FINAL PROJECT REPORT

Project Title: WTFRC Test Orchard (evolving to Smart Orchards Year 2 + Connectivity)

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Cooperators: Columbia Reach/Chiawana Orchards – Shawn Tweedy (area), Martin Ramirez (site), Amy Mattingly (data); WSU – Lav Khot (imaging, data interpretation), Dave Brown (micro climate), Bernardita Sallato (root nutrient uptake); Microsoft – Puneet Singh (Farmbeats data platform), . Sensor providers – Davis Instruments (weather), Tuctronics/AgriNET (weather, soil moisture, water pressure, PAR), AquaSpy (soil moisture, air temp/RH), MeterGroup (weather station API access), Teralytic (soil nutrients), Green Atlas (canopy mapping post-harvest), SmartGuided Systems, Phytech (dendrometer, Predictive Nutrient Solutions (soil lab testing). OSU unable to participate (sap flow) due to COVID.

Percentage time per crop: Apple: 100% Pear: Cherry: Stone Fruit:

Total Project Funding: $15,000 + $10,000 expenses

Budget History:

Item	**Year 1:**
Salaries	
Benefits	
Wages	
Benefits	
Equipment	
Supplies	
Travel	
Plot Fees	
Miscellaneous – “Ag Data as a Service” **“WSU imaging analysis services”**	$15,000 $7,846
Total	$22,846

Notes: $15,000 “ag data as a service” fully invoiced; $7,846 for “WSU imaging analysis services” to be fully invoiced by innov8.ag thru 5/30/21, to align with 1-year timeline from initial out-of-band grant funding by WTFRC.

Original Objectives:
The problem we are looking to address: set up an automated system that collects, and synthesizes data from an orchard to track performance over time, with the ultimate goal of providing decisions and insights for more consistent management decisions to enable optimization of fruit quality.

1.Sensorize an orchard block with an array of sensors, with goal to:

- Bring together disparate data silos from multiple vendors
- Shift grower decision making process to enable management decisions based on unified data, and 'smart management' where possible
- Compare pack-out (quality & quantity) vs a neighboring 'control block' (same soil, topography, variety, root stock)

The orchard blocks are owned by Columbia Reach's Chiawana Orchards location at 1741 Auburn Road, Pasco WA 99301. Block 662 (19.2 acres, test) will be compared against neighboring block 661 (20 acres, control).

2.Collaborate with WSU and sensor providers to

- Create opportunities for larger collaboration in the future.
- Learn capabilities of modern orchard decision making with basic AI and Data Analytics.
- Provide a learning orchard for scientists and industry to visit.

Significant Findings:

1. **Grower, equipment/sensor provider, & researcher engagement around a smart orchard showcase is extremely positive.**
    a. Growers were surveyed by WSU in the Spring, and overwhelmingly expressed positive or extremely positive interest in learning from and applying smart orchard learnings to their operation – with a particular interest in irrigation optimization. Due to COVID restrictions, we were unable to offer formal "field days" for growers, but instead had informal tours every 2-4 weeks through the growing season, all of which were attended by growers & ecosystem participants (eg GS Long).
    b. Participating sensor providers & researchers were highly engaged & supportive throughout the season – with donations of sensors, loaning of equipment, & investment of personnel onsite and remotely for training, research, & troubleshooting. Additionally, WSU researchers requested collaboration on two proposals to USDA & NSF and three proposals to WTFRC building upon smart orchard learnings from 2020. Finally, WSU requested a "digital transformation in ag" presentation at the 2020 Digital Ag Summit (attended by hundreds of researchers around the world), where smart orchard learnings informed a call to action for academia, industry, government, & all supporting stakeholders.
    c. Consolidated access to data enabled new collaboration & innovation opportunities, including hackathons (two with Microsoft, one with WSU) that highlighted new data-enabled approaches & insights.
2. **Data ingestion, normalization, & rationalization from many different sensor, equipment, & management data sources requires significant investment of time & resources for ag data solution providers.**
    a. Innov8 Ag partnered with several different providers to ingest data from APIs, CSV downloads, and Excel spreadsheets. While we generally selected providers that have

invested in streamlining data sharing, it's clear that there are categories of "data sharing lifecycle maturity"

i. Highly mature – published their own APIs for years, can also flow their data into API-centric datahubs (such as Microsoft Farmbeats), and have substantial documentation for both scenarios. Example – Davis Instruments
ii. Mature – published their own APIs for years, and have some published documentation. Example - AquaSpy
iii. Emerging – CSVs can be downloaded from website. Example - Phytech
iv. Early – can email CSVs or require manual download from originating sensors or databases. Example – Teralytic, SmartGuided Systems

b. Inconsistent formatting of times, dates, and units of measurement requires substantial investment in time for "data transformation" and normalization.
   i. For sensors & equipment data, this was anticipated.
   ii. For management data – specifically labor & chemical, this is more challenging as getting to the source of the data can be challenging (eg timesheet data may be summarized weekly and available/extracted from Famous vs. the timesheet source) and the summary lacks the frequency or consistency in units of measure to be of use for relation to sensor & equipment data.
c. Management data relatability requires substantial investigation to understand accuracy & context (underscoring criticality of machine-based data such as from a smart sprayer or smartphone-sourced labor tracking)
   i. Data may not actually be what it appears. Example – irrigation labor data is mapped to an orchard block, but when irrigator interviewed it's clear much of the time the time allocation is erroneous. Or sprayer application data is mapped to a block, but when sprayer lead interviewed - realistically it's averaged out across several blocks.

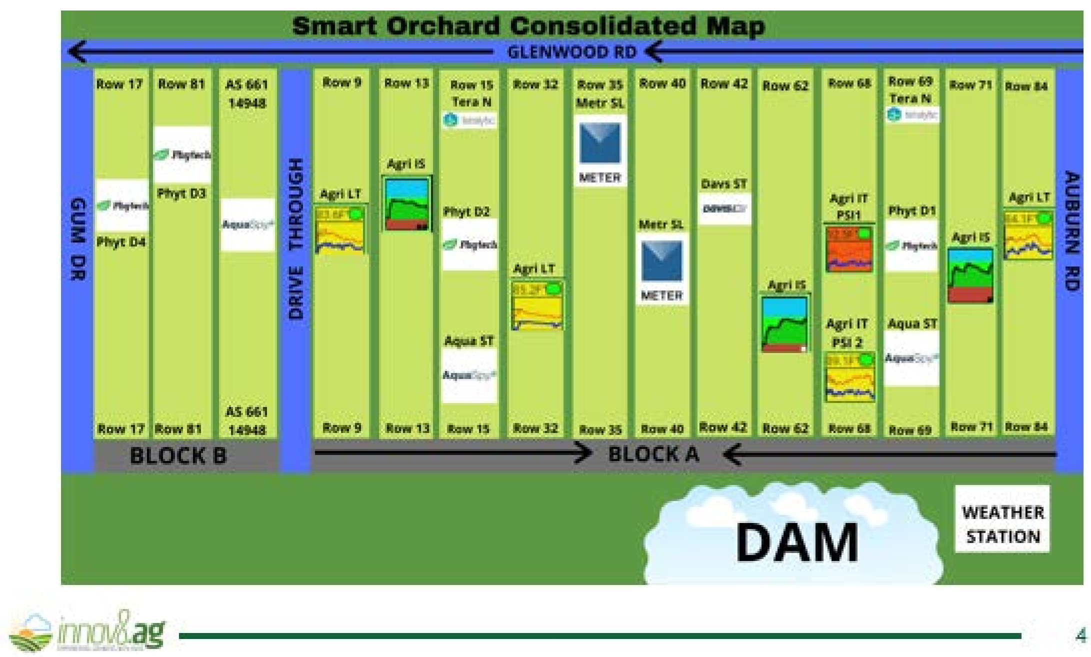
3. **Sensor, equipment, & imagery provider openness to data sharing of "raw data" is viable for most; unacceptable to some.**
   a. We've found that most providers were highly collaborative on sharing their raw data, particularly given the enablement to collectively learn as to how to provide more value to growers.
   b. There is a minority of providers that are resistant (or refuse) to share raw data out of concern that new data products will be produced resulting in emergence of competitive capabilities by other sensor/equipment/datahub providers.
   c. Point b unfortunately perpetuates the data silo challenge facing growers (including "who owns the data", particularly if the grower discontinues the service and/or the provider ceases operations), but at the same time – may bring value to the grower by providing a "one stop shop" for data insights. Industry examples reluctant to share raw data are Phytech & Semios; example of a provider that ceased operation in 2020 is Terravion, relegating access to "grower-owned" imagery to navigating bankruptcy court.
4. **Tracking of grower management data is dramatically more viable when a grower-employed data analyst is assigned; tracking – and influencing - grower management decisioning is more challenging.**
   a. At the outset of this project, the grower employed and assigned a data analyst to work with the project team. The analyst provided substantial value to the team, as they consolidated, rationalized, and interpreted data tied to management. This included labor & chemical records, water & electricity meter data, as well as context on "data holes" or system changes that impacted data quality.

   b. Tracking cause and effect requires prioritization of which decisions to track, then a systematic approach to consistently capturing those decisions, and mapping to anticipated outcome.

5. **Expecting tracking of pack-out and comparing against other blocks is unrealistic if expecting to show value from data-driven decisioning.**
   a. Pack-out data isn't always tracked at the block level. When it is, the data typically won't be available until 3-6 months post-harvest, as the relevant apples are counted when shifting from storage to packing production.
   b. Tracking/predicting yield at and within the block level is an approach that complements the latent packout data. Upon realizing this, innov8.ag invested in tree imaging/apple counting research with Microsoft & WSU, then subsequently obtained ATV-based imaging capability for crop density & tree height/area to pull into the 2021 smart orchards project proposal. This capability wasn't originally expected or scoped for 2020, but it's clear that this dataset will be fundamental to enabling data-driven insights *throughout the season* in future projects.

Results & Discussion:

Sensors were deployed across the 20-acre block #662 as indicated in the physical layout view depicted in Figure 1:



The sensor specifics deployed were as follows (table 1):

Category	Purpose/ location	Instrument	Manufacturer	Specifications*
Weather	Open-field & In-orchard	ATMOS 41	Meter Group	12 weather parameters
	Above canopy, in-canopy at 3' and 6' AGL	Vantage Pro2 6820	Davis instruments	5 weather parameters, A: 2%

	In-canopy at 3' AGL	ANTHA	Tuctronics	Temperature, humidity and leaf wetness
Soil, Water	Soil moisture at 2' depth	Drill & Drop	Sentek	Measurements every 4"
	Soil moisture, nutrients and temperature at 4'	AquaSpy probe	AquaSpy	Measurements every 4"
	Soil water potential	Teros 21	Meter Group	R: 0.1 kPa, A: 90%
	Soil quality at 6", 18", and 36" depths	Soil probe	Teralytic	NPK, moisture, salinity, aeration, respiration, temp., light & RH
	Irrigation monitoring	PS-1 irrigation pressure switch	Meter Group	Set point: 5 psi (± 1)
	Tree trunk and fruit size	Dendrometer	Phytech	Shrink-swell in µm
	Leaf wetness	LWS	Campbell Scientific	Measurement time: 10 ms, Output: 250–1500 mV
	Canopy health (NDVI, PRI)	Spectral Reflectance Sensor	Meter Group	A: > 90%; Green-1: 532 nm, Green-2: 570 nm, Red: 650 nm; NIR: 810 nm
	Canopy health (NDRE)	Custom development	WSU	Bands: NIR and RE
	Canopy vigor	2D LiDAR	Smart Guided Systems LLC	AR: 0.25º, Scan frequency: 25 Hz
	RGB imaging	RGB imager w/ DJI Phantom 4 (in WSU inventory)		PR: 12.4 Mega Pixels, SR: 5 cm @ 100 m altitude
	Multispectral imaging for canopy vigor/health	10-band dual camera imaging system	Micasense Inc.	SR: 7 cm @ 100 m altitude Bands: Coastal blue (444 nm), blue (475 nm), green-1 (531 nm), green-2 (560 nm), red-1 (650 nm), red (668), red edge-1 (705), red edge-2 (717 nm), red edge-3 (740 nm) & NIR (842 nm)

	Thermal imaging for canopy temperature and health	FLIR Duo Pro R w/ AgBOT quadcopter (in WSU inventory)	A: 95%, lens size: 13 mm, Spectrum: 7500–13500 nm, SR: 13 cm @ 100 m altitude

The ingested sensor data is available via

- web browser (figure 2), iOS and Android app for grower personas
- ODBC consolidated raw data access (figures 3a & b) for data analyst & researcher personas
- and PowerBI via web browser, iOS and Android app (figure 4) for management personas [focused around a irrigation planning use case, aligned to results from WSU survey seeking grower interest in the smart orchard pilot]

Fig 2 – web browser view of sensor data:

For the ODBC view (raw access to consolidated data, there are 11 tables for this dataset under the schema `ColumbiaReach` (left in Figure 3a) organized by provider and sensor type (right in Figure 2). All the sensor metadata, for example installed location (`latitude, longitude, elevation`), provider (`provider_id`), type (weather or soil), whether installed inside canopy or outside (`inside_canopy`), and in which table telemetry is stored (`table_name`) are included in table `ColumbiaReach.sensors.` These sensors are referenced in all telemetry tables by their unique `sensor_id`.

For example, the Tuctronics telemetry and sensor meta info will look like Figure 3b. Tuctronics provided five ANTHA sensors installed to monitor weather and three Sentek Drill & Drop probes to monitor soil. Figure 3 shows one weather sensor with id 104 and one soil sensor with id 125. Note that for the 5 ANTHA weather sensors, they all have measurements for air temperature and humidity, but only three of them have measurements for leaf wetness and two of them have measurements on irrigation PSI/temperature. For variables that do not have measurements from a given sensor, the corresponding columns will be filled with NULL. These sparse columns exist in almost all the weather tables in our database.

Figures 3 – ODBC consolidated raw access view, as supplied to smart orchard stakeholders & participants, Microsoft hackathon participants, and WSU hackathon participants:

Fig 3a. Tables included in the consolidated database (left) and their structure relationship (right)

Dimensions	ColumbiaReach.providers
	ColumbiaReach.sensors
Tuctronics (AgriNet)	ColumbiaReach.tuctronics_weather
	ColumbiaReach.tuctronics_soil
Davis Instruments	ColumbiaReach.davis_weather
Meter Group	ColumbiaReach.meter_weather
	ColumbiaReach.meter_soil
AquaSpy	ColumbiaReach.aqua_weather
	ColumbiaReach.aqua_soil_history
Teralytic	ColumbiaReach.teralytic_weather
	ColumbiaReach.teralytic_soil

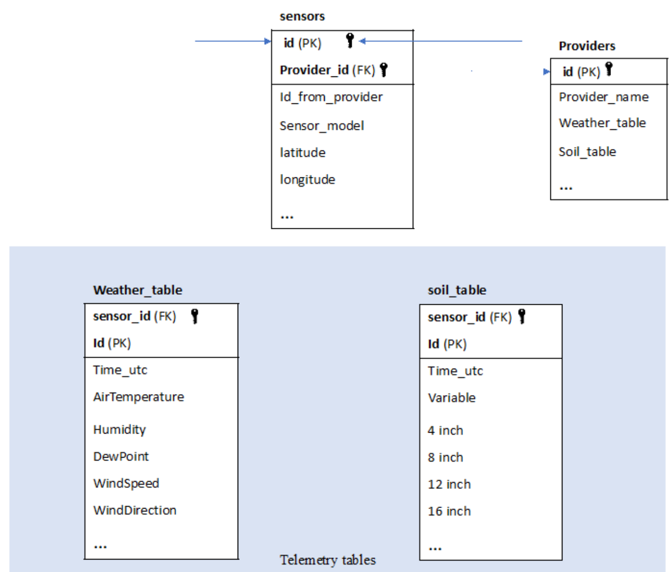


Fig 3b. Tuctronics tables

ColumbiaReach.providers

id	provider_name	weather_table	soil_table
1	Tuctronics	tuctronics_weather	tuctronics_soil

ColumbiaReach.sensors

id	sensor_model	id_from_provider	provider_id	latitude	longitude	elevation	type	inside_canopy	variables	table_name
104	ANTHA	ANM05033	1	46.47542	-119.222	NULL	weather	yes	Temperature (F), Humidity (%), LeafWetness	tuctronics_weather
125	Sentek-Drill&Drop	ANM01207	1	46.47458	-119.219	NULL	soil	NULL	Soil temperature (°C) and soil moisture (%)	tuctronics_soil

ColumbiaReach.tuctronics_weather

Time_utc	sensor_id	Temperature	Humidity	...	IrrigationPSI
2020-05-02 09:37:00.000	104	55.77	86.56	...	NULL
2020-05-02 09:52:00.000	104	52.34	91.04	...	NULL
2020-05-02 10:07:00.000	104	52.50	91.00	...	NULL
2020-05-02 10:22:00.000	104	52.66	90.85	...	NULL
2020-05-02 10:37:00.000	104	52.80	90.71	...	NULL
2020-05-02 10:52:00.000	104	52.91	90.50	...	NULL
2020-05-02 11:07:00.000	104	52.88	90.51	...	NULL
...	...	...	...	...	...

ColumbiaReach.tuctronics_soil

time_utc	sensor_id	variable	4inch	8inch	12inch	...	switch
5/2/20 23:07	125	moisture	36.318	36.146	36.308	...	NULL
5/2/20 23:27	125	moisture	36.264	36.097	36.276	...	NULL
5/2/20 23:47	125	moisture	36.264	36.127	36.276	...	NULL
5/3/20 0:08	125	moisture	36.2	36.121	36.259	...	NULL
7/15/20 1:59	125	temperature	22.317	20.05	19.46	...	0
7/15/20 2:40	125	temperature	22.064	20.07	19.48	...	NULL
7/15/20 3:00	125	temperature	21.906	20.03	19.53	...	0
...	...	...	...	...	...	...	...

1. Notes on Measurement Interpretation

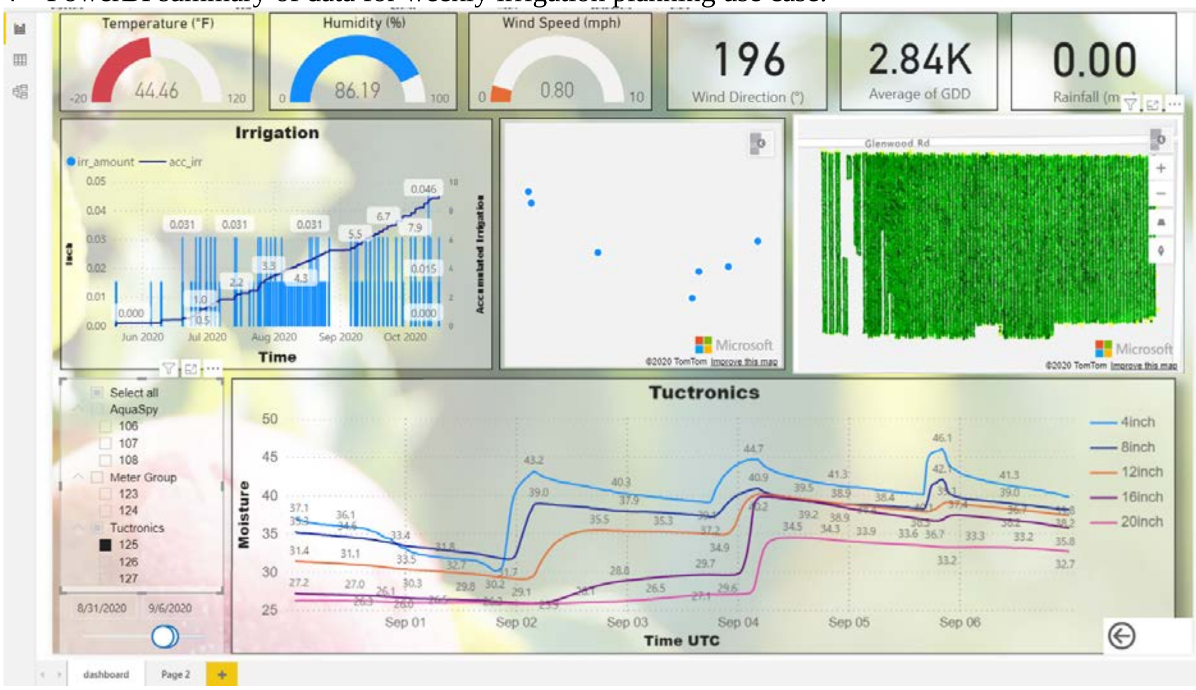
- Soil moisture measurement

For soil measurement, the main properties observed are soil temperature and soil moisture. Soil temperature are measured in either Fahrenheit or Celsius and the absolute values across different providers are comparable after unit transformation (Figure 5). Unlike temperature, soil moisture is measured by either the ratio of volumetric water content over field capacity (%, such as AquaSpy and Tuctronics) or by soil matric potential (kPa) (such as Meter Group's TEROS-21 soil sensor). Even when AquaSpy and Tuctronics both use % to indicate soil moisture, they are calibrated differently. Hence we might observe similar temporal variability but will also observe a systematic difference in the absolute values (Figure 4).

- Leaf Wetness measurement

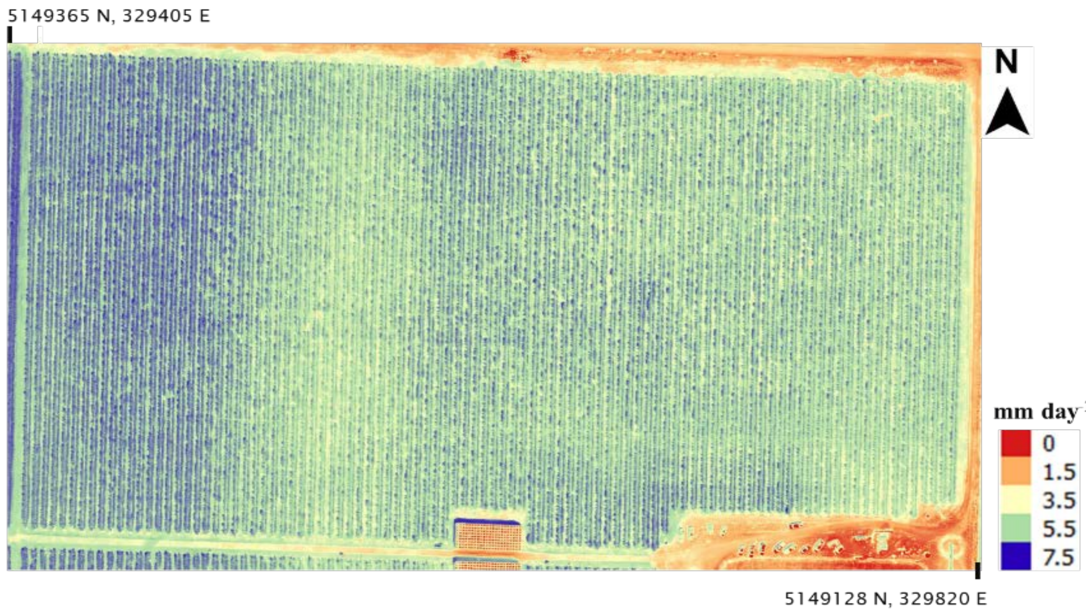
Unlike other variables that are either directly measured or prescribed based on directly measured variables, leaf wetness can be indirectly measured by change in electrical resistance or change in dielectric or change in some hygroscopic properties of the sensors. Hence the absolute values of leaf wetness provided by different manufacturers can have very different units.

Fig 4 – PowerBI summary of data for weekly irrigation planning use case:



A number of resultant data insights, presentations, and takeaways were built by various stakeholders (full summary presented in associated PPT & recording), with cross-data insights highlighted as follows:

Fig. 5. High resolution evapotranspiration map of smart orchard test-block, enabling reconsideration of irrigation application requirements throughout a block – Lav Khot team.



Fig

Fig 6. Air temp & RH variations from in-canopy vs above-orchard vs out-of-orchard, enabling reconsideration of spray timing/efficacy based on new in-canopy data (vs nearest AgWeatherNet station), as well as tuning application of disease & pest models

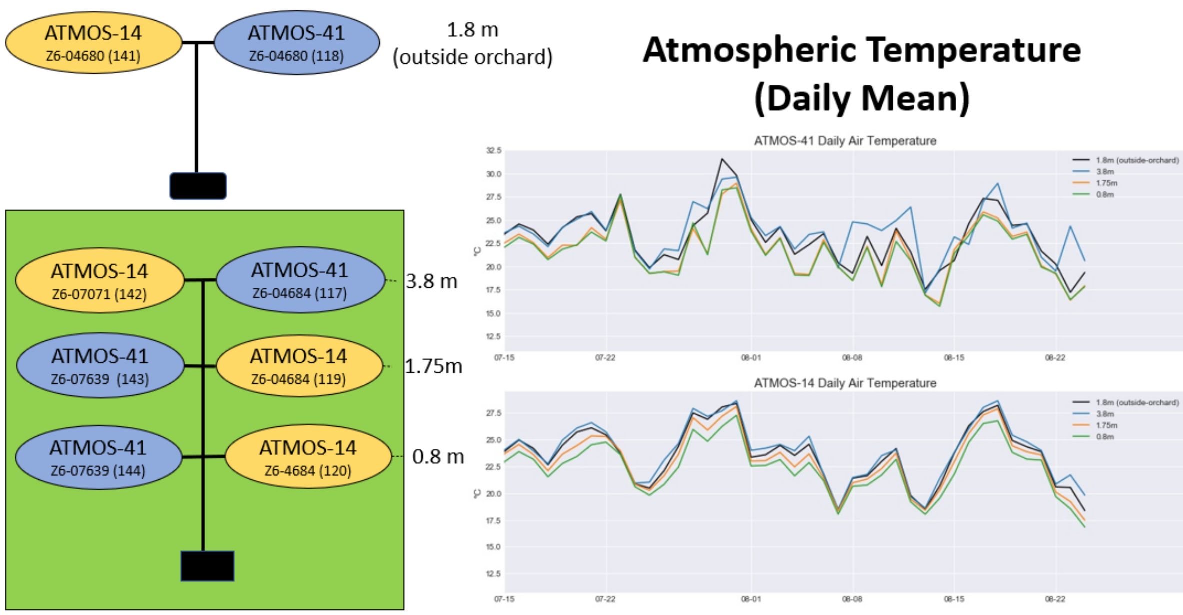


Fig 7 – Apple Counting using AI summary using video captured by smartphone analyzed at Microsoft hackathon, providing ability to look at yield predictions and tying to labor and/or chemical planning:

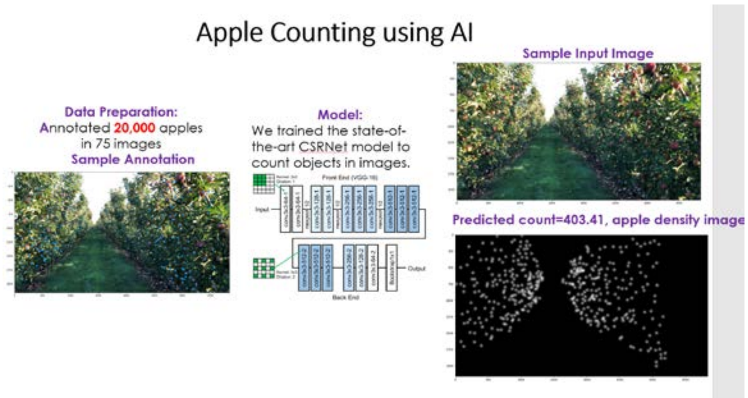


Fig 8 – Canopy area variability using Green Atlas at end of season, providing understanding of tree maturity/vigor for nutrient planning:

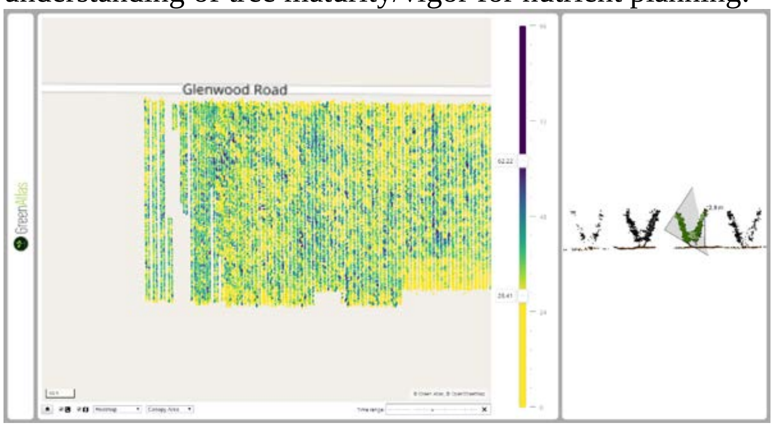
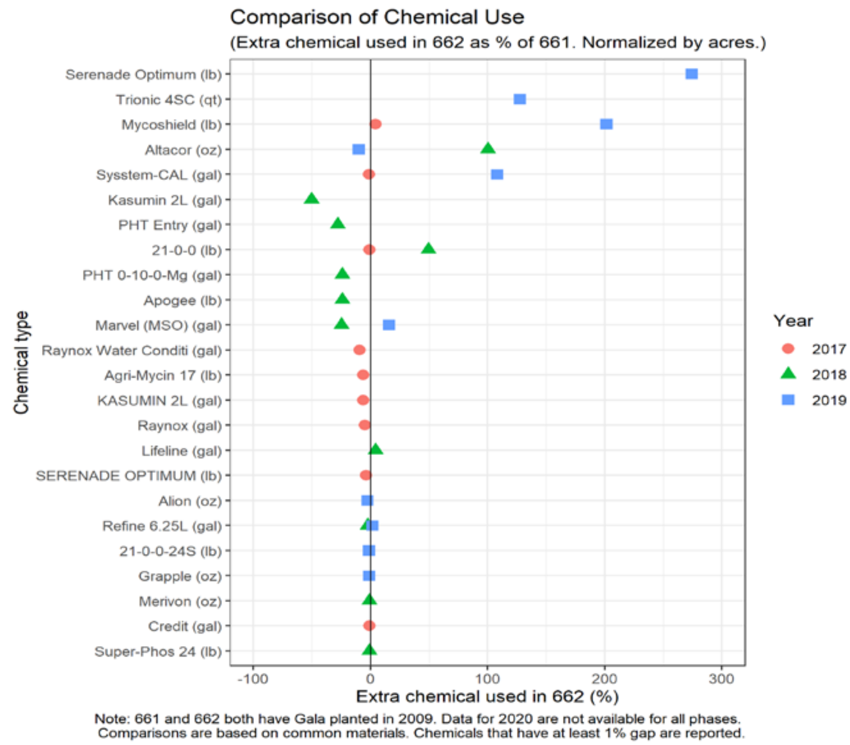


Fig 9 – Predicting fruit quality based on soil nutrient analysis from sensors & lab data, as detailed further by Bernardita Sallato in a separate report

Fig 10 – Analysis of chem applications across two blocks, complemented by reason for application:



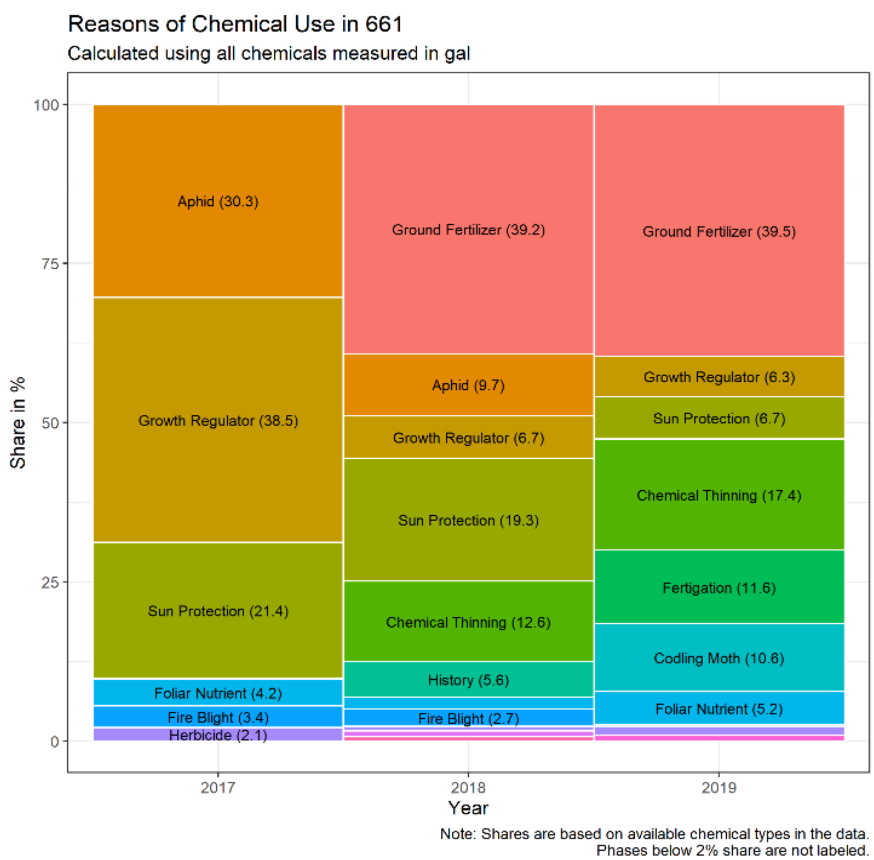
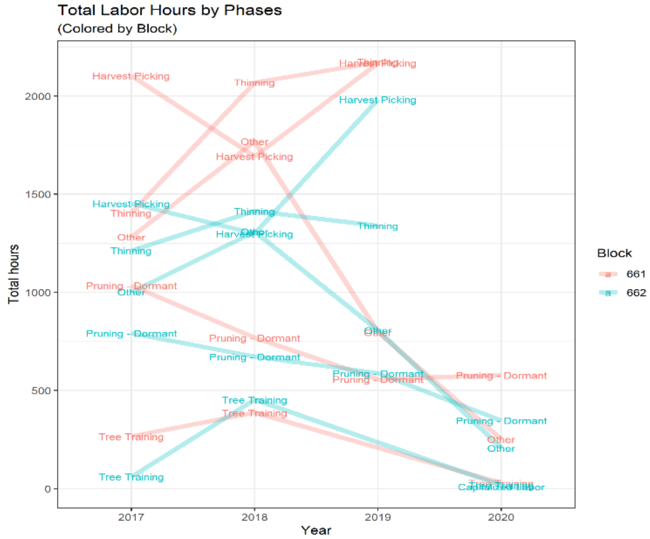


Fig 11 – Analysis of labor usage across two blocks, categorized by reason/type:



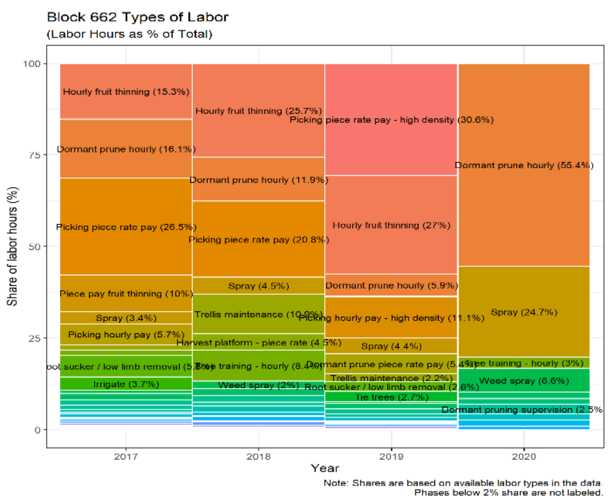
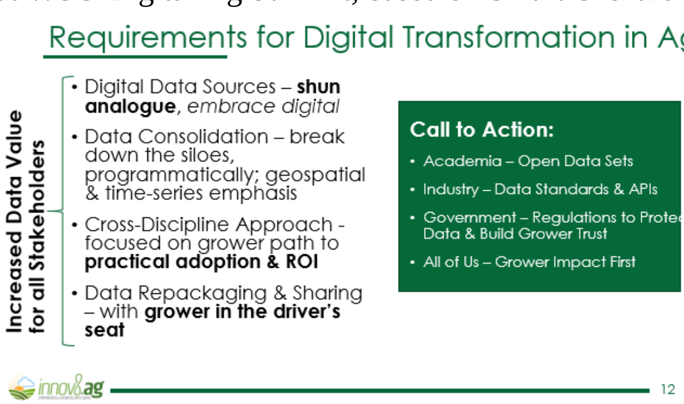


Fig 12 – Requirements for Digital Transformation in Ag takeaways shared with audience at WSU Digital Ag Summit, based on Smart Orchard learnings:



A playlist of videos that summarizes the project, including 3 smart orchard data research projects as part of the 1st WSU Digital AgAthon and 2 related hackathon projects at Microsoft, is available at www.innov8.ag/smartorchard

EXECUTIVE SUMMARY

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Key words: smart orchard, artificial intelligence, data, internet of things, sensors

Abstract: The Smart Orchard project started out-of-cycle in 2020, as the WTFRC technology committee identified that growers struggle with too many data siloes, impeding ability for growers to make informed decisions that may be better informed based on a unified view. Year 1 was about laying the groundwork for a smart orchard test block to collect data for many different sources. Our takeaways after 5 months of sensor implementation, data collection, and stakeholder collaboration:

1. Grower, equipment/sensor provider, & researcher engagement around a smart orchard showcase is extremely positive.
2. Data ingestion, normalization, & rationalization from many different sensor, equipment, & management data sources requires significant investment of time & resources for ag data solution providers.
3. Sensor, equipment, & imagery provider openness to data sharing of "raw data" is viable for most; unacceptable to some.
4. Tracking of grower management data is dramatically more viable when a grower-employed data analyst is assigned; tracking – and influencing - grower management decisioning is more challenging.
5. Expecting tracking of pack-out and comparing against other blocks is unrealistic if expecting to show value from data-driven decisioning.

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