function where the mineral nutrient concentrations of different tissues in grafted scion cultivars can be significantly modified according to what rootstock it is grafted on (Fazio et al., 2013, 2015, 2020; Neilsen and Hampson, 2014; Lordan et al., 2019, 2020; Reig et al., 2018). Some nutrients like boron seem to be tightly controlled by the rootstock genotype, while others like calcium seem to display environmental interactions which obfuscate the rootstock genotypic effect (Reig et al., 2018). The concentration of calcium and the ratios of nutrients like potassium/calcium in fruit have been connected to the incidence of bitter pit in apple fruit especially in the bitter pit sensitive cultivar 'Honeycrisp' (Fazio et al., 2018, 2020; Robinson and Fazio et al., 2022). The position of fruit in the tree canopy, crop load and fruit size have also been connected to the incidence of bitter pit (Serra et al., 2016; Robinson and Lopez, 2012). Controlling bitter pit in 'Honeycrisp' apple usually

Acta Hortic. 1333. ISHS 2022. DOI 10.17660/ActaHortic.2022.1333.54
Proc. IX International Symposium on Mineral Nutrition of Fruit Crops
Eds.: A. Dag et al.

requires numerous tactics including foliar calcium sprays (Rosenberger et al., 2004; Torres et al., 2017).

Timing of nutrient absorption and transport by root systems can be influenced by the mechanism employed to transport each nutrient, consequently a nutrient that is exclusively moved in the phloem and then into cells by energy activated symport proteins is going to be different than a nutrient that is exclusively passively transported through the xylem by evapotranspiration (Kalcsits, 2016; Wang and Wu, 2013). All nutrients, water and plant metabolites are transported to the fruit through the pedicel. Pedicels seem to be fully formed in size early in the fruit development and therefore capturing their nutrient concentrations at specific times of fruit development may reveal rootstock specific nutrient fluxes that affect fruit quality and development (Song et al., 2018). The goal of this experiment was to identify rootstock specific patterns in the timing and concentration of several nutrients and their ratios in leaves, pedicels, and fruits of the scion 'Honeycrisp'.

MATERIALS AND METHODS

The research orchard block used for this experiment was planted in 2007 at Geneva, New York State featuring 'Honeycrisp' scions grafted on 10 rootstocks (B.9, G.11, G.214, G.30, G.41, G.210, G.814, G.935, M.26 and M.9 Pajam2) replicated 4-5 times in the orchard. Leaf, pedicel, and fruit tissues were sampled 8-10 times during the 2016 and 2017 growing season (about every two weeks) from fruit set to about two weeks before harvest. Ten mid-position leaves on new extension growth and five fruit and pedicels randomly distributed throughout the tree canopy were processed, oven-dried, pulverized and pooled according to harvest time and tree replicate. Nutrient concentration data were obtained by via inductively coupled plasma optical emission spectrometry (ICP) from two years, 2016 and 2017 (Great Lakes Nutrient Analysis Lab). About 780 samples were evaluated for each year. Nutrient concentration data was analyzed with SAS JMP Pro 15 and Minitab 18. Rootstock genotype least squared means for each of the nutrients and harvest timings were obtained by mixed model analysis. Years were analyzed and plotted separately.

RESULTS AND DISCUSSION

The mean nutrient concentrations for each tissue type from the experimental unit (one tree) at each sampling time for most nutrients were highly correlated between 2016 and 2017 (Table 1; Figure 1). These high correlations indicate a stable physiological state for the rootstock-scion system. The values of potassium and boron for each of the three tissue types, displayed a continuum of values with considerable overlap in data points between tissue types, whereas the calcium and magnesium concentrations had different ranges among tissue types and different correlation values depending on the tissue interrogated.

When observing the behavior of potassium through the different sampling times and tissues (Figure 2) the K levels decrease with time in pedicels and fruit much faster than in leaves. Leaf K levels show a dip in mid-season in all rootstocks and then a small increase. The rootstock influence on K levels is also very evident where G.41, G.210, G.814 and G.935 display higher levels of K than the rest of the rootstocks. The fact that they start at higher levels perhaps shows effects from previous years, indicates either a higher capacity to store K and transmit it early in the spring or a better capacity to absorb that nutrient in the spring. M.26 and G.214 displayed some of the lowest levels of K. This tendency of G.214 to display lower levels of K has been observed in other plantings (Al Farqani, 2019; Fazio et al., 2020; Reig et al., 2018).

The pedicel calcium level was not affected by rootstock, but rootstock did have an influence on Ca level in leaf and fruit tissues perhaps indicating calcium saturation for the pedicels and fluxes in into fruit and leaves (Figure 3).

Calcium behavior through the season (Figure 3), shows a significant decrease in fruit, while in pedicels the Ca levels remain constant in pedicels and increase in leaves over time. The decrease in fruit is related to the fruit growing in size by cell division and cell enlargement which results in a three-dimensional growth potential, while leaves have a two-dimensional growth potential. This is exacerbated by the fact that any calcium in the xylem flow will be accumulated faster due to the increased transpiration rate in leaves compared to fruit. The constant levels in pedicels indicates a maximum capacity steady state is reached early in the development of the fruit suggesting a bottleneck behavior in this tissue type (Song et al., 2018). There was a significant rootstock effect on Ca levels where G.11 displayed the highest leaf Ca, and G.214 the highest for pedicels. G.30 and G.814 fruit ended up with the lowest levels of Ca in fruit at the end of the 2016 season.

Table 1. Correlation coefficients between fruit nutrient concentrations in 2016 and 2017 data of mature ‘Honeycrisp’ trees at Geneva, NY.

	B 2016	Ca 2016	K 2016	Mg 2016	P 2016	S 2016	N 2017	P 2017	K 2017	Ca 2017	Mg 2017	S 2017	B 2017
B 2016	1.00	0.73	0.87	0.77	0.84	0.74	0.88	0.91	0.90	0.90	0.92	0.88	0.89
Ca 2016	0.73	1.00	0.92	0.99	0.95	0.99	0.82	0.79	0.72	0.80	0.78	0.82	0.46
K 2016	0.87	0.92	1.00	0.95	0.98	0.94	0.97	0.96	0.94	0.94	0.95	0.97	0.71
Mg 2016	0.77	0.99	0.95	1.00	0.98	0.99	0.92	0.89	0.83	0.90	0.90	0.91	0.55
P 2016	0.84	0.95	0.98	0.98	1.00	0.98	0.98	0.97	0.93	0.96	0.97	0.96	0.69
S 2016	0.74	0.99	0.94	0.99	0.98	1.00	0.90	0.87	0.81	0.86	0.86	0.89	0.52
N 2017	0.88	0.82	0.97	0.92	0.98	0.90	1.00	0.99	0.96	0.96	0.98	0.99	0.73
P 2017	0.91	0.79	0.96	0.89	0.97	0.87	0.99	1.00	0.96	0.97	0.99	0.99	0.78
K 2017	0.90	0.72	0.94	0.83	0.93	0.81	0.96	0.96	1.00	0.91	0.94	0.96	0.83
Ca 2017	0.90	0.80	0.94	0.90	0.96	0.86	0.96	0.97	0.91	1.00	0.98	0.95	0.73
Mg 2017	0.92	0.78	0.95	0.90	0.97	0.86	0.98	0.99	0.94	0.98	1.00	0.98	0.76
S 2017	0.88	0.82	0.97	0.91	0.96	0.89	0.99	0.99	0.96	0.95	0.98	1.00	0.74
B 2017	0.89	0.46	0.71	0.55	0.69	0.52	0.73	0.78	0.83	0.73	0.76	0.74	1.00

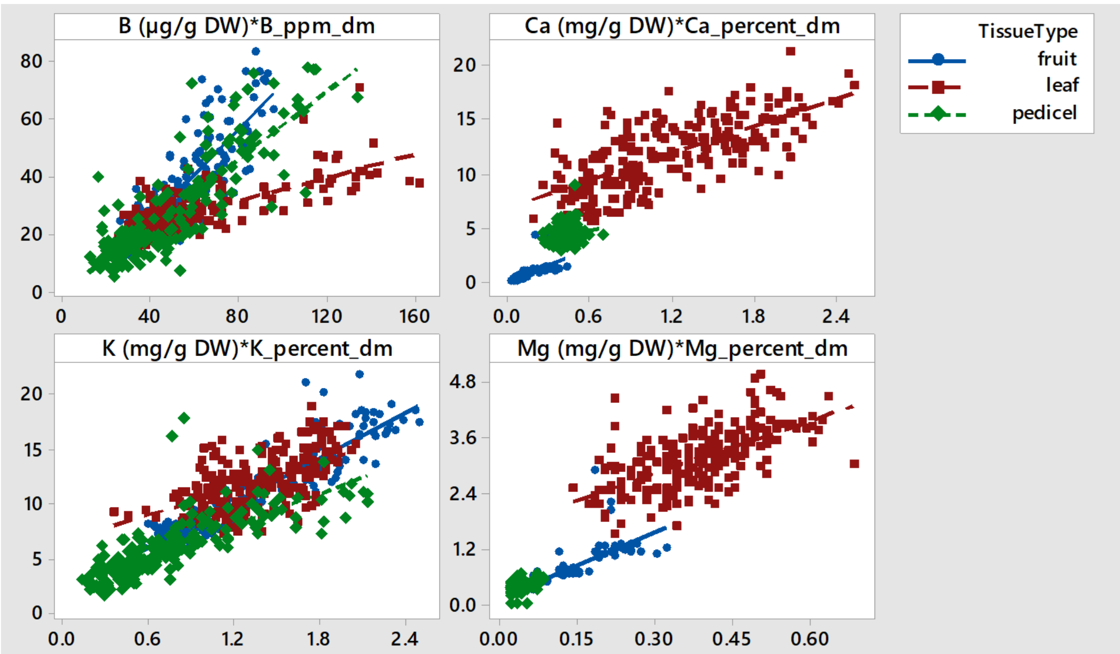

Figure 1. Single tree date mean correlations between 2016 and 2017 for boron, calcium, potassium, and magnesium at 2-week sampling times through the season for mature ‘Honeycrisp’ trees at Geneva, NY. *x*-axis values are for 2016 and *y*-axis values are for 2017.

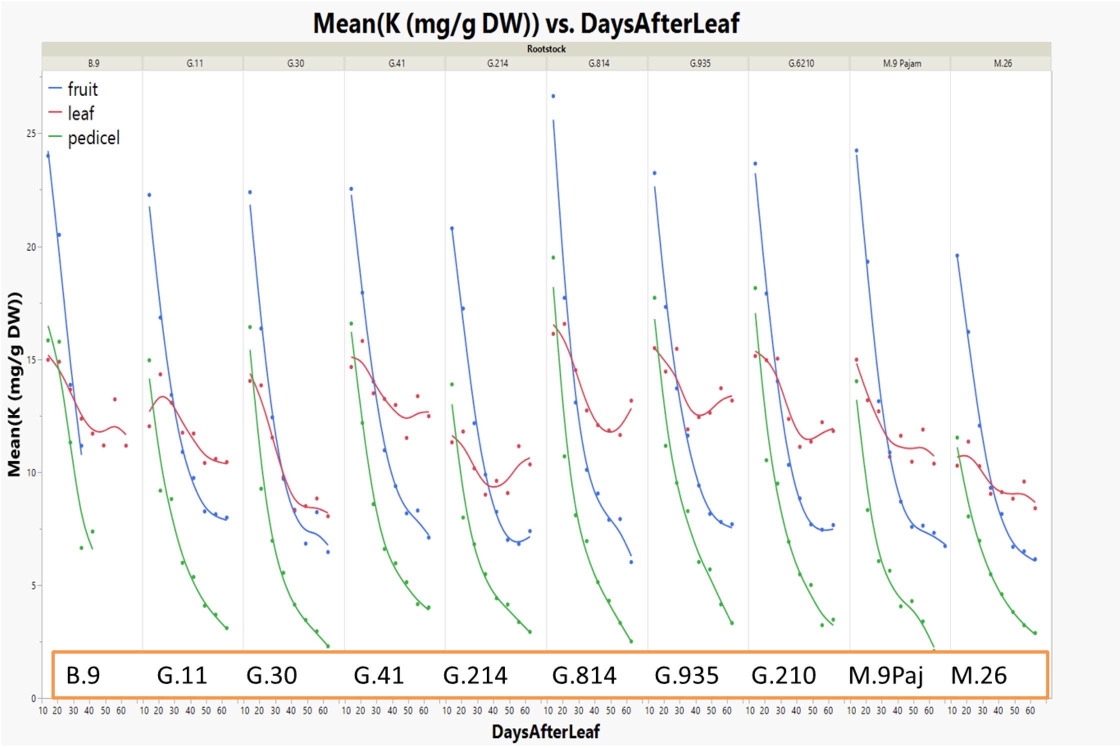

Figure 2. Interaction plot of rootstock and sampling date through the season (*x*-axis) on potassium concentration. in fruit, leaves and pedicels of mature 'Honeycrisp' trees at Geneva NY averaged over 2 years (2016 and 2017).

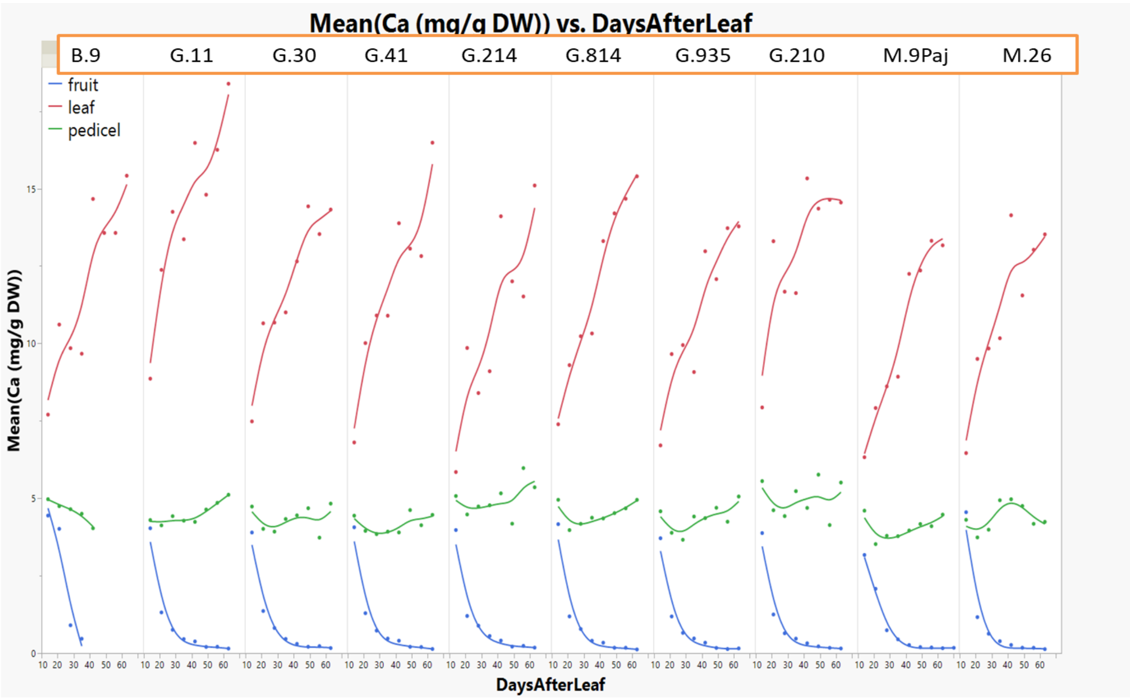

Figure 3. Interaction plot of rootstock and sampling date through the season (*x*-axis) on calcium concentration in fruit, leaves and pedicels of mature 'Honeycrisp' trees at Geneva NY averaged over 2 years (2016 and 2017).

A comparison among boron, potassium, and sodium levels through the season (Figure 4) highlights the differences in transport type where B features active transport, K features a mix of active and passive transport and Na features mostly passive transport. All these nutrients seem to decrease in concentration in fruit over time, however sodium concentration seems more variable especially in pedicels indicating different levels of flux throughout the season. It is important to note that these trees are rain fed and therefore water availability is a likely factor in this variation. Boron was highly correlated with potassium in this experiment, which matches other observations, however in pedicels the levels start high (perhaps indicating a strong sink by the flower and early fruit) and then tapers at the end of the season.

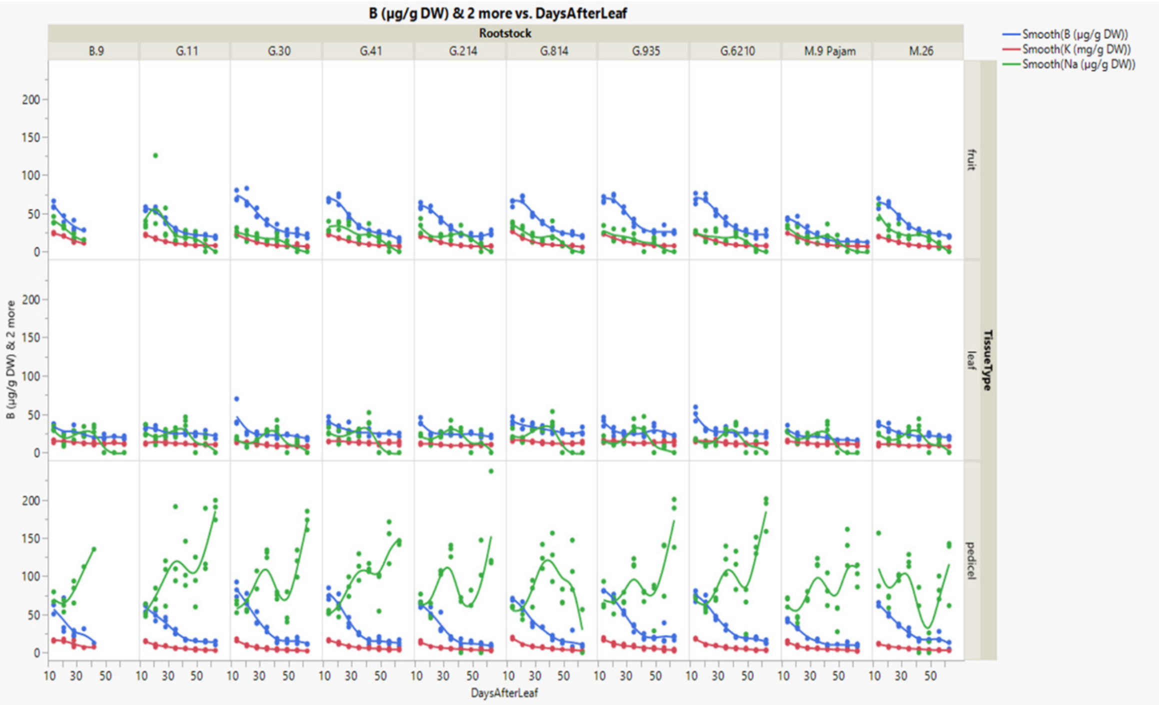

Figure 4. Interaction plot of rootstock and sampling date through the season (*x*-axis) on potassium, boron and sodium concentration in fruit, leaves and pedicels of mature 'Honeycrisp' trees at Geneva NY averaged over 2 years (2016 and 2017).

The ratio of potassium to calcium has been identified as one of the best predictors for bitter pit incidence. Rootstock B.9 and G.214 displayed some of the lowest K/Ca ratio in 2016 and 2017 (Figures 5 and 6) which matches pretty well their potential to exhibit low bitter pit incidence in fruit, whereas G.814, G.935, M.9, G.210 and G.30 all seemed to feature higher ratios in fruit (Valverdi et al., 2019). All rootstocks displayed lower ratios in 2017 perhaps indicating a shifted physiological status due to climate differences between the two seasons. We observed an interesting divergence in fruit K/Ca ratio with G.11 between 2016 and 2017 perhaps indicating a peculiarity in the way that rootstock perceives the environment. G.11 has been known to advance maturity in certain cultivars and environments.

CONCLUSIONS

Rootstock genotype had an effect on nutrient concentration and ratios for several nutrients in both seasons. Slight seasonal differences between years were evident in some nutrient/time curves perhaps tied to the seasonal variations in bitter pit experienced by growers. These data are in the process of being correlated with cumulative bitter pit incidence.

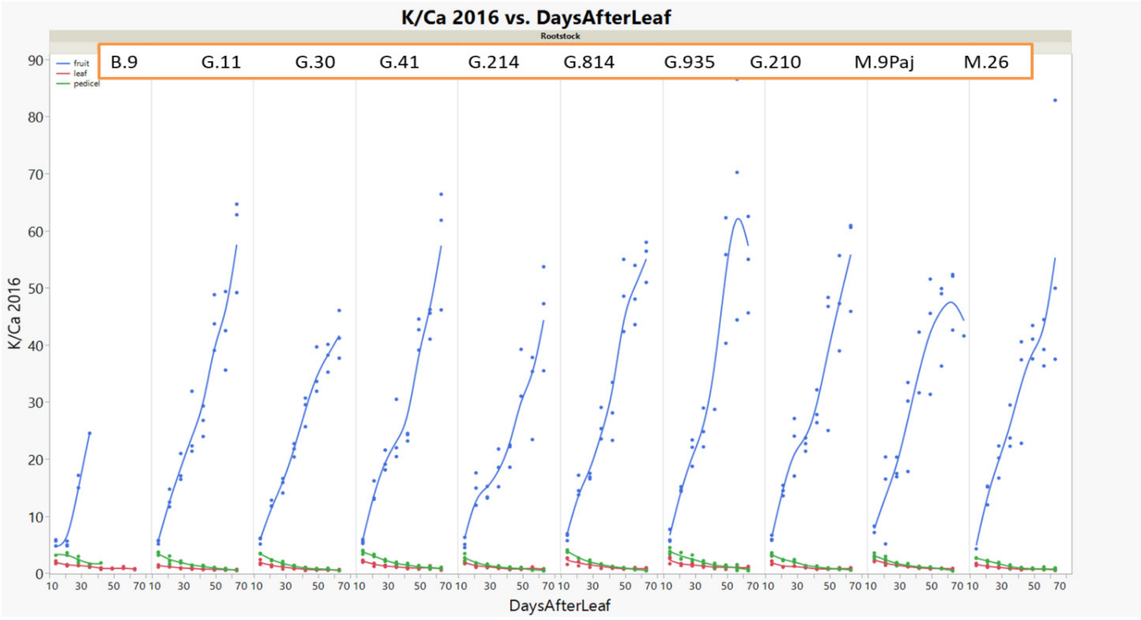

Figure 5. Interaction plot of rootstock and sampling date through the season (*x*-axis) on potassium/calcium ratio in fruit, leaves and pedicels of mature 'Honeycrisp' trees at Geneva NY averaged over 2 years (2016 and 2017).

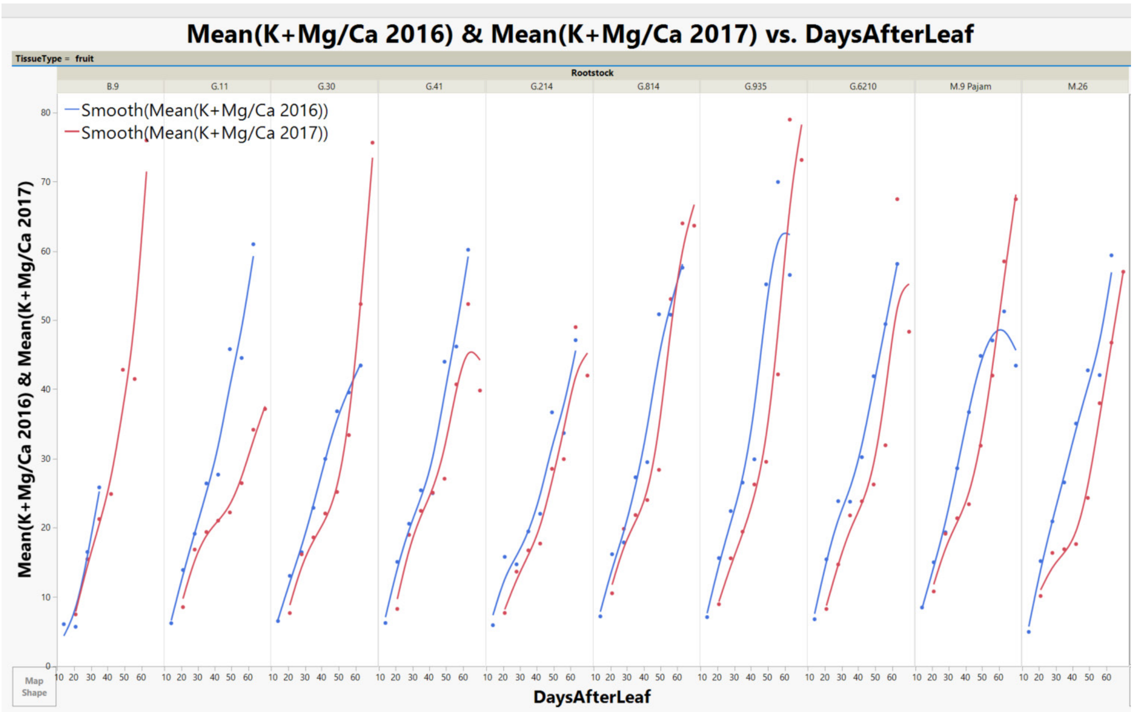

Figure 6. Comparison between 2016 and 2017 data of rootstock genotypic means for (potassium+magnesium)/calcium ratio in fruit arranged by sampling time (*x*-axis) of mature 'Honeycrisp' trees at Geneva NY.

ACKNOWLEDGEMENTS

We would like to thank technicians Abby Nedrow, Sarah Bauer and Todd Holleran for collecting plant material, setting up the experiments and collecting data. The projects described in this manuscript were also partially funded by the USDA NIFA SCRI CRIS PROJ NO:

NYC-145543 “Accelerating the development, evaluation, and adoption of new apple rootstock technologies to improve apple growers’ profitability and sustainability”. The content of this publication does not necessarily reflect the views or policies of the US Department of Agriculture, nor does mention of trade names, commercial products, or organizations imply endorsement by the US Government.

Literature cited

Al Farqani, A.S.A. (2019). Evaluation of Root’s Architecture, Growth Performance and Fruiting of Honeycrisp™ Apple Scion Grafted on 8 Rootstocks in Response to Soil and Solution’s pH Using Field, Aeroponics, and Minirhizotron Growing Systems (Ithaca, NY: Cornell University).

Fallahi, E., Westwood, M.N., Chaplin, M.H., and Richardson, D.G. (1984). Influence of apple rootstocks and K and N fertilizers on leaf mineral composition and yield in a high density orchard. J. Plant Nutr. *7* (*8*), 1161–1177 https://doi.org/10.1080/01904168409363273.

Fazio, G., Kviklys, A., Grusak, M.A., and Robinson, T.L. (2013). Phenotypic diversity and QTL mapping of absorption and translocation of nutrients by apple rootstocks. Asp. Appl. Biol. *119*, 37–50.

Fazio, G., Cheng, L., Grusak, M.A., and Robinson, T.L. (2015). Apple rootstocks influence mineral nutrient concentration of leaves and fruit. New York Fruit Quarterly *23*, 11–15.

Fazio, G., Lordan, J., Francescatto, P., Cheng, L., Wallis, A., Grusak, M.A., and Robinson, T.L. (2018). ‘Honeycrisp’ apple fruit nutrient concentration affected by apple rootstocks. Acta Hortic. *1228*, 223–228 https://doi.org/10.17660/ActaHortic.2018.1228.33.

Fazio, G., Lordan, J., Grusak, M.A., Francescatto, P., and Robinson, T.L. (2020). I. Mineral nutrient profiles and relationships of ‘Honeycrisp’ grown on a genetically diverse set of rootstocks under Western New York climatic conditions. Sci. Hortic. (Amsterdam) *266*, 108477 https://doi.org/10.1016/j.scienta.2019.05.004.

Kalcsits, L.A. (2016). Non-destructive measurement of calcium and potassium in apple and pear using handheld x-ray fluorescence. Front Plant Sci *7*, 442 https://doi.org/10.3389/fpls.2016.00442. PubMed

Lordan, J., Fazio, G., Francescatto, P., and Robinson, T.L. (2019). II. Horticultural performance of ‘Honeycrisp’ grown on a genetically diverse set of rootstocks under Western New York climatic conditions. Sci. Hortic. (Amsterdam) *257*, 108686 https://doi.org/10.1016/j.scienta.2019.108686.

Lordan, J., Francescatto, P., Fazio, G., and Robinson, T.L. (2020). Effects of apple rootstocks on nutrient concentration in ‘Honeycrisp’ scions. Acta Hortic. *1281*, 97–104 https://doi.org/10.17660/ActaHortic.2020.1281.15.

Neilsen, G., and Hampson, C. (2014). ‘Honeycrisp’ apple leaf and fruit nutrient concentration is affected by rootstock during establishment. J. Am. Pomol. Soc. *68*, 178–189.

Reig, G., Lordan, J., Fazio, G., Grusak, M.A., Hoying, S., Cheng, L.L., Francescatto, P., and Robinson, T. (2018). Horticultural performance and elemental nutrient concentrations on ‘Fuji’ grafted on apple rootstocks under New York State climatic conditions. Sci. Hortic. (Amsterdam) *227*, 22–37 https://doi.org/10.1016/j.scienta.2017.07.002.

Robinson, T.L., and Fazio, G. (2022). Rootstock affects fruit nutrient profile and bitter pit incidence of apple. Acta Hortic. *1333*, 373–378 https://doi.org/10.17660/ActaHortic.2022.1333.50.

Robinson, T., and Lopez, S. (2012). Crop load affects ‘Honeycrisp’ fruit quality more than nitrogen, potassium, or irrigation. Acta Hortic. *940*, 529–537 https://doi.org/10.17660/ActaHortic.2012.940.76.

Rosenberger, D., Schupp, J., Hoying, S., Cheng, L., and Watkins, C. (2004). Controlling bitter pit in ‘Honeycrisp’ apples. Horttechnology *14* (*3*), 342–349 https://doi.org/10.21273/HORTTECH.14.3.0342.

Serra, S., Leisso, R., Giordani, L., Kalcsits, L., and Musacchi, S. (2016). crop load influences fruit quality, nutritional balance, and return bloom in ‘Honeycrisp’ apple. HortScience *51* (*3*), 236–244 https://doi.org/10.21273/HORTSCI.51.3.236.

Song, W., Yi, J., Kurniadinata, O.F., Wang, H., and Huang, X. (2018). Linking fruit Ca uptake capacity to fruit growth and pedicel anatomy, a cross-species study. Front Plant Sci *9*, 575 https://doi.org/10.3389/fpls.2018.00575. PubMed

Torres, E., Recasens, I., Lordan, J., and Alegre, S. (2017). Combination of strategies to supply calcium and reduce bitter pit in ‘Golden Delicious’ apples. Sci. Hortic. (Amsterdam) *217*, 179–188 https://doi.org/10.1016/j.scienta.2017.01.028.

Valverdi, N.A., Cheng, L.L., and Kalcsits, L. (2019). Apple scion and rootstock contribute to nutrient uptake and partitioning under different belowground environments. Agronomy (Basel) *9* (*8*), 415 https://doi.org/10.3390/agronomy9080415.

Wang, Y., and Wu, W.H. (2013). Potassium transport and signaling in higher plants. Annu Rev Plant Biol *64* (*1*), 451–476 https://doi.org/10.1146/annurev-arplant-050312-120153. PubMed