Final Report

Phase 1: Scoping Workshop-Real time decision support system for remote monitoring of crops

Project leader:

Prof Ian Anderson

Delivery partner:

Western Sydney University

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Phase 1: Scoping Workshop-Real time decision support system for remote monitoring of crops (AS20006)

Disclaimer:

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Level 7
141 Walker Street
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Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Summary

Intensive cropping systems in horticultural industries have the potential to significantly increase productivity and profitability across a range of crops. At the same time, these systems are more vulnerable to a range of pests, pathogens and weeds that can significantly impact plant health. Furthermore, in high intensity horticultural systems, heatwaves and droughts are predicted to increase in frequency, duration and severity, leading to greater risks associated with loss of production in these systems.

In this project, through grower surveys, one to one grower interviews, and interactive design-led workshops, we worked with industry representatives to investigate the key problems different horticultural industries are facing. These problems were prioritised for each industry and smart farm solutions were identified for development or modification. The plan is for these to be tested in Phase 2 - Real time decision support systems for remote monitoring of crops.

The broad objectives include -

- understanding industry views on current technologies and assess gaps needed to meet industry needs.
- understanding how data and smart farm technologies impact on-farm decision making.
- exploring the role and potential impact of integrating smart monitoring tools for improved decision making.
- reviewing the opportunities and likely impediments for the development and implementation of decision support systems into Australia's horticulture industry.

Outcomes:

The project has developed a strategic vision and plan based on interaction with selected industries and assessment of current and future expectations across the horticulture industry, to help advise industry and researchers of future investment in need based technological gaps for Australian Horticultural industries.

Key learnings from the project include:

1. Spatial variability due to climate, soils, pests, diseases etc. across different growing regions for production systems (like almonds, avocado, macadamia, citrus, banana, vegetables, berries etc.) is sufficient to have significant impacts on crop productivity and profitability and warrant precision approaches and predictive modelling in crop forecasting to help manage this problem.
2. Adoption of digital technologies for decision making across selected industries needs to be targeted at addressing issues rather than focused on technologies alone.
3. There is a ready cohort of growers across horticultural industries who are primed to participate in Phase 2 through future investment.
4. Building capacity in industry and promoting development of cross industry network groups will help address current limitations and enable data sharing.

Keywords

Whole farm management, Data systems, Pest and Disease, Precision irrigation, Smart farm practices

Introduction

The Australian horticultural industry is on the brink of a step change, with methods available for transitioning from analogue business and production models to digital; this transition is creating multiple challenges but with equal opportunities. Many growers are finding it difficult to navigate the digital agricultural marketplace and worry about unwise investments without a guarantee of return. This is primarily because Australian production systems face some unique challenges that require home-grown, need-based solutions to enable appropriate data-based decision making. Producers lack trust in data management systems, especially those run by third parties and are unclear about the terms that govern their data including ownership. Many producers and stakeholders lack knowledge in the system and are frustrated by the unreliability of telecommunications connectivity and the inadequate scientific evidence currently supporting the available digital technologies.

A lack of producer control and underutilisation of data to make decisions are putting Australian horticultural industries at a global disadvantage. **Our industries cannot afford to be left behind.**

Australian horticulture sectors are well served by highly regarded researchers, innovators from leading businesses and SME's, who are working to make the sector more profitable and sustainable amid ever increasing threats of climate variability, pests, diseases, soil health, etc. Technologies that enable decision making on a whole farm basis and provide strategies for mitigating devastating impacts of crop stress have the potential to transform the industry. Whole farm decision support is enabled through integration of data collected by multiple tools and technologies including precision agriculture, internet of things, monitoring sensors, cloud computing and many other digital technologies and supporting functions. The algorithms, tools and real time monitoring integral to this system are developed and updated through accumulated knowledge from research and development. Such systems have the potential to assist producers in making data driven decisions with a much higher precision than has been feasible in the past. However, the Australian market for decision making products and services is still limited compared to the scale and pace of development happening in other parts of the world. Given the relatively low adoption and knowledge base of decision support systems in the Australian Horticultural industry, the project sought to engage primary producers and industry to develop a business case and clear value proposition for Australian horticultural industries, outlining the potential benefits of a whole farm-based decision approach.

Methodology

To design a collaborative innovation model that works for Australian horticultural industry, it was a requisite to understand how different industries (like Almonds, Avocado, Citrus, Macadamia, Banana, Mango Apple, Sweet potato, Vegetables, Berries etc.) operates today; the factors that encourage and impede innovation, assess instructive examples of success and failure and the structural and cultural features that guide and shape behaviours.

CD and R Turner was identified as the independent consultant to design and deliver the proposed consultations. He has a very good track record of delivering on design led thinking workshops for horticultural industries. He employed a design thinking approach to help the project team build empathy with the industry problems and start to understand the most important and compelling problems to solve.

The purpose of these consultation was to:

1. Develop empathy with the challenges and opportunities facing Australia's leading horticulture producers as they grow and expand their enterprises in the face of an increasingly complex environment.
2. Determine if there is an opportunity for a significant Hort Frontiers Digital Horticulture project to address any of these challenges and opportunities using real time monitoring technology and associated management and decision-based support tools.
3. Describe the most acute and urgent problems (technical and human behavioural) that if solved have the potential for significant benefit to multiple industries, thus the highest likelihood for adoption and the greatest cross sectoral horticultural impact.
4. Identify industries with common challenges and early adopter growers with an interest in, and a demonstrated likelihood to engage and deploy outcomes from a Phase 2 project.
5. Develop an understanding of the impediments to research translation and provide recommendations to guide the development, execution and commercialisation of the Phase 2 project to ensure the highest likelihood of industry adoption.
6. Create a project methodology that will test and develop a technology adoption and execution business model that is desirable, feasible and viable.
7. Assist prospective Phase 2 researchers and HIA to develop empathy with the growers and their challenges in order to design and deliver a project and associated specific activities with the highest likelihood of industry adoption, thus economic, social and environmental impact.

This was achieved through a series of design-led engagements with prospective researchers and leading horticulture industry stakeholders undertaken over the last 3 months including surveys, one on one interviews and focus group discussions. Responses to a survey, in-depth qualitative one-on-one interviews and interactive design lead workshop forums provided the contextual base.

Stakeholder consultation

Survey

An online survey was created by the research, extension and commercialisation team with the consultant and was sent out to various industries and industry leaders. To facilitate the questionnaire and data collection, the survey utilised SurveyMonkey, an electronic platform that can create user-friendly online surveys and allowed the team to receive feedback in real time. The survey had 22 questions and took approximately 8–12 min to answer (see Appendix 1). Questions specifically focused around

- Labour
- Smart irrigation system vs traditional methods
- Pests and diseases of greatest concern
- Current measures and its effectiveness
- Reliability and ease of use

The target audience for the survey included the following levy-paying industries: Citrus, Avocado, Macadamia, Banana, Mango, Apple, Cherry, Sweet potato, Almonds, Berries, a variety of vegetable growers and representatives from the Australian Almond Board.

Discovery interviews:

To aid the information gathered through the survey, it was decided to undertake a targeted one on one session with representatives from different horticultural industries. The purpose of these direct discovery interviews was to get a detailed understanding of the real farm problems, current solutions and research gaps. The interviews were conducted on Zoom and additional questions on crop production practices and issues regarding irrigation, pest and disease detection were asked.

One-to-one interviews were conducted in a flexible, conversational and semi-structured format around key themes so that interviewees could discuss concepts they felt important. This allowed for qualitative data to understand motivations and context important for the synthesis of findings. This method ensured a wide range of industries were represented in the consultation process and questioned current practices with sensing technologies for mitigating crop stress due to climate variability, pests and diseases etc. The in-depth zoom interviews were structured around the following main questions:

1. What are your current methods for dealing with major pains in your industry?

2. What technology are you using/are aware of industry using and is relevant for management of your crop, particularly irrigation?
3. Why was that kind of technology/equipment chosen? (specific to crop production issues)
4. What kind of technologies would you/can you see be invested in, if there is a reasonable return on investment? And why?
5. What prominent pest/disease are you dealing with in your crop/industry that can/cannot be detected with any of the available technology?
6. Where do you see the industry head to in the future regarding monitoring technologies and do you think this can solve your major pains?

Design Thinking Workshops:

Two sessions of interactive workshops on 28th September and 1st October 2021 was conducted to engage with key stake holders across sectors like Almond, Avocado, Mango, Vegetables, Macadamia, Citrus, Banana, Protected Cropping, Berries and Sweet Potato industries.

The aim of the design thinking workshop was to:

1. Define the problem that needs to be solved and the opportunity that can be created.
2. Discover the early adopter growers/industry stakeholders affected by the problem.
3. Develop empathy with the growers and an understanding of the impediments and benefits related to technology adoption.
4. Identify the underlying assumptions and hypotheses behind the business model required for successful industry adoption.
5. Create a project methodology that will address grower issues through developing and testing a technology, adoption issues and execution of a business model that is desirable, feasible and viable.

A workshop guide for stakeholder consultation was followed, which ensured that there was consistency in the information collected throughout the entire consultation stage to allow for the analysis of responses.

During the workshop, the first session focused on detailing valuable or challenging issues each industry faced all the way to the consumer. Issues were further evaluated by impact and complexity and grouped into themes. This was followed by a second session which involved analysis and use of the information to propose bold steps to solve the challenges identified and develop a vision for Australian Horticultural industry to help guide the solving of the issues identified. The design-led workshop involved selected representatives and were useful to understand the critical impediments and drivers impacting identified industries now and in the immediate future and to test the demand for decision support tools and technologies.

A detailed assessment of the current state of digital maturity in the horticultural sector, with a particular focus on its use of data to drive decisions was undertaken during the workshop. This assessment is an important starting point for the findings and recommendations in this report. Information derived also provides guidance to the horticultural industries for the transition to digital farming. The design lead workshop provided an opportunity for industry representatives to discuss, prioritise and untangle their problems together through designed interactive sessions to enable specific outcomes. Growers discussed major issues faced by individual industries and identified solutions through uniting diverse opinions and common problems across these industries. Engagement with different industry bodies through these workshops enabled upfront involvement of the industry in the process of identification of issues and developing strategies for addressing the grower needs through designing, modifying and on farm testing of need based smart solutions. This also provided an opportunity to capture some of their "Lessons Learnt" so that future programs could avoid these pitfalls and identify opportunities to co-design need based programs with these sectors.

Analysis:

The information collated during the survey, discovery interviews, and workshops was analysed in conjunction with an assessment provided by Cameron on the current industry operating environment. This analysis led to the identification of four key outputs which further guided the development of the RD&E road map for the Australian horticultural industry.

Outputs

Outputs

There are four main outputs from this study, posed here as questions that are then answered.

1. ***What are the major problems the industry is facing specifically and technologies available to resolve this?***

   Respondents provided a comprehensive overview of the main technologies and explained why they considered the technology either capable, or potentially useful for addressing their major problems. Potential technologies /solutions already in use in Australian industries were given emphasis with further discussion of their operational principles and known limitations.

2. ***What are the major issues impacting profitability to a point of concern irrigation, pest and pathogen?***

   Respondents provided a list of issues, including naming specific pests and diseases plus an attempt to control them using available technologies and discussed the priority needs in this space.

3. ***What industry thought about the whole farm management?***

   Respondents discussed the gap around data integration and the need for a location specific farm management system.

4. ***What impact new technologies could have***?

   Through interactive discussions, the groups explored changes that might result if decision making tools were more widely used.

We addressed this through summarising stakeholder consultations resulting from a widely distributed questionnaire survey, in-depth industry participant interviews and workshops in tables 1-3.The data was recorded and tabulated.

Table 1: Summarised evaluation of survey on major crop production issues, solutions, effectiveness and research gaps in major horticultural industries. (Appendix 1: Survey questionnaire)

Industry	Major problems	Impact	Current Solution	Effectiveness	Research gap
Almond	1) Pests: Carpophilus beetle and Carob moth 2) Disease: Hull rot 3) Irrigation/moisture management	Yield loss, reduce market quality of nuts, resulting in loss in productivity and profitability. Controlled irrigation	Early green harvest, drying crop in open fields, manual scouting to remove mummy nuts, targeted chemicals (looking at new formulas), increased mechanical pruning. Orchard Hygiene, take all nuts off trees out of orchard. Fully automated solution integrated for irrigation management along with weather sensors.	Effective but expensive, time consuming & challenging to manage. Limited benefit from chemical application, mechanical pruning provides better control with more air flow. Irrigation and nutrients are managed very effectively but the system warrants high maintenance.	Addressing research gaps to optimise systems will provide ability to monitor trees and reduce cost of production.
Macadamia	1) Shortage of agri/horti trained staff 2) Pests-Spotting bug and thrips 3) Disease: Phytophthora root rot and Botrytis blight 4) Irrigation/moisture management	Yield loss, reduce market quality of nuts, resulting in loss in productivity and profitability. Soil moisture variations not recorded.	Multiple biological & cultural control practices with chemical control programs are adopted and this is an ongoing cost. Irrigation management along with soil moisture probes.	Effective in controlling insect pressure over last 2 years, but weather conditions like heat waves triggered an increase in infestation. Yes, combination irrigation & soil water monitoring probes are good indicators of irrigation BUT fails to provide a larger scale picture i.e., soil moisture variances in field which can lead to phytophthora infestation.	Smart irrigation along with real time soil moisture status, crop forecasting, pest monitoring.
Avocado	1) Major pests: Spotting bug Leaf hoppers 2) Major Disease: Phytophthora 3) Soil moisture and irrigation	Yield loss, decrease in quality and marketability.	Physical root Barriers. Upfront and ongoing costs from tree deaths. Phytophthora - Phos Acid Sprays, upfront, and ongoing costs. Upfront blanket approach is leading to increase in cost of production Spotting Bugs -Pesticide sprays, Upfront. To prevent impact on pollinators a mixture of IPM and targeted spray	Positive signs so far, however unsure as tree death is slow. Phytophthora - Phos Acid Sprays and injections are time-intensive and costly. Positive Results are received on trees in good health however give varying results on the poorer trees.	Monitoring crop health/Biomass incredibly useful.

			program can reduce damage considerably, but not clean them up entirely. Irrigation managed using automation	Spotting bug - Can cause a significant amount of damage if left alone.	
Banana	1) Intensive labour requirement for crop management 2) Pests like nematodes, weevils 3) Diseases like phytophthora, Panama wilt, fusarium wilt, sigatoka and botrytis blight 4) Irrigation is a major issue	Quality loss with reduced yield.	Canopy management, increased intervals of crop protection applications, ongoing costs. Have a good scheduling for irrigation. Still lack tools for monitoring soil moisture status, which at different times of the year can differ and require a change in irrigation scheduling. No one size fits across the farm.	No proper results.	Proper irrigation and crop monitoring will be very useful for the industry.
Mango	1) Weather variables, 2)Pruning requirements 3)Controlling pests during flowering to protect bees. Major pests include spotting bugs, flower eating caterpillars and diseases are anthracnose.	Yield, quality, price, loss of market.	No reliable solutions are there as no research done, growers try managing pests and diseases using blanket measures as causes are not clearly identified. Practices include spraying, releasing of beneficial insects, pheromone traps- no results quantified to see impact. Measures add to ongoing cost of production.	Still getting excessive damage.	Needs work towards an integrated system.
Sweetpotato	1) Weather variables, cost/use of chemicals 2) Pest & disease Major pests- Nematodes and diseases include pythium and fusarium.	Yield, quality.	Agronomists scouting, traps, traditional insecticides & pesticides, compost, farm development to support more effective irrigation/retention & run off.	All add value but don't eliminate the challenges.	Technology for reduction of labour can provide desired outcomes. Utilisation and integration of data is also important for predictive modelling.
Broccolini	1) Soil borne disease such as club root	Yield, quality, harvest, lost market, customer loss.	Fumigate soil, additional hot lime, application of root growth stimulants	Solutions have helped but have not eliminated the	It will be great to have targeted

			overhead irrigation system and sub surface drainage system used which provides the ability to get good application of water to crop quickly. Traveller irrigators can move slowly but in some cases over irrigate crops triggering soil borne diseases.	problem. Also these measures are very expensive.	monitoring for needed response.
Berries	1)Weed management 2)Harvest 3) Lack of efficient spray in protected cropping 4) Spotting bug	Yield, quality, price, lost market,	New chemicals, alternative sprays.	Depending on pests, some require new chemicals. Hard sometimes to research activity properly.	Need solutions to fit corporate & other business categories.
Citrus	1) Pests like mites 2) Major disease is phytophthora, weeds & fruit fly.	Quality loss, harvest delay, pesticide residues.	Scouting, pesticides, augmented biological control releases (ongoing costs). Disease resistance breeding (upfront costs).	Religious application needed to manage & pesticide residue implications. Two seasons using phytech, looking at data, didn't work, ongoing tensiometers.	Automated pest trapping & monitoring, disease monitoring & prediction, smart irrigation sensing, weed spread, crop production, yield prediction, carbon capture.
Apples	Not too many issues - integrated pest & disease, trace elements & deficiency long term management	Don't have too many issues.	Ground moisture sensors assist in decision making.		Maybe, there are lots of factors outside the numbers that need to be considered. E.g. soil types & management, available water etc.

Outcomes

Table 2: Summarised evaluation of feedback from discovery interviews

Industry	Restricting growth/hardest to manage?	Current methods	Need
Almonds	Predictions on weather, availability of water, disease management are hardest to manage for almond industry. Almond growers are concerned how much water they use and what the return on the amount of water. Key pest & disease are carob moth and hull rot. Hull rot affects premium nuts, a huge problem, can't get nuts off, if left on trees these nuts harbour pests. Stable labour and doubling workforce at harvest time is an issue. Difficult to get senior agronomists into industry (they get paid a lot). Labour is a huge problem for industry, each year gets harder and harder.	Smart irrigation systems have been adopted for large scale farming to a greater extent but mostly limited for monitoring not managing. Initially industry was bit sceptical but soon picked up when it started getting really dry areas. Concern with smart irrigation systems is sometimes data doesn't match tree health & yield. ***Currently data is manually correlated for irrigation, pest & disease outputs.*** As of now, pest and disease are manually monitored and the gap is there is very limited knowledge on ***how to correlate/understand the outputs as a whole.*** Hull rot involves very expensive chemical management to minimise but still doesn't get rid of, and needs to be treated at precise time. 5-10% stress on trees is needed for controlling hull rot. Deficit irrigation, overstressing has an impact on crops but overwatering brings hull rot episodes on. There is no cheap labour to help with hull rot, so wetter summers with higher humidity is difficult. Almond board has projects on Carpophilus beetle, which crosses over from peach; however **identifying pheromones is a big gap for the industry.** ***It is important for the industry to understand what systems could help and fill in the missing gaps. Correlating transpiration, moisture & hull rot data is still in infancy.***	Industry would be interested if there is a technology that could perform better. Hull rot - understand why it happens and how to solve it. Note soil borne pathogens/pooling of water around roots is more sporadic, not a significant problem, largely promotes prevention knowing when & how it comes. ***Predictability data helping with how much pesticides and fungicides to use based on water and weather to predict disease is a key gap. Correlation of all the data -irrigation, pest & disease is needed. Hull rot- a model/tech showing when to spray and when not to spray***. ***Identification of precise pheromones and data automation is needed. Tech - Interpretation of tech and tools, trying to see where it fits, needing to manage it and make it work so growers can gain return on the cost of outlay.*** Tech needs to be simpler. Integrated system for yield estimation. Would be good to know - How do we run a program, how much to learn, how much $?Need good agronomists to run tech for increased yield, 1 for each 2000 hectares.

Industry	Restricting growth/hardest to manage?	Current methods	Need
Vegetables	Biggest problem in business is needing to meet yield & quality expectations, low availability impacts retailer & consumer. Therefore, **consistency of production is very important for the industry**. As most are multi-pick harvest crops , it is hard to anticipate recovery, how it will cope with environmental variables and what is needed to get it through. Labour is also the biggest problem as is a labour intensive crop, harvesting and in shed labour, skilled and stable labour.	Infrastructure -correct facilities are needed to chill, needs to be picked and chilled quickly, some have hydro coolers, others try and manage time in-between. Crops are grown under a variety of irrigation methods. Crops like lots of water -overhead drip or travellers or solid set sprinklers. ***Managing water is a big gap and if standardised will add value to growers, current systems needs improvement as sometimes growers fail to put enough water.*** Too much water is also an issue. Depending on the cycle of crop growers adopt different practices. Soil borne diseases are also an issue. If plants are young, growers try different types of fertiliser to push it along, but too much nitrogen can make it worse. If at the end of life, upload fertiliser, supplements etc to promote root growth for disease management. ***Previous irrigation systems didn't help that much as needed and weren't able to work with a database, growers will adopt something which is up and ready to go.***	Soil borne pathogens damage could be extensive, irrigation overhead. ***If there is a better way of predicting diseases, preventative spraying can be adopted which can help in avoiding spending extra $ for spraying. Having an integrated irrigation system to manage crops better, saving water, telling growers when to put water on, and working to a regime would benefit industry immensely***.

Industry	Restricting growth/hardest to manage?	Current methods	Need
Avocado	***Current tech doesn't play well together (use a lot of tech), growers are spending lot of time (20-30hrs a week) reading spreadsheets to interpret.*** Avocados – Phytophthora incidence is high on less draining soils. Best way to manage is always to act as soon as possible, high rounds, gypsum free draining soils, peg wheel. Spray trees without damage as a preventative measure. Problem trees are injected, difficult work but is meant to work. Sometimes it works well for a year and other times not at all, like a flip of a coin if it will be successful Cost or impact of Phytophthora is very high cost. Other soil -borne root disease is Phellinus Noxius. Fruit spotting bug is another major problem, it's hard to see as so shallow, very small, quite problematic. Can't spray for fruit spotting as coincides when bees are in, sadly damage fruit. Very difficult to monitor the pest manually particularly in trees which are 6 – 10m tall, it takes minimum 1 hour to check 3-4 trees.	Current tech includes- smart ***Irrigation management which performs irrigation job very well, however, doesn't work well with moisture sensor and weather stations data.*** Irrigation systems acts as a medium between the farms decision to water & turning on belts. Growers use moisture sensors to work out water usage hence are incredibly important and extremely valuable. Smart systems are time efficient. It will never replace touching and seeing crop however is a good service for them, is overly complicated but justified as there are many ***devices in the field it communicates with and can bring in a lot of data, however the biggest gap is data integration.*** Better irrigation systems which could learn what to do & schedule out the water use a bit more, can see working and would benefit and significantly help if data is integrated and analysed. For Fruit spotting bug, growers are relying on using organic solution traps as nothing can be done until bees leave. Will be good if there is a pheromone trapping mechanism to estimate the load.	***Growers need an integrated tech so don't have 1000 excel spreadsheets that take 20-30 hours a week, trying to collaborate different readings for making decisions.*** ***Tech to help with Phytophthora as spraying and injecting is very labour intensive***. Soil -borne root disease – Phellinus Noxius. Needs more research first as not sure how tech would help. It will be immensely useful to bring all data into 1 platform, identify pheromones, automating traps and quantifying them. ***Grower needs a message for example, this threshold is much higher. Also, the best way to measure is to measure damage previously done and predict future incidences. Interested, would like some definite decisions on pests.***

Industry	Restricting growth/hardest to manage?	Current methods	Need
Citrus	Focus on quality & low yielding specific varieties. More interest in quality, pest & disease management.	Smart irrigation system is adopted as it was off the shelf, ready to go product, installers installed, and the technology company made the process easier (there is not a lot of tech out there ready to trial & go). The industry didn't want to miss out on new tools to help manage effectively. Growers would always love peace of mind to manage things correctly. Note: After 2 years reliance on smart irrigation system was highly limited due to data insecurity issues. There was no clear strategy on data privacy Also, the tech company didn't correlate data with outcomes i.e. quality & yield. Growers also ended up seeing something different to what numbers were saying with a reduction in fruit size. ***This needs a research input, it is important to understand how irrigation could affect fruit quality with quantity.*** For validating a technology, it should be trialled for a minimum of 4 growing seasons, industry thinks a minimum of 3 growing seasons is all that is required to learn how to manage and grow for quality in QLD climate. ***Soil borne pathogens particularly phytophthora is a big stumbling block for the industry.***.	***No products out of trial stage, a lot still in R&D stage, access pipeline to technology has been too convoluted, there needs to be a constant focus on calibration – want a proper demonstration trial on the farm to consider options.*** Industry would like to see for example dealing with physiological disorders, currently pickers screen their own ID & bins are screened as they pick fruit, be good if all info could be displayed together along with this, for e.g., great efforts are needed into analyse data, is a stumbling block for a lot of growers, need time to put into technology to encapsulate bespoke systems so they fit the farm. Disease resistance programs can make much more $ and quality saving so trumps from an R&D planning point of view. ***Smart irrigation systems are around a long time, needs to be calibrated with water stress. Interfaces directly with trees rather than soil -this means relationship takes a while to develop (gap that needs to be crossed). Systems should provide good stream info & meaningful data which correlates with good quality product and better yield.*** Industry is also more focused on disease resistance & tools. As most of the citrus growing region is having a subtropical climate, efforts going into management of disease are huge. ***Tools to connect what's happening in the field and in the packing. Physiological disorder is a key problem when growers completely rely on these systems.*** Also, there is a complete disconnect between production (crop) and packing and the outcome is the poor end result in the market shelves***. The connect is important as this will help manage the waste, as mostly, most expensive produce gets thrown out at packing shed despite all efforts and money on nutrients, disease management etc.*** Phytophthora affected canopy is easy signal to pick up and any system automated to pick this would be immensely beneficial for the industry. Citrus pest mites are most critical, not many papers and are so small. Spots on fruit fly are weather dependent, want to prevent symptoms so 99% is more intervention, need to predict weather accurately 1 week in advance. ***Down the track – Question of where data goes, need confidentiality clause perhaps if cloud based to gain grower trust.*** More interested in pest disease management in connecting fields and packing. ***Tech solutions perhaps should start on the smaller problems first (these still cause strain).***

Industry	Restricting growth/hardest to manage?	Current methods	Need
Sweet Potato	***Good tech could make the industry smarter and assist in making decisions***. ***Water is another challenge, water is expensive. Need to be mindful also of how much water is used and needed***. Ties back to electricity as well, need to tie electricity and water into a bundle. Industry is interested in sustainability. It is difficult to get a good yield if the full cycle of irrigation is not used, it is important to give required irrigation to get to the optimal yield and quality. ***Delivering water to crops is the biggest factor .***	Current tech includes- On field irrigation/automation giving weekly reports Drone tech for spraying – not used in large scale spraying due to logistics. Drip irrigation can be fully automated – provides weekly report but is only used more as a reference tool. Sensors on the blocks could provide information on which blocks are stressed, however it is not practical for the growers to install thousands of sensors so most of them currently do digging checks in field through blocks. It will be useful to get an automated mechanism to monitor soil moisture. For pest monitoring, most growers rely on physical pheromone traps for sweet potato weevil which is the biggest issue. Anything tech that can identify pests would make a significant difference so industry can take efforts pro-actively to NOT knock out beneficial pests also.	***Will be good to get enough sensors to get a true indication of what is happening across the whole farm.*** As of now cant completely rely on any automated technologies, but willing to see what's available and what could help. Option could be using a satellite to integrate it over large areas for monitoring soil and water. Systems with accurate info could be very useful. ***Good tech could make industry smarter and absolutely assist the grower. Any advance in detecting pest and disease/pathogens in soil will be of huge value***. Anything tech that can identify pests would make a significant difference. Currently physical traps & pheromones are used for sweet potato weevil which is the biggest issue. Analysis of historic data can inform on what happened in the past and will also help to understand the spread pattern. Soil borne pathogen notification can aid in early spraying. ***A platform where all data combined, calibrated & analysed will be useful. Information which can help in understanding real moisture by satellite over the entire crop would be very goo***d. Sensors over all blocks could let us know which blocks to stress when growers want to stress them, currently they do digging checks in the field through blocks which is very labour intensive. ***Real time understanding of soil moisture by satellite over the entire crop would be very good. Real time data will therefore be super handy.***

Industry details	Restricting growth/hardest to manage?	Current methods	Need
Protected Cropping	Currently looking for tech to save labour costs, particularly pollination. Interest from many other companies looking to gain full control/knowledge on future prediction of pollination estimation from bees & forecast yield. Main barrier to not using technology: Investment is more in broad acre not protected cropping. However, irrigation wise crops in protected system is doing a good job. Pest & disease & changing temperature most important, vital improvement should be focusing on the impact which needs an intensive data correlation and analysis. Labour is another impediment, anything that can make labour more efficient or reduce labour costs on operational side is a big opportunity.	Current models of tech don't fit well in protected cropping. Will be good to provide the growers with reliable tools to help them make these decisions, which would impact profit greatly. Harvest cost in tech would save a lot of money, taking 30-50% of costs. Pest & disease monitoring could also be an expensive exercise for crops, industry usually employ 3 people to go around every 2 or 1 week depending on the farm.	Currently looking for tech to save labour costs, particularly pollination. Information on future prediction of pollination estimation from bees & forecast yield. Greatest need metric to be measured & tech – Problem with bees, different methods needed, bee health has to be monitored, many things affect pollination. i.e. no. of bees per metre etc Protected cropping structures different to broad acre ones – impact of pollination success is very critical. Concerned protected cropping areas will lag behind if all automated work like pest and disease monitoring is more focussed to broad acre farms. **Challenge: Need to have systems in place to catch problems in technology before they occur**. We still need people to control tech. ***Have forecasting crop tech ready, for example: imaging, counting of fruits & flowers, recognising stages of fruit.*** Improving yield = improving $ - a mix, both as are saving on labour also. ***The industry is very interested in tech , have invested a lot in structure – often current models don't fit well in protected cropping, protected cropping is only going to grow, would like tech feedback particularly on Fruit load and crop health.***

Table 3: Summarised evaluation of Design lead Workshops

Product	Restricting growth/hardest to manage?	Current methods	Need
Almond	Labour, middle management, bee access, hull rot and mummy nuts, Carpophilus beetle, Carbon moth. Sustainability - finding road to carbon neutral, identify carbon footprint whether fertiliser, machinery.	Use external agronomists (ABA key rep body) and internal, looks at pest & disease, and teach how to scout. Overhead drone imaging which can pick up blackspot, phosphorus overload etc. Use smart irrigation systems but not for decision based. Use deficits in irrigation to reduce hull rot.	Need modelling to go with new developed tech, needs to address future disease issues too. Great to see enthusiasm & interest in tech space, important sensor modelling to go with sensor input, very important integrating different data scales in soil & across the whole orchard & being user friendly. Whatever is developed needs to include growers and should be tested for a point of difference for growers to accept it, evidence-based information on return on investment. Proper tool like right pheromones for pest management and protecting bees. Opportunities for scaling up pest monitoring is a high possibility. Landscape monitoring for identifying crop stress at a better resolution and linking pest and disease incidence could be effective. Interested in testing novel sensors developed by Tasmanian research group.
Macadamia	Labour -Farm hands, lack of skill, willingness. Linking crop water requirement and crop physiology is a big gap, industry should be partnered and be involved in innovation to meet above requirements. Lack of basic soil & knowledge in water use efficiency is lacking. Is restricting large yield increases.	All methods include intensive labour and lack of skill.	Programs linking crop physiology, soil science and monitoring is a big gap for the industry. Upskilling industry on proposed programs with sufficient training options is highly desirable.
Avocado	Reliability of data is an issue, growers use lots of sensor probes, dendrometers, however data is not integrated. Industry currently deals with huge amounts of data silos. Lack of understanding the tree physiology is a disadvantage as they are not able to interpret crop stress and understand if trees are looking good or bad, whether it means trees are doing well or are affected by any stress. A data integration program	Apps measuring biomass have been a distraction so far. Too many separate apps/tech sheets to look through, is a full time job in itself. Apps fail in the lack of ability to measure applicable outcomes from all the inputs including yield, biomass, pest and diseases.	If cost effective, sensors developed by Tasmanian and WSU teams could be put on 600 Hectares would be amazing. Sensors that are scalable across a large area would be very useful. Saleability of tech & confidence in the data is key. Phytophthora issue in avocado crop – injecting in trunks to keep alive is not great. A pheromone monitoring system for shy weevil including opportunities for testing efficacy of biological interventions to help retain bee population would be very useful. Understanding pest biology better is needed. Estimate biomass and relate to crop stress. Understanding microclimate for phytophthora is also a key area to be addressed.

	linking tree physiology to water requirement will be immensely useful. Lack of proper monitoring and controlling measures for phytophthora and shy bugs is a big gap.		
Citrus	Smart irrigation systems used was an excellent system but had inherent issues like couldn't automatically turn on and off all pumps. Need proper algorithms for the system to understand/integrate more information related to crop physiology. Data integration is a key gap.	Major R&D focus is in breeding, disease resistance program, new varieties of interest, physiological, links with unis, DPIs. Smart irrigation systems helped growers to understand what they were doing, helped push the boundaries of water stress, allowed withholding of water than they would normally allow. However, the irrigation factor was not correlated with crop physiology as fruit size targets were not being met but the app said they were ok. Disconnect between app & growing conditions were obvious. Most of the growers stopped using the technology after 2 seasons. Addressing water usages is a challenge as choosing water tolerant rootstock will not override species that produce good quality & yield. Considered trailer clever trap but came at $80K each time.	Will be good to know failures in irrigation system e.g. leaks before they became evident and integrate location specific weather information to deliver need based input. Technology should be flexible enough to combine bin picking data (incl bar code) with a geo ref (scanning event) so consumers know where fruit comes. Tech needs to be set up specifically for each farm. Tools to tell us when to spray, as some new cultivators don't need to spray at all. Let's just start with something i.e. automated sticky traps, people want a smart trap to do it and do it perfectly. For the citrus industry, to just start with trialling something and getting better at it as time goes on will be very effective. Implementation & using tech seems to be harder than developing it. Camera imaging/volatile sensing for phytophthora optical system for real time to actually give phosphorus acid would be immensely useful as the need may vary through the field. One problem is that it is very unpredictable to work with, if root rot can only tolerate an amount of phosphorus acid, hence is difficult in a block situation. Phytophthora has more impact on citrus, industry wide the loss has large impact. High resolution mapping to identify crop stress for targeted spraying could also be a starting point.
Protected Cropping	Crop forecasting- forecasting is difficult in industry. Timing of crop. Always looking at ways to improve the applications of sensors. Data integration is a gap. Ability to process data and display it in a useful format is a big gap.	Irrigation systems and current monitoring systems are designed to use remotely but not everyone trusts the technology. From experience – things can go wrong. Technology not robust enough – possibly installed incorrectly, unforeseen natural	Important to understand what the features and benefits around a good system and identify the gap. Data is generated in systems and silos- data integration is needed. Ability to process data and display in a useful format is a big gap. Ability to access information from anywhere is important. Systems have the ability to access information however including a pest and disease monitoring system would be immensely important. High resolution spatial is needed for pest and disease, forecasting and growers should be able to assess information in an integrated format. There are a lot of systems out there. Caution to not just have

	Pest and disease monitoring is another issue.	events. i.e. lightning. People on the ground doing other things as well.	another system. Connect fields with outputs through tailored algorithms. Historic data – industry can learn a great deal from this if it is properly analysed and integrated. Many farmers have a variety of data sources – data mining for historic data over machine learning can be very useful. Need to address the issue of data sharing – for competitive business.
Vegetables	Hardest thing to manage is varying climates, growers are juggling with crop production practices to meet anticipated demand. Crop forecasting is very important – 3 to 4 weeks out but also over 6, 12 months. This is a challenge across vegetable industry and can be quite complex. Even experienced growers find it difficult to anticipate crop production. Irrigation, managing water is also very important as most vegetables are thirsty crops. Critical issues are water, soil borne disease and pest management. Works okay when weather is consistent but when variables, makes it very difficult.	Soil sensors – measure changing environment and weather conditions. Some growers have tried technology but the tool is not well integrated for the growers to make a decision based on it. As of now this technology would complement or confirm but has never provided precise data from the ground. Lots of variables in outdoor production. Growers haven't really transitioned to use of technology to enhance their productions. Currently use historical yields to forecast, a bit of guesswork to be honest. Lunar cycles, changes in weather,warmer at night, factors and events impact on crops. Slowing down in production that is not anticipated is a major problem for the industry. Would be good to get information from growers and add a theoretical view to find a happy medium. Growers get it wrong three to four times a year, shoulder periods change in season, is when they get caught out and there is a huge gap.	Forecasting weather, disease, irrigation requirements is a big gap and need for the industry. This will immensely help as earlier growers become aware, they can inform suppliers and outline supply issues – helps to manage portfolios in stores. Lining weather forecasting, historical data evidence and informing crop forecasting will help growers in decision making. Supermarkets being caught out – 3 or 4 weeks in advance with sales activity. Optimising big farms – extract information that affects everyone i.e. a pest outbreak. Ability to draw on fundamental relationships between microclimate and crop stress will enable growers to customise and help in making them very innovative. A flexible tool that would enable them to manipulate their settings. Pool data from a variety of experiences – keep flexibility in the tool. Between technology or information – can only take you so far. Sharing what is done is a challenge. There seem to be similar challenges across the board. Anticipating yields and forecasting is a major theme. Programs to model crop biomass/yield for industries would also be very useful.

Sweet Potatoes	Have programs and methodology to manage, generally works. Industry is reactive to problems, beneficial programs but if there is a breakout then growers are reacting to something that can be detrimental. As of now, understanding historic data around pest pressures is not well planned out. Information is lacking on tailoring management practices, e.g., how and when do we minimise use of synthetics and chemicals? Industry is looking to minimise those things. What level and rates can be adjusted to minimise risk i.e.. Arguably do a 60% spray rather than 100% - but how to work out where threshold is? Detrimental if you get it wrong. Automated irrigation is used but the risk is with a blowout or a pressure change which these systems are not able to communicate therefore there is always a need for manual monitoring on the ground to address the issue. Learning is not used well enough because the information is so disparate across systems.	No proper monitoring systems. Trickle irrigation is used. Occasional data collection through imageries, drone data and multiple soil moisture probes on ground. Work with few local data and imaging providers again leads to lots of dispersed data sets.	Data integration to get better insights on what is happening on ground is a key gap. Understanding the threshold will help in minimising sprays. Definitely need more user-friendly software, systems, technologies. They are not physically in the field trying to use it, on the ground covered in dirt, painful to use the technology. Also, data is not utilised well enough. Dashboarding data is valuable but software applications with specific service being provided are not holistic or trying to integrate data from soil moisture probes etc. Integrated information is not available. Though, the commercial companies promote their technologies as a holistic tool, most of these technologies don't provide information on seedling to soil testing, monitoring moisture and temperature and none do it as one. Crop biomass and soil moisture snapshots in real time being able to analyse in one full suite can be a break through. Sharing of information between agricultural businesses – a gap/challenge. Confidentiality versus commerciality. Aside from having post season data, not a lot of sharing is happening. Proper platform for sharing information on common problems could be worthwhile.
Banana	Crop forecasting is one of the biggest issues along with on farm connectivity. To make the industry profitable, growers need to be well informed on what is happening in their farm from a landscape perspective. Climatic conditions at bunch	No proper monitoring system. Current monitoring carried out by growers and biosecurity officers who are not well trained enough to differentiate between various symptoms.	Data integration, analysis of historic data and developing crop forecasting is very important. The forecasting or some form of prediction model for early warning to growers. Monitoring systems that can determine disease, pest, yield, quality, irrigation can help in predicting impact on production. It is important to understand how technology and human role is deciphered, what information will be shared, who does what? How to process and scale the technology? Scalability and confidence in data.

	formation is very critical for the industry. Communication to customer base and suppliers potential volume in the market, what that can mean to pricing and marketing strategies. The forecasting or some form of prediction model for early warning to growers. Technology i.e. phone notification – this event will happen, active ideas on how to mitigate the impact, what actions to take based on the potential forecast so they can be proactive, it is difficult to reduce the stress on plants after the event. Want to be proactive rather than reactive. Data integration is a big gap.		Historic data, especially management practices that could have resolved an issue will be very useful. Growers would be interested in looking at farm data that is tied up/unseen and this could be an important component for developing predictive models.

The current operating environment for each identified industry was assessed in conjunction with the impact, solution and its effectiveness to understand the research gaps and how these might drive future RDE&C processes to ensure the sustainability and profitability of the selected horticultural industries. The issues identified were validated during consultation with industry members through surveys, one to one discovery interviews and design lead workshops. The issues, their implications, current practices, and need for future R&D for the industries are discussed in Table 1-3 . Based on the design thinking report submitted by Mr Cameron Turner, the RD&E drivers were identified (see table 4) and were used for identifying objectives and development of road map for RD&E activity in Phase 2.

Table 4:

Key issues and RD&E drivers facing the Australian horticultural industries proposed based on the design thinking consultation report- Mr Cameron Turner

Insights	Discussion and Recommendations	Proposed RD&E Drivers
Un/low skilled labour Labour was a common problem identified, the lack of low skilled or unskilled labour for planting, general maintenance, harvesting and packing etc. This is not likely to be solved through a real time Digital Hort project.		Packaging and harvesting could be addressed through robotics. This is not the focus of Phase 2 smart farm program.

Interestingly the very large farms that require a significant amount of low skilled labour do not see this as a significant challenge as they are of a size where they have enough diverse seasonal work (harvesting, pruning, planting, spraying etc) to maintain a consistent and often locally engaged workforce. Nevertheless, there were a number of companies with a large seasonal workforce requirement that did experience pain associated with this issue, however these challenges are being addressed through developments in automation and robotics, hence are not recommended to be addressed in the Phase 2 Smart Farm project.		
Crop management and forecasting Almost all the producers regardless of industry indicated that while there were significant opportunities to optimise water, fertiliser and pest and disease controls, understanding and identifying interactions between these inputs for improved quality and yield was a gap. The challenge for the individual producer is to extract integrated data from historical to current when they need it, to make the decisions that will increase profitability and deliver reduced risk.	Digital platforms like farm beats can collect, integrate and analyse farm management information from multiple data streams. This would save duplication of time and effort from multiple analogue recording systems.	The research team should start by working with collecting and analysing extensive historical data and optimising data collection and storage capabilities including water, quality and yield initially to develop systems to correlate this data. This will include the review of available forecasting methodologies and technologies for a number of tree crops, through linking to current work delivered through parallel Hort Innovation investments. IP will be dealt directly with individual organisations. For example, tools developed through UNE and Circul8 collaboration for yield monitoring would be tested for its applicability.
Crop Quality monitoring All the producers agreed that perhaps the greatest challenge was the ability to accurately predict fruit/produce yield, size, quality, maturity, and time to harvest.	As horticulture production systems intensify, they will become increasingly more hi-tech, and businesses will require technological support to be competitive. The impact of digital technologies is likely to be the greatest in sectors that have routine tasks with a high degree of predictability and that need to be performed with a high degree of accuracy. Process automation can replace subjective human assessment. Adoption of low-cost smart tools for monitoring crop quality will help the industry to become more professional and profitable.	Test and modify available technologies through linking to current work delivered through parallel Hort Innovation investments. IP will be dealt directly with individual organisations. Integration of these tools into the data hub will help in improved monitoring, faster response times and implement electronic documentation and data capture mechanisms. The camera system in development by Tasmania and WSU team or other optical system could potentially offer better diagnostics tools, needs to be tested and integrated.
Harvest time and yield monitoring		Standardising sensing technologies to accurately monitor and predict yield, quality and maturity. If sensing tools and next generation technologies can collect multiple data points such

It was suggested that this capability would provide significant benefit to the growers and their customers and allow for enhanced management of their value chains to ensure consistent supply and therefore consistent prices and availability for consumers. At present each of the growers indicated that a number of times a year the industry and the retailers are caught off guard with either surplus or deficit of supply which resulted in potentially significant financial losses for the producers and retailers.		as water use, nutritional status, pest, and disease pressure and maybe even fruit/crop characteristics (from optical cameras), this would be a game changer. The camera system in development in Tasmania potentially offers this capability. Information derived will need to be correlated with on ground diagnostic measurements devised for crop quality monitoring for accurate projections.
Irrigation and Quality: Though large-scale horticulture enterprises are actually quite confident in their ability to manage and optimise water, none of the growers used their quite sophisticated real time sensor-based irrigation technologies exclusively to make irrigation decisions and all of the growers indicated it **DID NOT reduce the need for specialised agronomic labour on farm**. In fact, it highlighted the importance of trained and experienced staff to synthesis various often disparate pieces of data and observations to make decisions about inputs and interventions. Growers were of the opinion that smart irrigation tools used currently on its own will not result in significant uplift in value because the system had issues, for example, as pointed by citrus grower - • Smart irrigation systems allowed growers to use water more sparingly when water was getting very tight, and keep the trees healthy. However, letting the system guide the irrigation scheduling did not achieve adequate fruit size in the two seasons the system was implemented. • The weather data the system uses was not sufficiently location-specific, hence no zone management could be undertaken leading to errors in evapotranspiration by the system. The focus for growers is not to just optimise water use efficiency. It's also important to optimise specific characteristics which they can extract the most value from, which often is not limited to yield. Many growers indicated they have taken years to fine tune their irrigation including using deficit irrigation (similar to the wine industry's partial root zone drying) to seek certain specific characteristics such as sugar	Precision agriculture has under-delivered partially because it has been based on technologies which only focused on automation, with less effort in incorporating the physiological principles of crop responses to environmental variation. The automated systems do not account for a whole-farm precision agriculture approach which accounts for the physiological processes underlying the relationship between environment and crop development, growth and yield ("zone management") which bridge yield gaps, increased farmer profit and reduced risk. This is the reason why many smart irrigation systems failed to achieve the required fruit size in two of the seasons. Moreover, integration of location specific weather information is critical for developing and adopting zone management for any crop.	Develop/Modify and /or trial existing technologies that can be applied to larger farms integrating with data sourced from satellites or aerial images. This spatial data should be calibrated with real time sensor data to ensure accuracy, reliability and confidence in the tool. Most desirable would be a networked sensor system that links real time measurements of plant stress and performance with specific physiological thresholds (set points) for the crop / cultivar being grown. This would include feedback based on fruit size and quality metrics. IP issues will need to be considered for each tool involved.

and moisture levels, size and harvest timing. Hence enhanced real time water use and irrigation tools on its own will not result in significant uplift in value to many parts of the higher value horticulture industry, it is important to correlate the data with changes in crop physiology. However, a useful feature was the irrigation line pressure sensor, and being able to quickly identify lines with low pressure.		
TRUST and Data integration: Feedback from Macadamia and Avocado producer *As an agronomist he spends most of his days with multiple reports and spreadsheets open on his screen trying to work out what's going on with the crop. Doing this at scale is impossible.* *"If sensors could be put on 600 Hectares, it would be amazing if cost effective. We need sensors that are scalable across a large area. Scalability of tech & confidence in the data is key.* There was a view that pest and disease management, yield, quality, maturity and harvest timing can't be determined or predicted by any single data point alone. Many growers indicated they DID NOT and probably would not TRUST a piece of technology alone to predict and deploy an intervention such as irrigation, nutrition and pest and disease control. However, many growers did say that data would be more useful if there was a mechanism to correlate water requirement data with other characteristics of interest such as fruit size, yield, maturity, localised current and forecast temperature and humidity and pest and disease pressure. It was suggested that if desired quality attributes, yield, water and nutrition could be correlated, this would be incredibly useful. However at present this can only be achieved by experience (and lots of data analysis) and not able to scale up to large farms. Growers indicated while borderline in usefulness they did see significant potential to extract site specific insights from improved analysis and synthesis of the data they had if combined with other data such as quality attributes, pest and disease pressure and yield. Many producers indicated they had in some cases decades of data,	From soil moisture probes to weather data, satellite imagery and robots, individual producers and industry researchers are collecting a massive amount of digital information which combined, has a potential to revolutionise the way we make decisions on farms. However, the current digital maturity of the horticultural sector has been rated as 'ad hoc', meaning it does not systematically and consistently use data to drive decisions. The impact of this is that the sector is missing out on opportunities to improve productivity and realise greater profits.	Review of types of data collected on farms and the availability of historical data collected. Develop and test algorithms and tools for data integration and generate visualisation maps for decision making purposes.

which potentially could be used to develop much smarter systems if correlations could be made with other characteristics of value. Utilise existing data - Growers indicated that remote sensing tools did provide off site management assurances that everything was on track remotely, which provided a degree of insurance for staff not on location. Producers indicated they have an overabundance of data and they just don't use it. Therefore in some cases the pain is not just data, it is synthesis and interpretation.		
Phytophthora is a significant issue for the avocado industry and also citrus to a lesser degree. There is currently no method to determine progression of this condition, hence growers spray lots of expensive chemicals as a preventative. Therefore, developing tool to monitor this disease would be of significant value for these industries.		Develop a monitoring mechanism. This could be through high resolution imageries, data calibration using ground based optical systems or through quantifying plant stress volatiles. Explore the advantages of biosensing systems for detection of plant pathogens like phytophthora and fusarium based on both antibody and DNA receptors.
Hull Rot , Carob moth and Carpophilus beetle is a significant issue affecting the almond industry which remains an unresolved pain. Many of the tree fruit and nut producer's spoke about the complexity of managing pest control and bee pollination. As such, there is an increased focus on biological control, to avoid impacting the pollination process. This required further exploration to understand the importance of establishing the right pheromone and then determining if trap automation is needed for real time sensor-based solution to address this problem.	There is an opportunity to validate visualisation maps with hotspots developed through integrating irrigation, temperature, humidity and disease presence to enhance control of this pest. The ground truth data can be used to validate these hot spots. Gap - there is no availability of ground truth information due to lack of accurate pheromone.	Develop/identify pheromone for Carpophilus. Monitor threshold using pheromone traps and correlate with hot spots identified in maps. Explore the opportunities for automation.
Implementation over new sensors – Few growers indicated that they would prefer to utilise their existing irrigation systems and even modify existing sticky and biosensor traps for real time assessment rather than having to install new high tech systems.	For example a Citrus grower indicated- Tech needs to be set up specifically for each farm. Tools to tell us when to spray, as some new cultivators don't need to spray at all. Lets just start with something i.e. automated sticky traps/bio sensors, people want a smart system to do it and do it perfectly, let's just start with sticky/bio traps. For the citrus industry, to	Sticky trap - Test methods for automating sticky traps offering a low-cost solution to spore or small insect trapping for real time general assessment of a pathogen or species population. Modify and test efficacy of sticky traps and biosensors for pest and disease monitoring.

	start with trialling something and getting better at it as time goes on. Implementation & using tech seems to be harder than developing it.	
User Experience - A common feature growers commented on was that they liked that current smart irrigation tools are easy to buy (click on add to cart), simple to install and did not require too much complexity in getting staff to be able to use the system. That is, it was intuitive. Growers suggested any future smart farm system should have an excellent user experience interface, be easy to engage (buy) commercially and be easy for multiple staff to use with limited training. A major constraint of the current tool is that it is not economically viable to scale to extremely large farms.		Focus on developing enhanced "User Experience" (UX) for interpretation and action. This will ensure an enhanced likelihood of technology adoption.
Confidentiality - There was some concern about the use of the data and the cloud based platform used by some of the current smart monitoring tools. In fact one of the users indicated that he felt that *"Perhaps companies employing these smart tools were learning more about our agronomic practices than we are"*. Given this company invested significant resources into optimising water use for specific yield and quality criteria and that this was a substantial competitive advantage, they suggested the risk of others learning about their agronomic IP was of a significant concern.		Data storage, sharing and associated security system developed in collaboration with Microsoft.
Tree fruit and nut producers are early adopters - It seems that fruit and nut producers were more likely to use real time irrigation sensor technologies due to the fact they have the ability to monitor trees over a number of years and the sensors can be placed on the trees and left there for annual comparison. Fruit and nut growers also have the most in common in that they may be able to utilise similar equipment for water use sensor technologies. Banana and Vegetable producers are less likely to use real time irrigation sensors, possibly because their profitability may not be as high.	Large tree crop producers especially including nuts, avocados and citrus are most likely to be the early adopters to use any developed technologies from the Smart Farm project. Banana, protected cropping and vegetable industry are keen and are interested to be part of the trial involving technology testing.	Developing solutions for these industries should be the first priority as they are the most likely to adopt first and there are likely to be a number of economies of scale in developing new technologies applicable to multiple industries. Establish demonstration sites in banana, vegetable and protected cropping industries for testing effectiveness of the technology in multiple crops and locations would be a rational method to increase the awareness of the technology.

Data sharing for common problems - Growers may be willing to share data to gain insights into common problems that are not competitive in nature. Data is being collected across industries, however, foundational datasets have yet to be defined, interoperability is an issue and good data management skills are still to be developed.	An example of this was the correlation between irrigation, temperature and humidity and the development of Hull Rot in almonds in January. This would require data gathering across multiple sites and the synthesis of this data to assist the industry to take preventative action. Another example of this could be the development and progression in phytophthora in avocados and citrus to a lesser degree. At this point many avocado growers spray probably too often to ensure they can control phytophthora.	Analysis of data from multiple farms/ across multiple industries about the progress of hull rot/phytophthora, may enable identification of microclimate which can be monitored for the reduction of pre-emptive sprays, which are costly. Digital platforms like Microsoft Farm beats that can collect farm management information can be integrated with compliance requirements to achieve data security.
Plant and soil sensors don't scale - Many sophisticated growers have areas under production of greater than 500Ha and in many cases up to several thousand Ha. Therefore plant and soil based sensors are difficult and cost prohibitive to scale to very large crop areas. Therefore aerial and or satellite technologies are most likely to be required to gain whole of crop information of agronomic data. It is likely that plant and soil based sensors could still be used to calibrate more remote sensing technologies. One of the growers indicated that if fruit size, quality and yield from bin picking data could be correlated with inputs, that would enable enhanced fine tuning of management for each block and variety.		Data from soil sensors or plant based sensors should be used to calibrate remotely sensed data from airborne and satellite sensors. Remote sensing has the capacity to cover large areas but always required ground validation and training to be useful. This may require the development of new remote sensing algorithms, exploring high resolution imageries from "PLANET" etc. to accurately monitor and predict yield, quality and maturity. This spatial data should be calibrated with real time sensor data to ensure accuracy, reliability and confidence in the tool.

Overall Summary

The feedback from growers across different sectors from the survey responses, discovery interviews and design led workshops, show there is genuine grower need and opportunity to invest in smart tools that could meet specific areas of farm stress and importantly improve production. A common theme was grower dissatisfaction on some of the current technologies with a lot of individual data streams. Growers emphasised the need for an integrated solution that meets individual crop and unique farm needs, particularly solutions that are reliable/predictable. All growers agreed the industry needs to be 'tech prepared' for future changes e.g. water usage, chemical application restrictions, 'these impacts need to be caught early'. Growers were unanimous in the need for a data integration platform that can correlate between irrigation, nutrition, pest & disease, yield and quality needs. Impeding factors on growth or issues needing resolving to sustain future growth included the need for a trained workforce in middle management, agronomists and on ground farm hands in both Protected & Broad acre farming. Smaller grower issues were also highlighted, although not significant in scale these cause large stress and investigation would have significant impact on profitability if suitable solutions were developed.

Feedback from the 2 design lead workshops reinforced the responses collected from growers in the surveys and discovery interviews, i.e. there are big, compelling issues in the future of horticulture in Australia and there is need for real time whole farm management systems. All relayed the need for simple user friendly, reliable tech for pest and disease management & integrated systems, including early warning and forecasting or a prediction type model that could inform yield.

In conclusion, there is opportunity for a significant Hort Frontiers Digital Horticulture project to address the challenges and opportunities outlined in this report that industry is facing. The use of appropriate real time technology and associated management and decision-based tools will greatly benefit the Australian Horticulture Industry.

Recommendations

Recommendations:

Recommendation 1:

Data integration and organisation strategies are very important for horticultural industries because data contains the keys to profitable and cost-effective crop management. Insights derived from data integration could help horticultural industries to identify best management practices, generate more revenue, predict future trends, optimise current operational efforts and produce actionable insights.

Recommendation 2: Predictive analytics and modelling using historical data to predict future events. The combination of real-time events with historic patterns allows predictive analytics. Such analysis will allow crop scientists and managers to solve current issues and prescribe solutions in real-time.

Recommendation 3: Precision irrigation has under-delivered in horticultural industries mainly because it has been based on technologies which only focus on automation, with less effort in incorporating the physiological principles of crop responses to environmental variation. Most of the current automated systems do not account for a whole-farm precision agriculture approach which accounts for the physiological processes underlying the relationship between environment and crop development, growth and yield (“zone management”) which bridge yield gaps, increased farmer profit and reduce risk. This is the reason why the Phytech system failed to achieve the required fruit size or improve yield in almonds.

Recommendation 4: The ability to accurately predict fruit/produce yield, size, quality, maturity, and time to harvest is a major gap identified. This was seen as possibly one of the greatest unmet needs and that there was no technical or human mechanism to accurately determine these factors in almost any crop at any substantial scale. Such a capability would provide significant benefit to the growers and their customers and allow for enhanced management of their value chains to ensure consistent supply and therefore consistent prices and availability for consumers. The proposed camera system in development by Tasmania and WSU team and other optical systems could potentially offer this capability.

Recommendation 5: Phytophthora is a significant issue across horticultural industries, specifically avocado, citrus and banana. There is currently no method to determine progression of this condition, hence growers spray lots of expensive chemicals as a preventative measure. Developing real time sensor technology to monitor this disease would be of significant value for these industries.

Recommendation 6: Hull Rot, Carob moth and Carpophilus beetle is a significant issue affecting the almond industry and Spotting bug for Avocado; both remain an unresolved pain. Many of the tree fruit and nut producer's spoke about the complexity of managing pest control and bee pollination. As such there is an increased focus on biological control, to avoid impacting the pollination process. Gap is no availability of ground truth information due to lack of accurate pheromone. Identifying the pheromone blends for improved monitoring and population estimation of carpophilus beetle will help growers in precise monitoring of the pest. The ground truth data obtained from these traps could be used for validating hot spots identified in visualisation maps developed through integrating irrigation, temperature, humidity, and disease presence to enhance control of this pest.

Recommendation 7: Data security and sharing is a major problem - growers are willing to share data to gain insights into common problems that are not competitive in nature. Analysis of data from multiple farms/ across multiple industries to understand the common issues like progress of hull rot/phytophthora, may enable identification of microclimate across different regions which can be monitored for the reduction of pre-emptive sprays, which are costly. One of the main gaps is even though huge amounts of data are collected across industries, there are no defined foundational datasets, interoperability is still an issue and good data management skills are still to be developed.

Recommendation 8: User friendly delivery models and need based prompting. A user-friendly output like **visualization** allows growers to better absorb the data and see new paths. This can help to identify new patterns and trends that were impossible to see using tabular data. It allows decision-makers to view data using graphical representations including charts, fever charts, and heat maps.

Recommendation 9: Industry education and training on the monitoring system needs to be considered while developing the program. Strategies to monitor, measure adoption and promote marketing of successful outcomes.

Road map for Phase 2:

To address these recommendations a follow up program on Phase 2-Real time decision support system for remote monitoring of crops is proposed.

Proposed objectives for Phase 2 program:

Objective 1:

Develop a datahub enabling integration and analysis of industry specific data sets across providers – sensor, satellite, drone, weather, farm equipment etc.

Objective 2:

Design industry specific baseline survey to collect historic data on crop production, farm management and other practices. Integrate the information in the proposed data hub and develop models that capture important trends on predictive modelling of yield, pest, and disease incidences.

Objective 3:

Modify/develop and/ or trial existing novel technologies to meet the demands of individual industries like Almond, Avocado, Macadamia, Citrus, Banana, Sweet potato, and Vegetables. Tailor irrigation monitoring tools through integrating with data sourced from satellites, aerial images and ground-based sensor systems for scaling up monitoring at a landscape level. This proposed tool, to be calibrated with real time sensor data to ensure accuracy, reliability, scalability, and confidence in the tool. Related IP to be discussed and agreed with relevant partners.

Objective 4:

Engage with relevant research programs and investigate the utility of diagnostics tools for improved monitoring of fruit/produce yield, size, quality, maturity, and time to harvest. Implement electronic documentation and data capture mechanisms. Integrate plant physiological metrics determined for specific crops / cultivars into models used for automated systems (e.g., irrigation and nutrient delivery) to improve forecast of yield. Predictions to be continuously improved by feedback between forecasts and real time measurement systems.

Objective 5:

Investigate the efficacy of sticky cards/spore traps/novel biosensors/volatiles concentrations for detecting soil borne fungus Phytophthora and integrate the monitoring tool on soil moisture data for scaling up monitoring at landscape level. Test and trial methods for automating sticky/biosensors/spore traps offering a low-cost solution to spore or small insect trapping for real time general assessment of a pathogen or species population.

Objective 6:

Standardise the effectiveness of the current pheromone trapping mechanisms. Further, monitor threshold using pheromone traps and correlate with hot spots identified in maps. Explore the opportunities for trap automation through collaborating with relevant organisations like IMap, DTN, RapidAIM etc.

Objective 7:

Develop a grower network with representatives from major horticultural industries. Finalise terms of reference for data sharing and develop a foundational data set. Digital platforms like Microsoft Farm beats can be used to integrate the compliance rules and requirements to achieve data security and growers privacy.

Objective 8:

Develop user friendly interface for data visualisation and comparison with prompt for action on real time basis.

Objective 9:

Develop a participatory action research model involving industry in the technology translation right up front. Adoption, communication, and marketing pathways to be developed and implemented with collaborating industries. Include a strategic plan for testing and monitoring growers attitude, perception and constraints and identify measures to validate these characteristics. Monitor and map industry assumptions at regular intervals.

Intellectual property, commercialisation and confidentiality

The report must be confidential as the all the information shared by the growers along with their name has been shared in here.

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Appendices

All the appendices will be provided separately.