Project Title: Reliable Soil Diagnostic Technology for Smart Nutrient Management

Report Type: Final Project Report

Primary PI: Bernardita Sallato C.
Organization: Washington State University
Telephone: (509) 786-9205
Email: b.sallato@wsu.edu
Address: 24106 North Bunn Road
Address 2:
City/State/Zip: Prosser, WA 99350

Co-PI 2: Lav R. Khot
Organization: Washington State University
Telephone: (509) 786-9302
Email: lav.khot@wsu.edu
Address: 24106 North Bunn Road
Address 2:
City/State/Zip: Prosser, WA 99350

Cooperators: Steve Mantle, Gilbert Plath, Ramon Cuevas, Jenny Bolivar-Medina, SoilTest Lab, Predictive Nutrient Solutions, Inc. in Walla Walla, (PNS), Northwest Agricultural Consultants, Inc. Stuart Goatley (WTFRC).

Project Duration: 2-Year.

Total Project Request for Year 1 Funding: $ 15,670
Total Project Request for Year 2 Funding: $ 14,970

Amount awarded: $152,938
Agency Name: Washington State USDA- Specialty Crop Block Grant
Notes: PI: B. Sallato. Co-PIs: L. Kalcsits, M. Whiting. Costs associated with Objective 1 and wages for hourly support during sample collection incurred in this proposed WTFRC project will be covered by this SCBG Grant.

Amount awarded: ~$35,000
Agency Name: Universidade Federal de Viçosa (UFV), Capes-Print project, Brazil
Notes: Khot's Precision Ag lab has an ongoing collaboration with UFV-Brazil and will host a visiting scholar from UFV, Brazil for a 1-year period (March 2021-February 2022). The UFV-Brazil group has developed a field portable soil nutrient(s) sensing system. In this WTFRC project, we will leverage the expertise of the visiting scholar to test the suitability of this sensing module for mapping the soil attributes from chosen orchard sites. We will then relate those results to other ground-reference methods and other data products.

Budget 1
Primary PI: Bernardita Sallato C.
Organization Name: Washington State University
Contract Administrator:
Telephone: (509) 335-2885
Contract administrator email address: arcgrants@wsu.edu
Station Manager/Supervisor: Naidu Rayapati
Station manager/supervisor email address: naidu@wsu.edu

Item	**2021**	**2022**
Salaries		
Benefits		
Wages		
Benefits		
Equipment		
Supplies[1]	15,670	14,970
Travel		
Miscellaneous		
Plot Fees		
Total	$15,670	$14,970

Footnotes:

[1] Supplies: laboratory analyses of 300 samples @ $35.50/sample for complete soil test including standard and paste extract, and 240 tissue samples (leaves, fruits) @ $18/sample.

INTRODUCTION

A smart orchard project was implemented in Chiawana Orchards, Pasco, in 2020 in collaboration with several industry and university partners. This collaboration initiated a system that enabled the assessment and ground truthing of conventional and new technologies. Under the umbrella of the smart orchard initiative, this project focused on technology for soil chemical management for reliable diagnosis.

Soil physical and chemical testing has been used for more than a century to guide nutrient management practices. Today, new technology could provide opportunities for precision and remote management. Our goal is to develop “smart nutrient management” strategies based on quantifiable needs. For these, our specific objectives were to: a. *Characterize different soil testing methods/technologies and their relationship with plant response, b. Investigate tools to assess and map soil variability and c. Contribute to the “smart orchard initiative” in the area of soil nutrient sensing and management.*

SIGNIFICANT FINDINGS

- Grandview ‘Honeycrisp’ fruit load was 4.4 and 2.2 times higher in site 3 (S3) compared to site 4 and site 1. While bitter pit incidence was lowest in S3 (2%) and highest in S4 (52%). In 2022, cracking was also significant, with 64% in S3 and no cracking in S4.
- Based on yield, size and culls, S2 was the most productive (or less limited) site.
- Nutrient levels in leaves and soils were adequate for the most part. Leaf N, Ca, Mg, Mn, P and K were good indicators of growth and quality differences among sites.
- Fruit diameter was strongly correlated with leaf Ca and Mn, while BP incidence correlated strongly with P and cracking with B. The ideal timing for leaf tissue sampling were between June 28th and July 28th.
- Soil chemical, physical and biological indicators were significantly different among sites. In general, S3 had higher pH and more Ca, Mg, M.O and microbiological activity. While one of the most limited in terms of fruit quality.
- Soil K and P were excessive in the soil in S4, while adequate in leaves. This suggests uptake issues in the root zone, which could relate to the higher BP incidence in S4. BP incidence correlated negatively with soil pH and positively with P-Olsen. This relation does not imply cause effect, rather provided information regarding limiting conditions at a root level.
- There was a strong correlation between laboratories and soil testing methods.
- Aerial mapping tools provided equivalent maps for vigor distribution, evapotranspiration, and canopy density. While SoilOptix® provided with a more precise variability map for soil texture, Ca, Mg, CEC and B. However, SoilOptix® did not correlate well with the absolute values reported. Thus SoilOptix ® should be utilized for mapping relative differences, not for determining nutrient availability or management.
- E.C mapping correlated well electric conductivity of the soil, at one time. The use of E.C mapping should be timed properly, preferable, at the beginning of the season.
- None of the tools were good predictors of tree productivity, health, and fruit quality on their own. However, the integration of tools; mapping, soil test and tissue samples, provided insightful information related to differences in the block and possible causes.
- Here, soil profile analysis was key to understand the cause of high vigor and quality disorders.

METHODS

This project was conducted in two commercial apple orchards: Chiawana 'Gala' orchard and Grandview 'Honeycrisp' apple orchard. The Chiawana orchard was evaluated in 2020 (unfunded) and 2021, complete details on Chiawana methods and report can be reviewed in previous report (Sallato and Khot, 2022). The Grandview orchard was evaluated in 2021 – 2022. We selected four distinct sites, based on the historical vigor and productivity. Sites 1 and 3 (S1 and S3) were low vigor areas, while sites 2 and site 4 (S2 and S4) were high vigor.

Plant productivity and fruit quality

From each area, three consecutive trees were designated for whole tree monitoring. Two of these areas were also utilized for plant base monitoring systems (Kalcsits), and weather sensors (Mantle and Khot). From each tree, five representative shoots and fruiting spurs (n = 60) were measured for length and diameter during the growing season. At harvest, total fruit per tree were counted to assess yield differences and a sub sample of 40 fruit per tree was taken to the laboratory for fruit quality analysis, including defects, weight and size.

a. Characterize different soil testing methods/technologies and their relationship with plant response.

Soil profile analysis

In-situ soil profile analysis were evaluated March 29th, 2022. Soil pits were excavated with a backhoe in seven areas across the orchard, including sites 1 to 4. The same day, soil profiles were described following USDA NRCS soil taxonomy guide, which includes effective depth (or root depth), color, texture, porosity, structure, drainage, reactivity to HCl (effervescence) and presence of limiting factors. From each profile, two samples were collected at 8 and 12 inches deep for physical and chemical analyses.

Soil laboratory tests; physical, chemical, biological

For each site, three soil samples were collected throughout the growing season, totaling seven timings. On each sampling time, three to four soil cores were obtained from around the tree, combined and sub-divided into three homogeneous samples. Each sample was distributed to three different laboratories. Two laboratories L1 and L2 conducted soil standard analysis tests; soil pH (pH), organic matter (OM), electric conductivity (E.C), soluble solids (SS), cation exchange capacity (CEC), nitrate (NO_3), ammonium (NH_4), phosphorous (P-Olsen), extractable potassium (K), calcium (Ca), magnesium (Mg) and sodium (Na), and micronutrients copper (Cu), manganese (Mn), zinc (Zn), iron (Fe), and boron (B). In 2022, we included additional indicators associated to soil health, and validated by USDA NAPT program; Active carbon (POX-C), ACE protein, Soil Respiration, Potential mineralizable N (PMN, 7-day anaerobic nitrogen), total C and total N. The third sample was sent for resin test analysis (Predictive Nutrient Solution, Inc. in Walla Walla (PNS)) for soil pH, OM, E.C, SS, NO_3, NH_4, P, K, Ca, Mg, Na, Cu, Mn, Zn, Fe and B. All three laboratories are certified by the Soil Science Society of America and the North American Proficiency Testing Program's (NAPT) Plant Performance Assessment Program, Soil and Plant Program, and Soil Performance Assessment Program.

Leaf tissue analysis

Leaf tissue sample were collected to determine nutrient uptake from each replicated tree during the summer. In 2022, we added three additional dates to better understand and correlate nutrient levels over time. At each sampling time, we selected the most recently mature leaf from none bearing shoots.

b. Investigate tools to assess and map soil variability.

Soil variability and mapping were assessed through several methods (Table 1). For each method, we ground truth the information provided by the map, by selecting the values associated to the position of our pre-selected sites. The values obtained from each method were correlated to the corresponding ground truth value obtained in situ. For chemical analysis the correlations were conducted against soil standard analysis.

Table 1. Soil mapping methods and frequency evaluated at the smart orchard project.

Method	Detail*	Frequency
1. SO	SoilOptix® – gamma radiation mapping	2 / Spring - Fall
2. E.C	Electric Conductivity mapping Simplot	1 / 2021
3. SW	Web Soil Survey (NRCS, USDA)	1 / Historic
4. GE	Satellite (Google Earth Pro)	1 / Historic
5. UAS	Drone image: 5-band multispectral sensor	7 / Season

*Details of each technology were reported in details in our previous report.

c. Contribute to the "smart orchard initiative" in the area of soil nutrient sensing and management.
Results from soil and plant measurements were shared with Mantle et al. (Innov8ag) to incorporate into their platform and visualization scope of work, as well as to the AgAID project to contribute to their modeling, extension, and broadening participation scope of their project. Field days and outreach activities were coordinated among all smart orchard PIs and coordinated by Jenny Bolivar-Medina.

RESULTS AND DISCUSSION

For synthesis, this report will focus on 2022 results and referring to 2021 when appropriate.

a. Characterize different soil testing methods/technologies and their relationship with plant response.

In Grandview 2022, overall fruit size was 5% smaller than in 2021, while harvested approximately 10 days after. At the beginning of fruit development, S1 had the smallest fruitlet, however, as the season progressed, S2 was the largest and S3 ended with the smallest fruit (Figure 1). In contrast, S4 had the largest fruit in 2021. In 2022, shoot growth was maximum between June 28th and July 28th, being higher in S4, while in 2021, maximum shoot growth was observed between August 4th and August 28th, with no differences between sites (data not shown).

In 2022, total fruit count per tree varied tremendously, between 2 and 135 fruit per tree, being 4.4 and 2.2 times higher in S3 when compared with S4 and S1, respectively (Figure 1). Fruit size at harvest was 11% smaller in S3 (67 mm, 150 box size). Although there were statistical differences between the other sites (S1, S2 and S4), box size remained the same (113) (Figure 1). Bitter pit (BP) levels were highly variable in 2021, ranging from 74% and 1%, however with no differences between sites. In 2022, BP levels at harvest were significantly different among sites, being lowest in S3 (2%) and highest in S4 (52%), still with great variability across the orchard (Figure 2). In addition, cracks and splits accounted for 26% of overall fruit damage, being highest in S3 (64%), while not observed in S4 ($p = 0.004$) (Figure 2).

When estimating production per site, based on yield, size and culls, S1 and S3 were the least productive sites, with estimated 7 and 12 bins per acre, respectively and 7 packs per bin. Although in S3, fruit were smaller (below 150 box count). Site 4 had an estimated 12 bins per acre, with 10 packs per bin, and S2 was the most productive (or less limited) with 23 bins per acre and 17 packs per bin (based on 20 bu/bin and 42lb/bu).

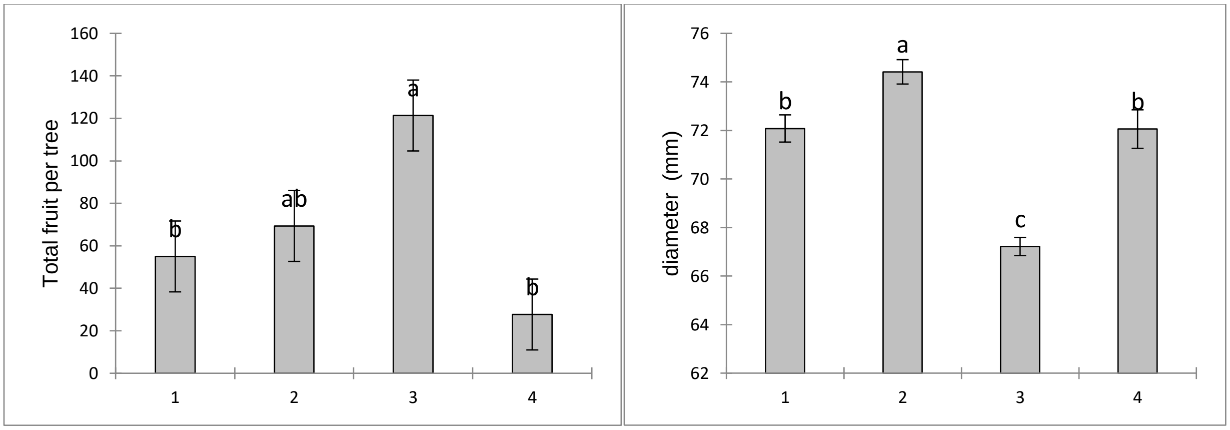


Figure 1. Number of fruits per tree (left) and fruit diameter at harvest (right) between sites in 2022 Grandview orchard. Different letters indicate significant differences between sites (Tukey test, $p < 0.07$)

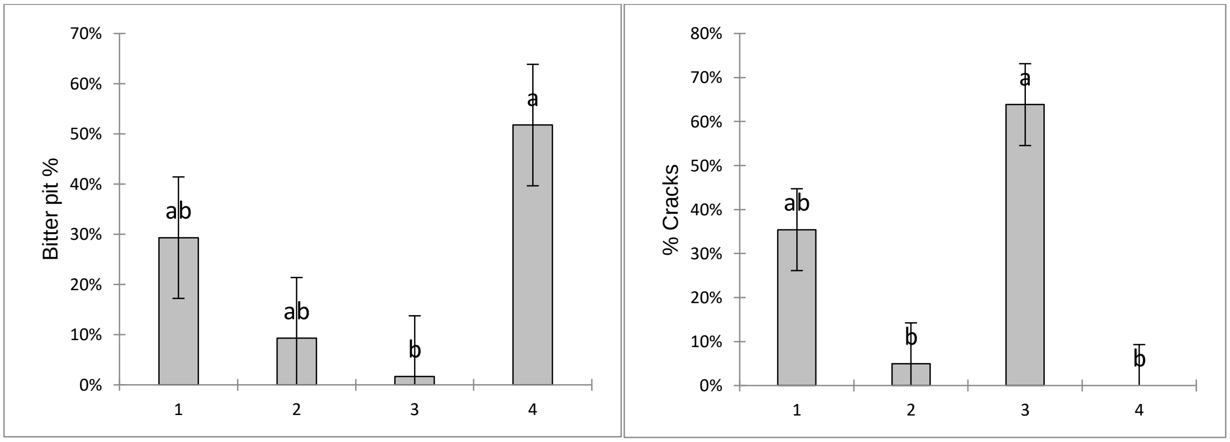


Figure 2. Percent bitter pit (left) and cracking (right) between sites in 2022 Grandview orchard. Different letters indicate significant differences between sites (Tukey test, $p < 0.07$)

Our results agreed with the warehouse pack-outs of Grandview orchard, were out of 93% of total bins processed, 45.5% was packable fruit with estimated 9.6 packs/bin average. Most relevant physiological related culls were undersized fruit, bitter pit and cracking.

Based on the information above, we utilized several tools and technology to identify A) what were the limiting conditions contributing to poor yield and quality, and B) which technologies/or combination of technologies provided us with better information to understand these conditions.

1. *In situ profile analysis*

Soil profile analysis demonstrated great diversity in soil types across the orchard, with distinct stratification (number and depth of soil layers), structure, effective depth, effervescence, porosity, root growth, drainage, among others. While we evaluated seven soil profiles throughout the orchard, in this report I will focus only on those developed at sites 1, 2, 3 and 4.

Site 1, located in the south-east side of the block was associated to Hezel loamy fine sand; with sand in the top 5 inches, followed by loamy fine sand up to 30 inches deep. Roots where scarce in the upper soil, concentrated in the transition between the second and third strata, below 30 inches (Figure 3). The sandy texture and lack of structure leading to excessive drainage and reduce water holding capacity.

Site 2 and 3 were associated to Warden silt loam series. Although S2 had a deeper effective soil depth of 24 inches of sandy loam, lightly alkaline, transitioning smoothly to a highly effervescent silt loam. In S2, roots were more abundant in the upper stratum. While Site 3, was shallower with roots concentrated in the first strata (7 to 10 inches), above a heavier soil (massive), evidencing deficient drainage. In S3 there were fewer roots and signs of anoxia. Also, S3 had a caliche layer at 40 inches. Site 4, was also very different, associated to the Starbuck silt loam soil, with a shallow effective depth of 16 inches over basalt rock. In S4 roots were abundant (Figure 3).

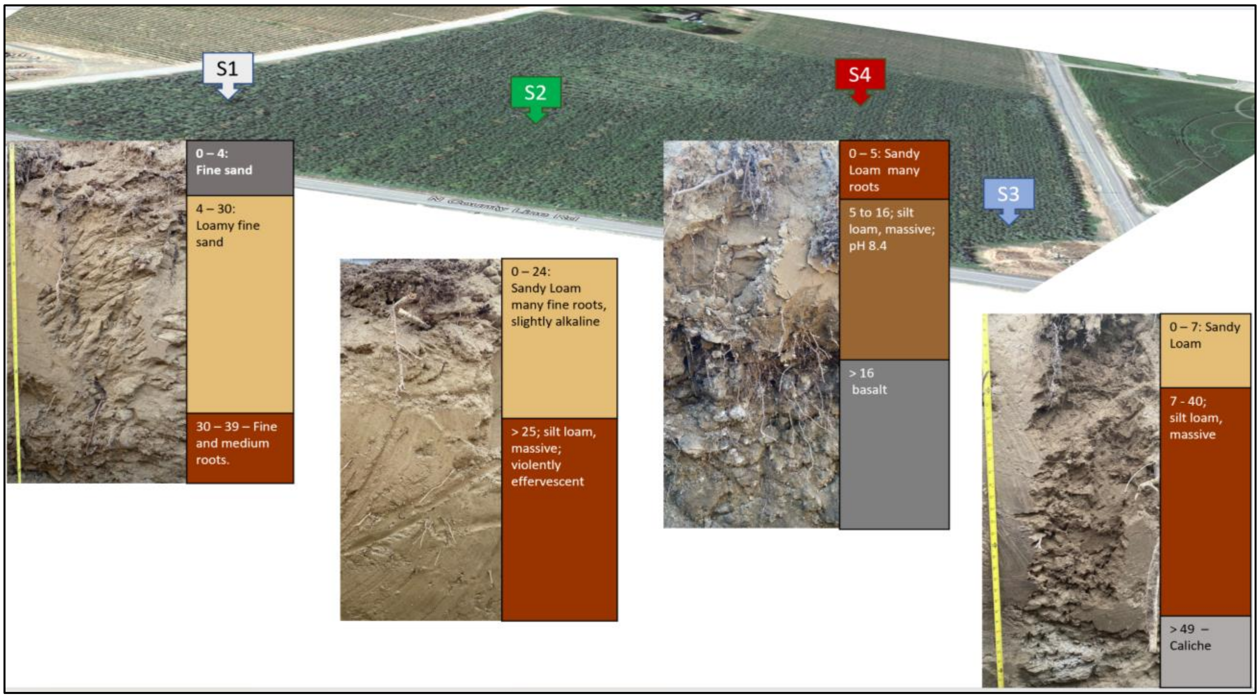


Figure 3. Soil profiles for S1, S2, S3 and S4 sites in Grandview orchard.

Soil profile analysis provided insightful information regarding limiting conditions of the block. Clearly, S1 suffers from excessive drainage, reduced water holding capacity and nutrient leaching. Thus, over time, roots have moved to deeper soil (> 30 inches) in search for moisture, while nonmobile nutrients (such as P) is limited. In contrast, S3 also associated to lower vigor, present opposite limiting conditions; where roots are concentrated in the upper stratum (first foot), due to lack of oxygen, excessive water, and high pH.

Sites S2 and S4, while both were associated to higher vigor, they had distinct fruit quality (S4 had greater BP incidence and reduced crop load). Likewise, S2 has greater root dept compared to S4, while less volume of soil, with higher nutrient accumulation (to be discussed later under soil chemical analysis).

2. *Leaf tissue analysis*

In 2021 and 2022, nutrient tissue concentrations were within adequate range for all nutrients except for Ca in S1, and Zn levels in all sites. Nutrient differences among sites were consistent throughout the season, however samples obtained during June 28th and August 10th, were better correlated with site conditions. Leaf N (2.07 – 2.65), Ca (1.11 – 2.13) and Mg (0.31 – 0.43) were higher in S3, correlating with smaller fruit size and increased fruit cracks. Mn was also higher in S3, which can be associated with excessive water, as Mn becomes more available under anaerobic conditions. In contrast, S2, had more P (0.16 – 0.22) and K (1.03 – 1.74), correlating with higher fruit size and reduced defects (data not shown).

S levels were also within range (0.16 – 0.21) and generally higher in S2 and S3 (heavier soils), but only during the first two sampling times. Micronutrients Zn where below adequate range (< 22 mg/kg) however with no differences between sites, while Fe, Mn, Cu and B were within adequate range and differences were inconsistent (data not shown).

Shoot growth was correlated but weakly with Ca (r = 0.52) and Mn (r = 0.54), while fruit diameter was strongly correlated with Ca (r=0.69) and Mn (r=0.61), but weakly (Figure 4).

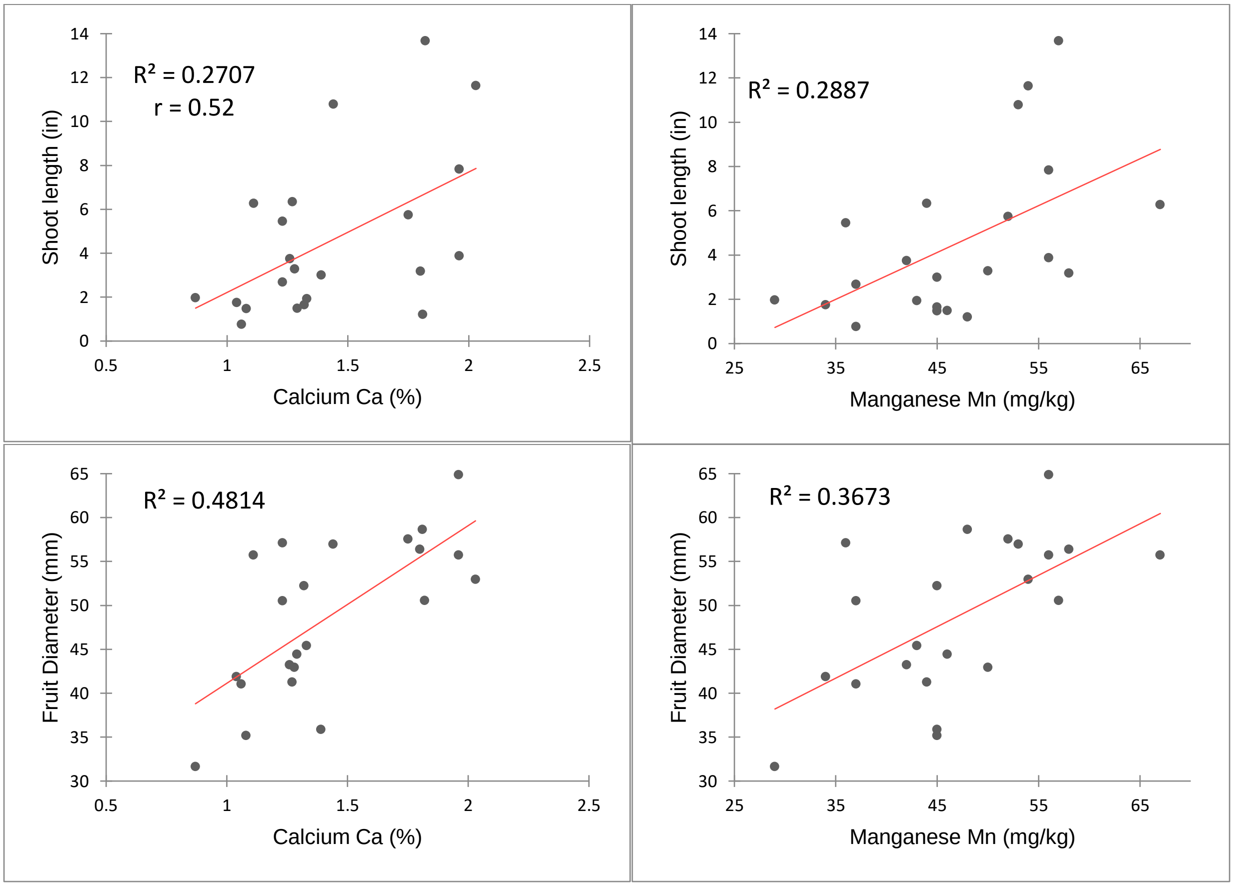


Figure 4. Correlation between shoot growth (top) and fruit diameter (bottom) with Ca (left) and Mn (right) in Grandview ‘Honeycrisp’ orchard. Where ‘R^2’ indicates coefficient of determination and ‘r’ indicates correlation.

Fruit BP incidence was negatively related with N (r = -0.4), P (r = -0.63), S (r = -0.40) and Mn (r = -0.47), thus only strong correlation with P leaf levels. When P levels were above 0.2%, BP incidence was less than 10%. While these relations do not imply cause - effect relationships, they provide insightful information regarding overall conditions where fruit quality was superior. Cracking incidence was weakly correlated with N (r = 0.48), while strongly correlated with B (r = -0.60). Trees with tissue levels above 46 mg/kg, had less than 11% cracking (Figure 5)

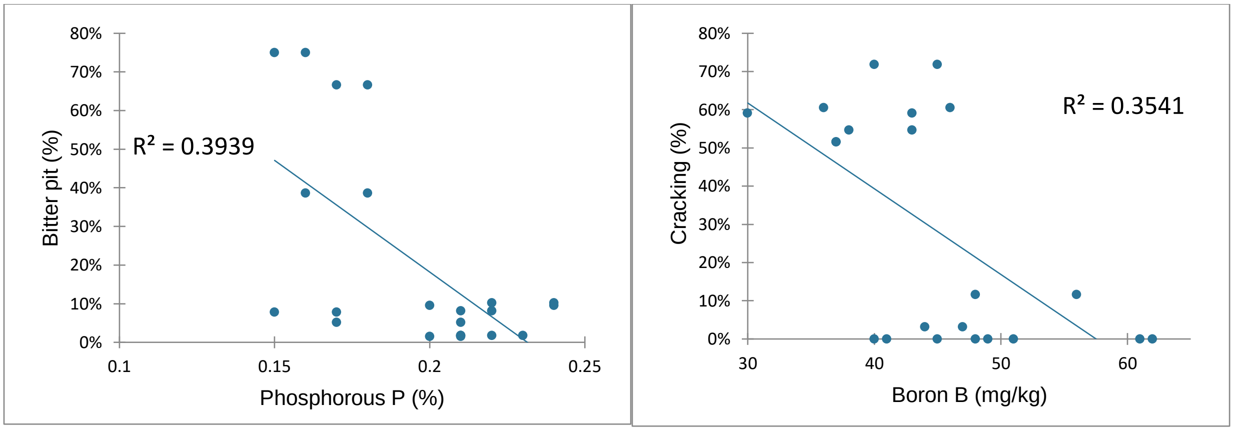


Figure 5. Correlation between bitter pit and leaf P concentration (left) and between cracking and leaf B concentration (right) in Grandview 'Honeycrisp' orchard. R^2 refers to the coefficient of determination, r refers to the correlation.

In agreement with the literature, the most consistent and predictive sampling times were June 28 and July 28th. The later sampling dates were consistent, but only for mobile elements N, P, K. Thus, leaf tissue analysis, collected once per year, from recently mature leaves between June and July, provided useful information to monitor nutrient uptake and deficiencies. However, leaf analyses alone will not inform about causes, nor management.

3. *Soil chemical analysis*

Soil chemical conditions were significantly different among sites, with close association to soil texture, effective depth, and presence of impermeable layers (rock or caliche). Soil pH fluctuated in about 1 point within each site throughout the season averaging 6.4 on S1, 6.7 on S2, 7.7 on S3 and 6.0 on S4. Being consistently higher in S3, with no differences between S1, S2 and S4. Higher pH in S3 is associated to $CaCO_3$ in depth. In agreement, soil available Ca was also significantly higher in S3 across all dates, a condition almost identical to 2021 (Figure 6). Higher available Ca was reflected in higher Ca in leaves (data not shown). Soil available Mg, was stable across the season, ranging from 1.4 and 3.7 meq/100g, being highest in S2 and S3 (data not shown).

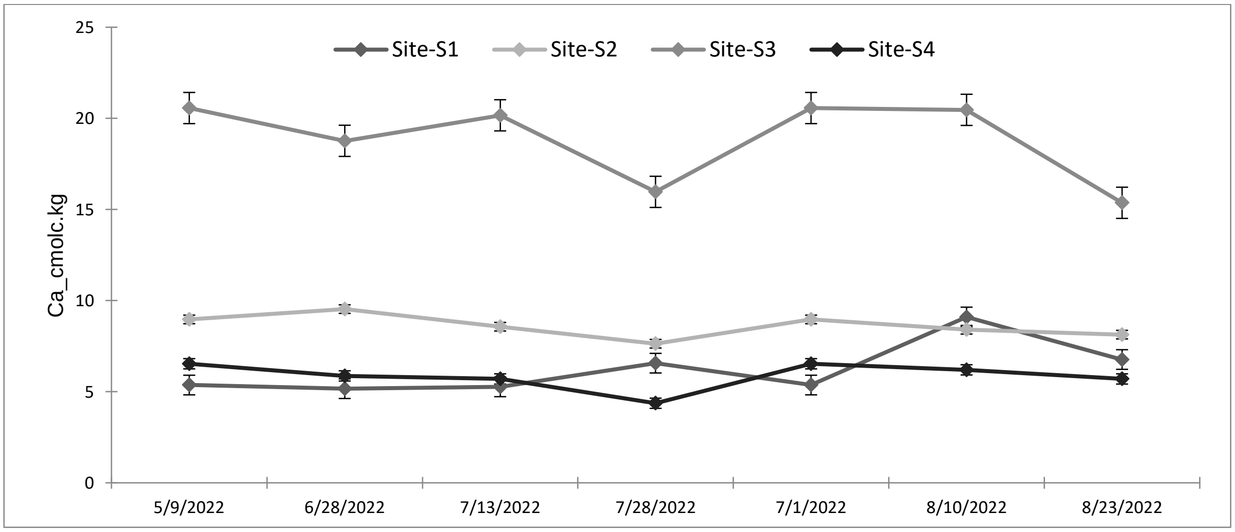


Figure 6. Soil available Ca throughout the growing season in Grandview orchard sites S1, S2, S3 and S4.

Mobile nutrients such as NH4 and NO3, were variable throughout the season, and positively correlated to with irrigation and temperature conditions, with no difference or inconsistent differences between sites (data not shown). Thus, inadequate indicators of N availability, fruit quality or vigor.

Soil K ranged between 222 and 702 mg/kg (Figure 7), considered above adequate range for 'Honeycrisp'. Here S4 had the highest levels for most of the season, followed by S2. However, leaf K was higher only in S2, which could suggest uptake limitations in S4. In both years, K values obtained at the beginning (May 9th) or at the end of the season (Aug 23rd) were better predictors of site conditions and fruit quality differences.

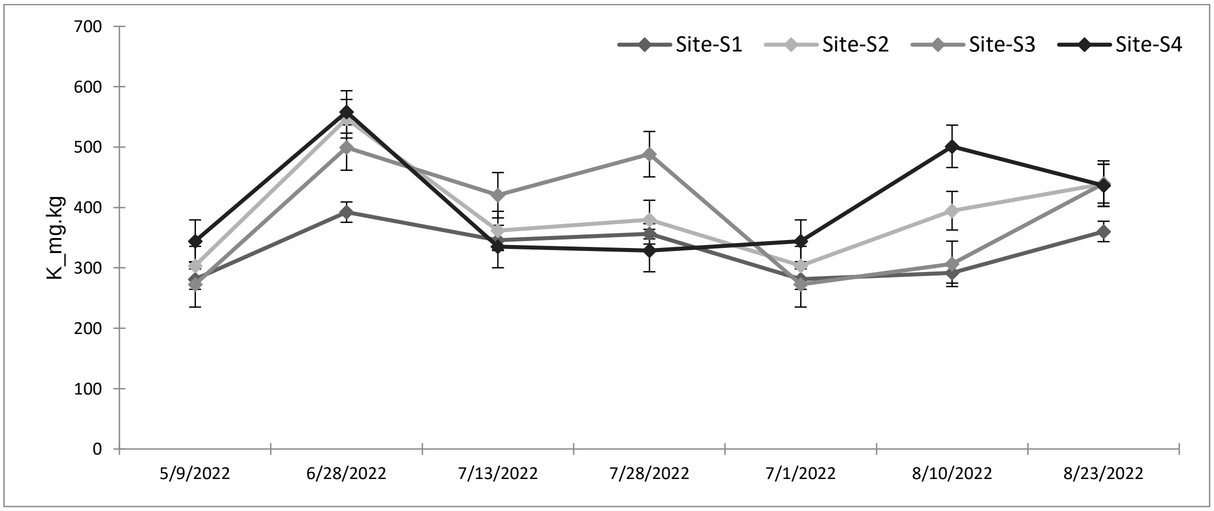


Figure 7. Soil available K throughout the growing season in Grandview orchard sites S1, S2, S3 and S4. Dots corresponding to mean values for site x date. Error bars correspond to standard error.

Similarly, soil available P (Olsen-P) was consistently higher in S4, with levels above recommended (> 40 mg/kg). Surprisingly, it varied throughout the season, however consistent within site (Figure 8). And despite being higher in S4, leaf uptake was higher in S2. Reinforcing possible limitations in uptake.

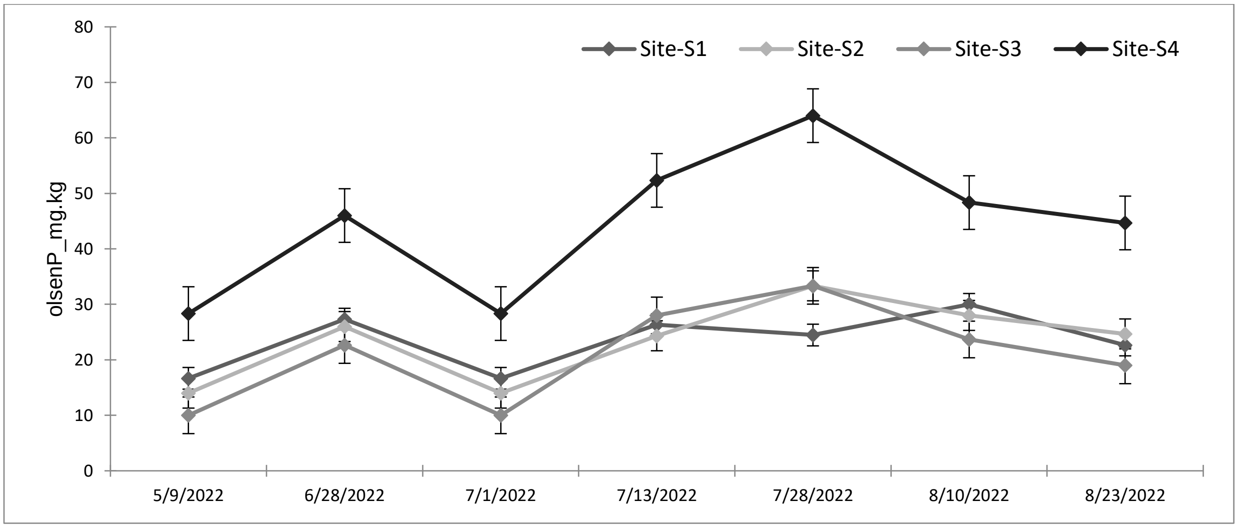


Figure 9. Soil Olsen-P throughout the growing season in Grandview orchard sites S1, S2, S3 and S4. Dots corresponding to mean values for site x date. Error bars correspond to standard error.

Soil Zn, Mn, Cu were adequate and equivalent in all sites for most of the season, while B was generally low (0.09 and 1.3 mg/kg) being higher in S3 and lowest in S1. Soil micronutrients did not correlate with leaf micronutrient uptake (data not shown).

Fruit diameter and weight had weak correlations ($-0.65 > r < 0.65$) with soil chemical condition. While BP there was a strong negative correlation between BP and soil pH (Figure 10) and Mg ($r = -0.73$), while strong positive relation with P-Olsen (Figure 10) and Fe ($r = 0.76$). However, these relations were observed in two or three dates throughout the season, being stronger on June 28th and July 28th.

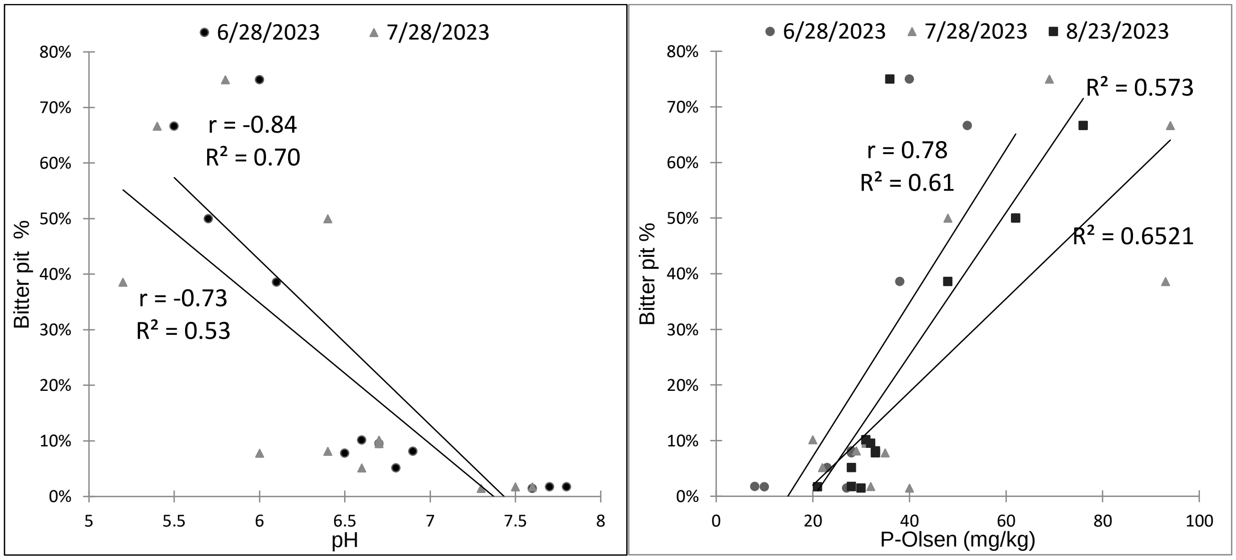


Figure 10. Significant ($p < 0.001$) and strong correlation between bitter pit incidence and (a) soil pH, and (b) available P (P-Olsen) observed on (●) June 28th, (▲) July 28th and (■) August 28th.

Similarly, cracking incidence also correlated significantly and strongly, however in opposite direction with pH ($r = 0.79$), P-Olsen ($r = -0.73$), Zn ($r = 0.77$) and Ca ($r = 0.77$). But again, not always, with stronger correlations observed when samples were collected on June 28th or end of the season (August 23rd) (data not shown).

4. *Soil Health indicators*

In 2022 we included additional soil health indicators that relate to biodiversity and habitat capacity of the soil. Soil respiration increased 40% throughout the season, being higher in S3 for most of the season (Figure 11). Interestingly, anaerobic nitrogen was also significantly higher in S3 throughout the growing season (data not shown).

Total N, C, O.M, were strongly correlated throughout the season, and differences between sites were observed only in July and August, where S3 had higher levels compared the other sites. Oddly, ACE protein, another indicator of microbiological activity, was lowest in S3. POX-C and mineralizable C were contradictory and inconsistent throughout the season (data not shown).

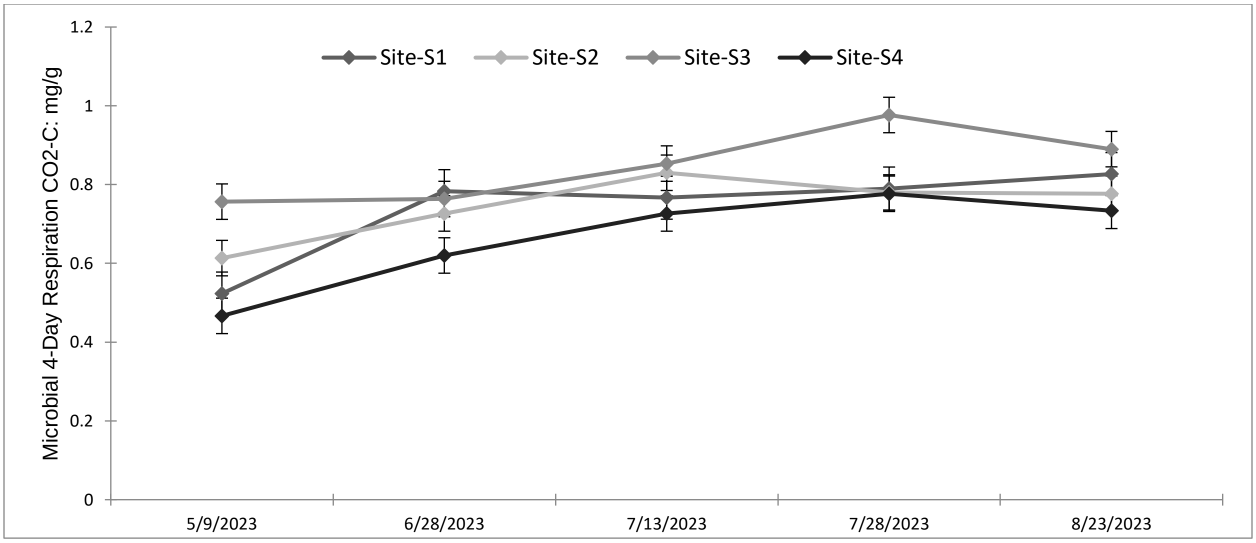


Figure 11. Soil microbial 4-day respiration (CO2-C:mg/g) in S1, S2, S3 and S4, Grandview orchard. Dots corresponding to mean values for site x date. Error bars correspond to standard error.

5. *Correlations between methods and laboratories*

When comparing the two laboratories that conducted the standard test, values were strongly correlated (r > 0.70) for most elements; pH, M.O, NO3, P-Olsen, K, Ca, Mg, Zn, Cu, S, B and POX-C, except for NH4, Na and Mn. (Figure 12). Likewise, the standard test was strongly correlation with the resin test (PNS) (r > 0.56) for NO_3, NH_4, K, Ca, Mg, S, Zn, Fe and Cu under loamy soils, while in sandy soils only NO_3, Ca and K, were correlated (Figure 13).

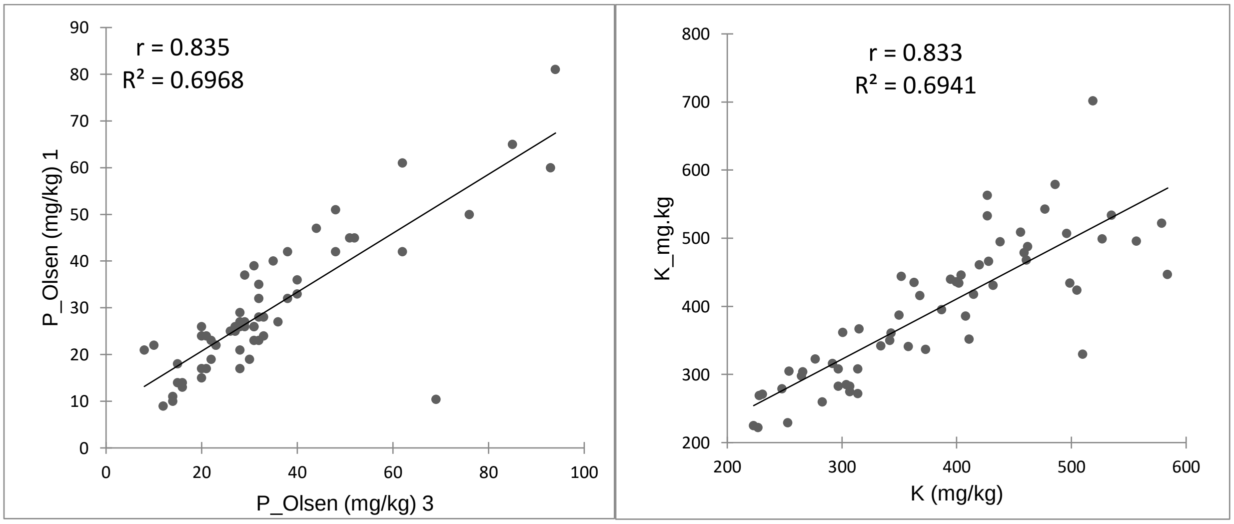


Figure 12. Correlation between laboratories for a) P_Olsen and b) extractable K.

The strong correlation between laboratories utilizing same methodology suggests confidence and accuracy, and values should be comparable. While, although strongly correlated, the resin test uses a different method, thus absolute values are not comparable.

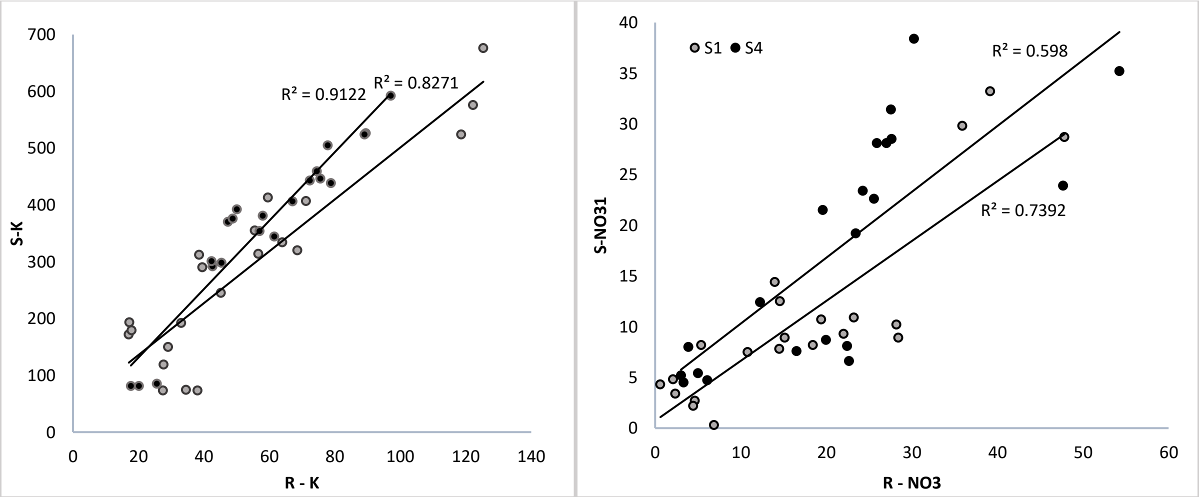


Figure 13. Correlation between a) standard K and resin K and b) standard NO3 and resin NO3, in sandy soil (S1) grey circle and in silt loam soil (S4) black circle.

2. Investigate tools to assess and map soil variability.

SoilOptix® provided 27 variability maps of special information: altitude, physical parameters: Sand, Silt, Clay (Texture), PA water, and chemical parameters; O.M, CEC, pH, NO3, P, K, Ca, Mg, Mn, Fe, Cu, B and salts. When correlating with ground truth values obtained closest to the mapping date, there were positive but weak correlations with pH (r = 0.52), K (r = 0.50) and NO_3 (r = 0.52), and positive strong correlations with O.M. (r = 0.81), Ca (r = 0.95), Mg (r = 0.88) and B (r = 0.85). However, when correlating across for different timings, only Ca (r = 0.95), Mg (r = 0.74), B (r = 0.93) and CEC (r = 0.65) remained significant and strong. The rest of the elements had no correlation or weak with SoilOptix® mapping. In addition, SoilOptix® provided a useful tool to map relative differences, however absolute values were different, thus should not be used for fertilizer recommendations.

The E.C mapping provided three levels of E.C across the orchard (Figure 14), where red is lowest (23.5 – 28.2), yellow intermediate (28.2 – 30.2) and green high (30.2 – 34.8). Here, S1 and S4 were rated low and S2 and S3 were rated intermediate. This relative difference was observed during June 13th, but not the rest of the season. Given that EC is variable and will change in response to irrigation events, the EC should be interpreted accordingly.

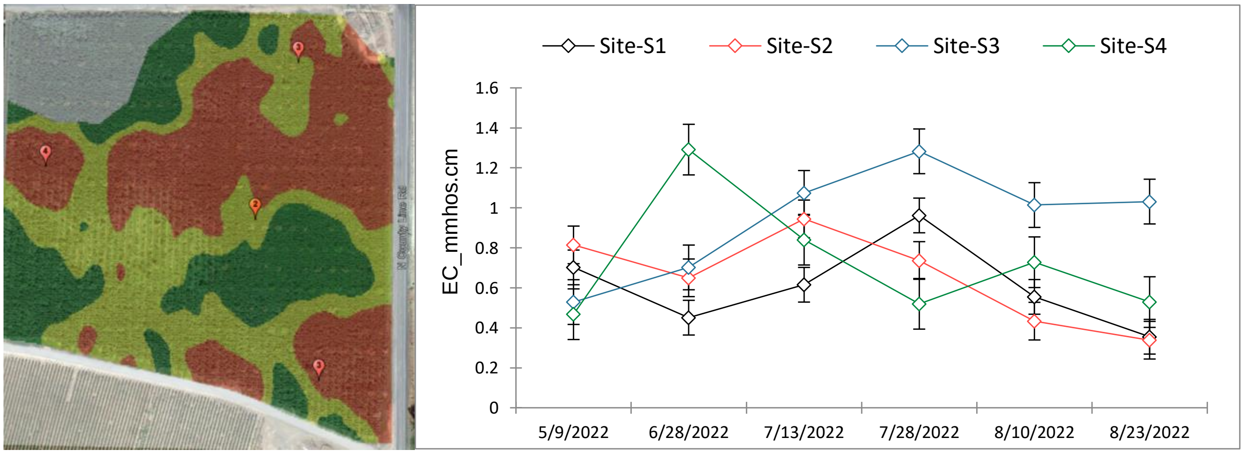
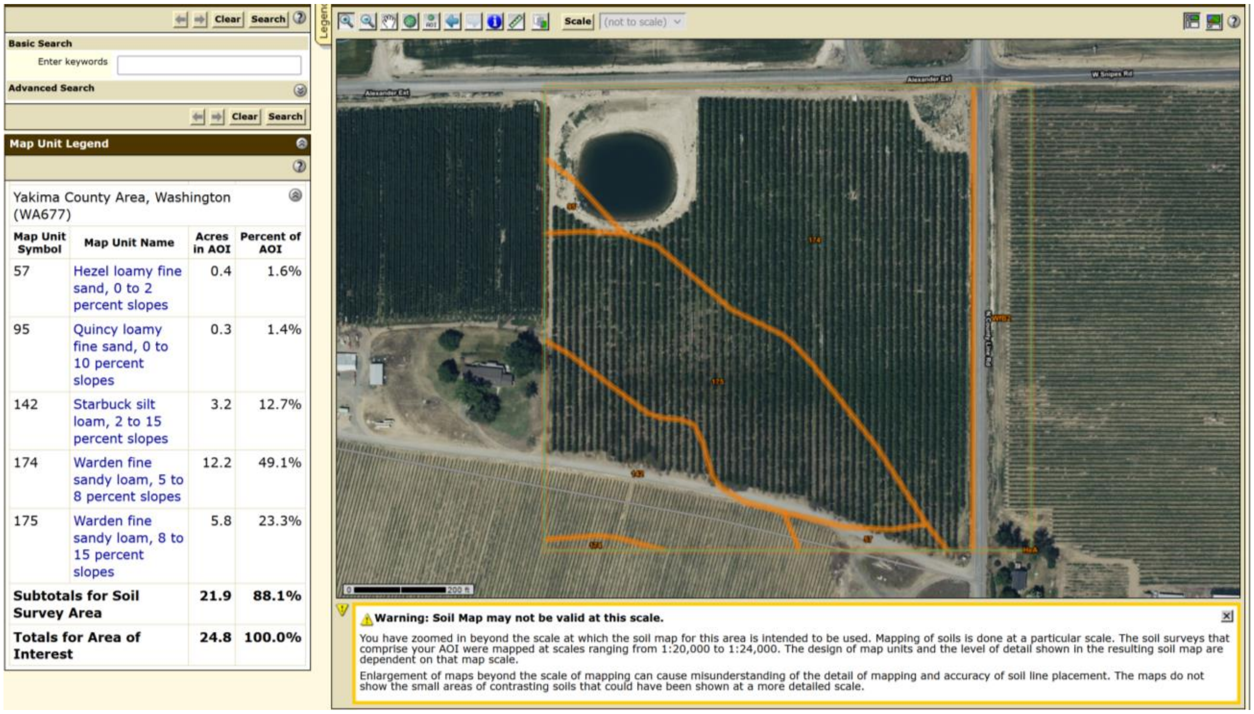


Figure 14. Soil E.C map (left) and E.C readings throughout the season in S1, S2, S3 and S4.

The Soil survey service (SW), provided the greatest amount of information, including elevation, parental materials, ecological, physical, chemical, and biological indicators, water content and availability at field capacity and wilting point, among others. The survey divided the block in five zones; Hezel (1.6%), Quincy (1.4%), Starbuck (12.7%) and Warden (72.4%) (Figure 18). These series were present when evaluating the soil profile, however the area allocated to each unit were inaccurate. Depending on the location, the scale of the information and mapping vary between 1:20,000 to 1:24,000, thus macro scale that needs in situ verification.



Yakima County Area, Washington (WA677)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
57	Hezel loamy fine sand, 0 to 2 percent slopes	0.4	1.6%
95	Quincy loamy fine sand, 0 to 10 percent slopes	0.3	1.4%
142	Starbuck silt loam, 2 to 15 percent slopes	3.2	12.7%
174	Warden fine sandy loam, 5 to 8 percent slopes	12.2	49.1%
175	Warden fine sandy loam, 8 to 15 percent slopes	5.8	23.3%
Subtotals for Soil Survey Area		**21.9**	**88.1%**
Totals for Area of Interest		**24.8**	**100.0%**

Warning: Soil Map may not be valid at this scale.

You have zoomed in beyond the scale at which the soil map for this area is intended to be used. Mapping of soils is done at a particular scale. The soil surveys that comprise your AOI were mapped at scales ranging from 1:20,000 to 1:24,000. The design of map units and the level of detail shown in the resulting soil map are dependent on that map scale.

Enlargement of maps beyond the scale of mapping can cause misunderstanding of the detail of mapping and accuracy of soil line placement. The maps do not show the small areas of contrasting soils that could have been shown at a more detailed scale.

Figure 15. Web soil survey mapping system (USDA) for Grandview site.

Other aerial mapping strategies provided single layers of information associated to tree vigor: water use, evapotranspiration, canopy density, etc. with similar area aggrupation (variability). While all mapping were predictive of vigor differences, no mapping tool could predict fruit size, diameter, or bitter pit incidence, not the rate needed for nutrient application. More detailed comparison between mapping tools were reported in our previous report and it will be summarized in upcoming newsletter article.

3. Contribute to the "smart orchard initiative" in the area of soil nutrient sensing and management.

In 2021 and 2022 we participated in four field days, two in English and two in Spanish. We had over 170 participants, where surveyed individuals indicated they valued the information (95%), and 50% indicated knowledge gain.

EXECUTIVE SUMMARY

Title: Reliable Soil Diagnostic Technology for Smart Nutrient Management

Key words: Soil mapping, soil health, bitter pit.

Abstract:

A smart orchard project was implemented in Chiawana Orchards in 2020 in collaboration with several industry and university partners. This collaboration initiated a system that enabled the assessment and ground truthing of conventional and new technologies. Under the umbrella of the smart orchard initiative, this project focused on technology for soil chemical management for reliable diagnosis.

Soil physical and chemical testing has been used for more than a century to guide nutrient management practices. Today, new technology could provide opportunities for precision and remote management. Our goal is to develop "smart nutrient management" strategies based on quantifiable needs. For these, our specific objectives were to: a. *Characterize different soil testing methods/technologies and their relationship with plant response, b. Investigate tools to assess and map soil variability and c. Contribute to the "smart orchard initiative" in the area of soil nutrient sensing and management.*

This project was conducted in two commercial apple orchards: Chiawana 'Gala' orchard and Grandview 'Honeycrisp' apple orchard. Within each orchard we selected four distinct sites, based on the historical vigor and productivity, two sites were low vigor, and two high vigor. In 2022, Grandview 'Honeycrisp' fruit load was 4.4 and 2.2 times higher in S3 compared to S4 and S1. Bitter pit incidence was lowest in S3 (2%) and highest in S4 (52%). Cracking was also significant in 2022, with 64% in S3 and no cracking in S4. Based on yield, size and culls, S2 was the most productive site, while S3 the least. Leaf N, Ca, Mg, Mn, P and K were good indicators of growth and quality differences among sites. Fruit diameter was strongly correlated with leaf Ca and Mn. BP incidence correlated strongly with P and cracking with B. Soil chemical, physical and biological indicators were significantly different among sites. In general, S3 had higher pH, Ca, Mg, M.O and microbiological activity, while it was also one of the most limited in terms of fruit quality. Soil K and P were excessive in the soil in S4, while adequate in leaves, which suggests uptake issues in the root zone, that could explain BP incidence in S4. BP incidence correlated negatively with soil pH and positively with P-Olsen, however this relation does not imply cause effect, rather provided information regarding limiting conditions at a root level.

When comparing different tools, there was a strong correlation between laboratories and soil testing methods. Aerial mapping tools provided equivalent maps for vigor distribution, evapotranspiration, and canopy density. While SoilOptix® provided with a more precise variability map for soil texture, Ca, Mg, CEC and B. However, SoilOptix® did not correlate well with the absolute values reported. Thus SoilOptix ® should be utilized for mapping relative differences, not for determining nutrient availability or management. E.C mapping correlated well electric conductivity of the soil, at one time, thus should be timed properly, preferable, at the beginning of the season.

None of the tools were good predictors of tree productivity, health, and fruit quality on their own. However, the integration of tools; mapping, soil test and tissue samples, provided insightful information related to differences in the block and possible causes. Here, soil profile analysis was key to understand the cause of high vigor and quality disorders.