Final Report

Adoption of precision systems technology in vegetable production

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Delivery partner:

Department of Agriculture and Fisheries Queensland

Project code:

VG16009

Project:

Adoption of precision systems technology in vegetable production VG16009

Disclaimer:

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Content

Summary

The project 'Adoption of precision systems technology for vegetable production' generated significant evidence for precision agriculture (PA) implementation in vegetable systems. Given the relatively low adoption and knowledge base of precision agriculture in vegetable production systems; the project sought to engage producers and commercial providers in order to develop underlying spatial management approaches and evidence of crop variability. This involved establishment of key grower led case study sites across Australia for increased adoption of a broad range of PA technology and approaches.

The project significantly increased knowledge and awareness of how PA approaches can be applied to vegetable system using a broad suite of communication products including 12 case studies, 8 factsheets, 4 'Youtube' style videos, 2 webinars and 15 industry magazine articles. The project connected over 900 vegetable industry representatives with the latest application of PA approaches in vegetable systems through 23 face to face extension activities.

The project achieved the development of accurate and reliable yield prediction capabilities from remotely sensed satellite imagery in carrots and sweet corn across the country. Overall accuracy of the forecasted yield were 82% (Tasmania) and 91% (Western Australia) and ranged from 74-99% accuracy.

The project facilitated increased adoption through a collaborative approach to implement a range of PA technologies and practices across a range of vegetable productions systems. These include: crop sensing imagery, yield forecasting from remotely sensed crop imagery, yield and profit/loss mapping, a range of soil mapping technologies, variable rate application, precision drainage technologies and various drone applications.

Over 90% of grower co-operators indicated continued use of PA approaches implemented through the project with 72% expanding to other precision technologies. All project co-operators indicated that involvement in the project accelerated PA adoption, some by more than 2 years.

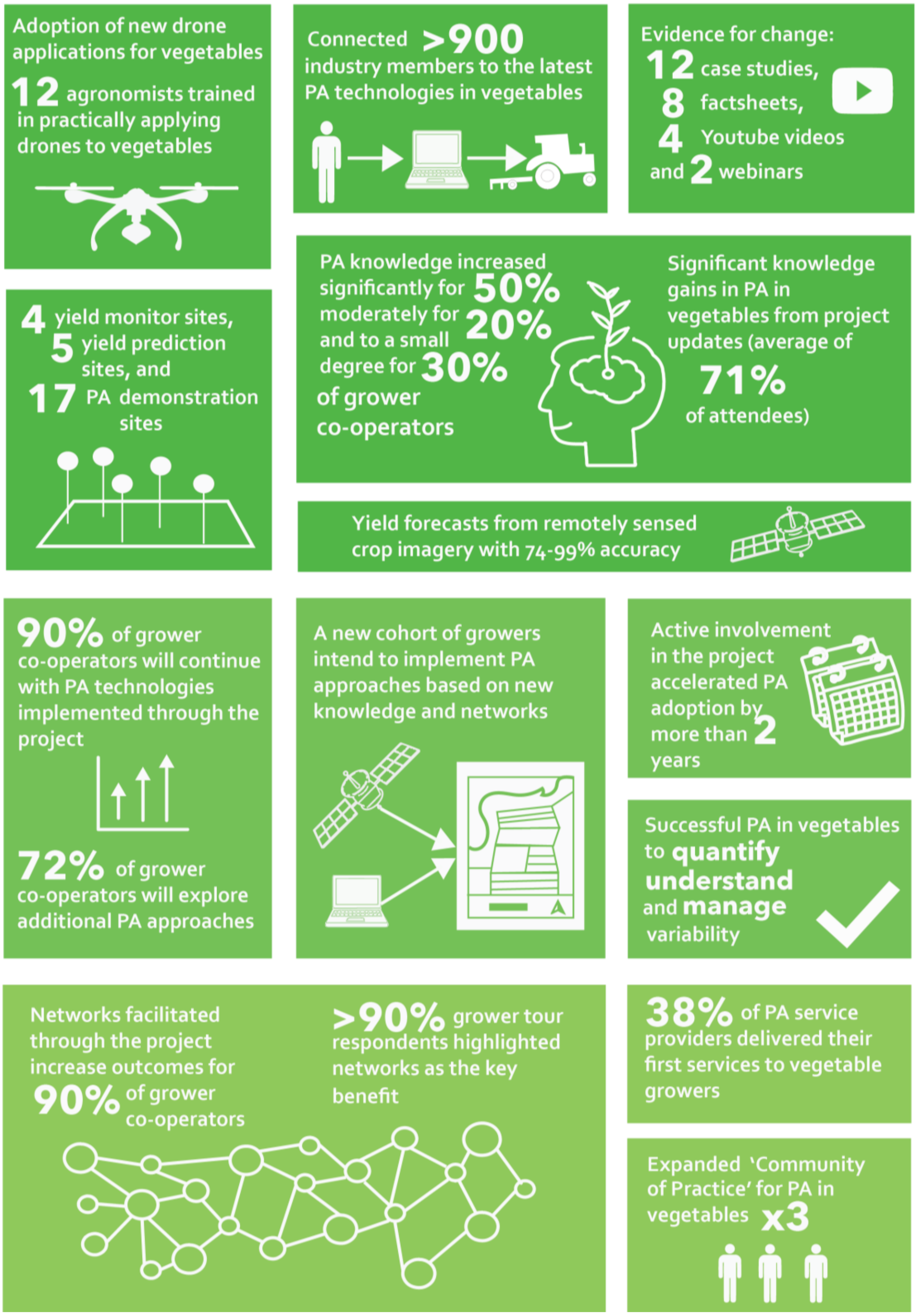
Key learnings from the project include:

- Spatial variability in vegetable production systems is sufficient to have significant impacts on crop productivity and profitability and warrant precision approaches to manage this and PA technology and management options were successfully implemented.
- PA adoption in vegetables needs to be targeted at addressing particular issues rather than focused on technologies alone.
- There is a ready cohort of growers across Australia that are primed for PA adoption with support through future investment.
- Building capacity in PA service providers and regional support networks would help address current limitations in this area that have been identified as a key barrier for PA adoption in vegetables across the country.

Key recommendations from the project include:

- Given an observed disparity in PA adoption between states and regions, there is a need to understand the regional enablers and barriers that could explain these differences.
- Leverage the outcomes and networks developed during the project through VG18000 'National vegetable industry communications program' for further outcomes.
- Facilitate a process of communication for the developing community of practice.
- Further research and development is required to effectively deploy yield prediction from remotely sensed imagery as a commercial service as well as guarantee the robustness of the approach across all growing regions.
- There is great potential to similarly evaluate the potential of remote sensing technologies for the improved monitoring of high risk pest and diseases, including those of high biosecurity importance.
- Widespread PA adoption will require a more robust extension pathway which was repeatedly highlighted throughout the project.

Figure 1. Infographic depicting a summary of project outcomes



Keywords

Precision agriculture

Adoption

Remote sensing

Sensing

Mapping

Technology

Yield prediction

Variability

Introduction

Precision agriculture (PA) encompasses a suite of practices and technologies to identify, understand and manage the inherent variability that exists at a spatial level across agricultural production systems (Bramley, 2009). Depending on the extent and nature of the variability, it can have a significant impact on yield, quality and profitability of vegetable production (Limpus et al., 2016). Worldwide, agricultural management and production is likely to be increasingly associated with ag-tech areas such as Internet of Things (IoT), SMART technologies, drones, robotics and automation. With precision spatial technologies underpinning these ag-tech areas, the Australian vegetable industry will need to increase adoption to remain competitive and viable.

While interest and investment in agricultural technologies is at a high, prior to 2015, there had been minimal investment by the vegetable industry and providers in precision agriculture technologies and their application to vegetable production systems. Consequently, adoption of PA across the vegetable industry has been limited to a few early innovators. Despite a range of commercially available technologies and practices with immediate application in vegetable production systems (crop sensing, soil mapping, variable rate, yield monitoring, spatial data platforms), there has been a lack of regionally relevant case studies and dedicated support for both producers and the PA service industry to increase adoption.

With an emphasis on precision agriculture technologies and specifically adoption of these approaches and technologies, VG16009 links with both Outcome 3 Improved farm productivity (Advanced technologies) and Outcome 5 Improved industry capabilities for adoption and innovation (Communication and Extension/Innovation Support) of the 2017-2021 Vegetable Strategic Investment Plan.

While this project represents the first national level investment concentrating on the adoption of PA approaches and technologies, it does have linkages to previous investments. It continues on from the Queensland focused INNOV-312 *'Adoption of variable rate technology in Queensland's intensive vegetable production systems'* which was the first concerted effort in Australia to optimise advanced spatial management technology in vegetable systems and produced some of the first case studies in PA in vegetables. VG16009 project activities were also directed towards expanding the PA Community of Practice that was initiated through VG15704 '*Grower Study tour of New Zealand: precision vegetable production'.* With significant industry investment in the development of robotics, automation and sensing systems in horticulture (VG15003, VG15023, VG15024, VG13113, RnD4Profit14-01-008) and some desktop work on the application of PA/mechanisation technologies for vegetables (VG05060, VG08087, VG13081), VG16009 has facilitated necessary steps in the adoption of agtech in vegetables.

The available technology, and the practices that support it, can provide the precision required for vegetable producers to progress to more innovative approaches in crop and data management. This project addressed the low knowledge base and adoption levels of PA in vegetables by developing a suite of producer led case studies that focused on a range of PA approaches in collaboration with producers and regional PA expertise (*the supply chain*). These case studies focused on management outcomes for vegetable production systems and cost benefit information wherever possible. Remote sensing technologies are effective tools for quantifying and managing the spatial and temporal variability in crop performance across many cropping systems. In vegetables, and particularly, root crops such as carrots, the implementation of these sensors is limited. The project progressed yield prediction capabilities from remotely sensed high resolution crop imagery in carrots and sweet corn. In this project, commercially available satellite remote sensors were evaluated for their accuracies in providing surrogate yield maps and yield forecasts pre-harvest, for both carrots and sweet corn crops.

Project updates and outputs were also extended through linkages with the VegNET program. As a result the vegetable industry now has evidence for change in the adoption of PA approaches and technologies.

Methodology

VG16009 was a national program over three years, led by DAF but delivered through a series of collaborative agreements. The program was aimed at increasing the adoption of precision approaches in vegetable systems, specifically targeting vegetable producers, vegetable agronomists and precision agricultural service providers to deliver outcomes across Australia.

Governance

Collaborator agreements were established with multiple organisations across Australia to deliver the outputs and outcomes for VG16009. These included University of New England (UNE), University of Tasmania (UTAS), Harvest Moon, Vegetables WA, Primary Industries and Regions, South Australia (PIRSA) and the Society of Precision Agriculture Australia (SPAA).

DAF convened a project advisory panel comprised of project personnel, vegetable producers involved in the project and agronomists. This group met on four occasions throughout the project and provided advice on initial direction of the project, feedback on progress and ideas for additional work program activities.

Review

A review of international PA systems and technologies and the potential and opportunities for application in Australian vegetable systems was undertaken as part of the project by UNE, UTAS and DAF.

Demonstration/case study sites

Case study and demonstration sites were established in each state (with the exception of the Northern Territory as negotiated in project development). These sites were a mix of new and existing (engaged through previous R&D investment) case study farms. Sites were identified through various means, including project collaborator networks, VegNET networks, previous involvement in PA investment (VG15704 and INNOV-312) and cold calling by the project team.

Table 1. PA demonstration and case study sites

Demonstration/case study sites	
20	PA technologies and practices were implemented across 20 vegetable businesses. These included yield prediction sites, yield monitor sites and demonstration of other PA technologies. Some sites hosted more than one demonstration, for example, a yield prediction site as well as other PA approaches such as yield monitoring or soil mapping.
17	*Precision agriculture technology demonstrations* These sites included a ranges of technologies from soil mapping, variable rate applications, precision drainage modelling and technology, crop sensing approaches and application of drones and imagery analytics.
5	*Yield prediction sites* Four yield prediction sites were established in carrots in Tasmania, Queensland, South Australia and Western Australia. • Kalfresh (Kalbar, QLD) • Harvest Moon (Forth and Sassafras, TAS) • Parilla Premium Potatoes (Parilla, SA) • Center West (Gin Gin, WA) One yield prediction site was established in sweet corn in NSW. • Simplot (Bathurst NSW)
4	*Yield monitor sites* Yield monitors (carrot harvester) were installed at 3 sites across Australia, with a fourth existing site also included.

A broad mix of precision approaches were implemented, customised and evaluated at these sites. Technologies implemented at these sites encompassed:

- soil sensing and mapping technologies (EM38, Veris®, Soil Information Systems™, Radiometric and grid sampling);
- crop sensing technologies (satellite and drone);
- yield monitoring technologies (carrot harvesters);
- variable rate technologies (soil amendment, nutrients and irrigation);
- precision drainage modelling and installation and;
- application of drone technologies and imagery analytics (automated plant counts, 3D modelling, flowering area estimation for maturity assessments).

The majority of these sites were developed into case studies (see appendices). However, in some cases the sites did not progress beyond demonstration of a particular technology or practice. Some sites involved the provision of hardware on farm. For grower co-operators engaged through previous R&D projects, the project offered ongoing support and development.

Farm action plans were developed for each case study/demonstration site. This outlined in detail the roles and responsibilities, equipment required, critical data capture and groundtruthing events based on the individual farming system and technologies to be implemented at each site.

The key areas of investigation at each site centred on the following questions:

- Is there farm/block variability?
- Is the observed/quantified variation having an economic impact?
- Can this variability be understood and managed?
- Are current management practices/equipment suitable for addressing any variation?
- Will a precision approach elicit a yield/quality response?
- What is the return –on –investment?

By necessity these documents were ultimately more fluid than intended, as co-operating growers expanded on the PA practices they were implementing as they became aware of other technologies and additional PA approaches.

Yield prediction

The relative small field sizes and the high rotational systems restrict the systematic implementation of other PA technologies such as tractor mounted yield monitors, used in cotton, sugar cane, and grains.

In this project, commercially available satellite remote sensors were evaluated for their accuracies in providing surrogate yield maps and yield forecasts pre-harvest, for both carrots and sweet corn crops. Yield monitoring capabilities, similar to those that are available in cotton, sugar cane and grains, are currently not commercially available for most vegetable crops with the exception of root vegetables such as carrots, potatoes and sweet potatoes which must be retrofitted after purchase. Furthermore, yield monitors only provide information at harvesting, therefore too late to assist growers with managing variability within the growing period or forecasting for marketing purposes.

The yield prediction component of the project was led by University of New England (UNE) with assistance by DAF and Vegetables WA, UTAS in logistics, resourcing and coordination of the associated intensive field groundtruthing events. Carrots and sweet corn were selected by the project advisory panel, carrots as a national crop and sweet corn as another high value widely grown vegetable crop. Yield prediction sites included four carrot sites (South Australia, Western Australia, Queensland and Tasmania) and one sweet corn site (New South Wales). Detailed scientific methodology and a summary of results for this element of the project is outlined in Appendix 1.

This work initially focused on establishing whether there was a relationship between yield and reflectance data from remotely sensed satellite imagery at crop maturity. The value of yield forecasting is only realised if the prediction can be achieved in advance of harvest and can therefore be used for market forecast, harvesting logistics or in crop management. Once a relationship between yield and crop reflectance data had been determined at crop maturity, this element of the project then focused on whether accurate yield forecasting could be achieved from early season (approximately 50 days post planting) crop imagery using the same methodology.

A couple of points to note regarding the field work component:

- The field sampling methodology for the yield prediction component in regard to sampling point location was ideal for sampling the full range of reflectance data within the crop. However, this was not necessarily ideal for understanding agronomy and variability within the field.
- The yield prediction component of the project was significantly more time demanding on project resources than originally anticipated due to the intensive field work component and DAF's responsibility in coordinating, resourcing and carrying out the field sampling component. Future work in this area would require consideration and provision of the resources required at the project development stage.
- The nature of the vegetable production system with intensive production and rapidly moving harvest dates also meant that some field work events ended up not aligning with harvest or else fields were harvested prior to field work being completed.
- Many yield prediction sites do not have the operational design to provide a complete value for harvested yield (generally waste isn't measured or documented or even total harvested tonnages) which limited comparison with forecasted yield.

Data Science

UNE was responsible for sourcing high resolution satellite image products and post –processing and analysis of this imagery. Where time permitted, UNE also processed other spatial data such as EM38 soil mapping and some yield monitor data. However, as the project progressed this was increasingly outsourced to commercial data processing service providers to facilitate relationships with these providers and for continued future use of these technologies as a legacy of this project.

The majority of case study co-operators were supported by a range of service providers which included data science and processing components. These include yield monitor data processing, precision drainage modelling, drone imagery and outputs and soil mapping outputs. A range of data access platforms were used throughout the project including PCT/agcloud, Decipher Ag, Atlas Micasense and DataFarming.

Communication and Extension

The key elements of the communication and extension program were:

Evidence for change in case studies: With limited documented examples of PA adoption in vegetables prior to VG16009, a key focus for the project's Communication and Extension program was the development of evidence for change through the producer led regional and crop specific case studies.

Communication product development: DAF in conjunction with SPAA developed communication products (fact sheets, case studies, workshop events, and social media). The DAF project team was responsible for all communication product content and SPAA for coordinating design and layout of the factsheets and case studies, and as a central source for social media using the #PA4Veg hashtag as well as coordinating and delivering workshop events. In an agreed change to the proposed methodology, DAF led the video product development so SPAA resources could be redirected to other project deliverables. A six monthly project newsletter was distributed to all project stakeholders (project partners, grower cooperators, PA providers) and the VegNET network. Communication products are listed in the Outputs section of this report and in Appendices 5-6.

Community of Practice: Grower tour and cross-linking events were built into the Hort Innovation funded project VG16009 'Adoption of precision systems technology in vegetable production' as an opportunity to further develop a Community of Practice for precision agriculture in vegetables. Community of Practice refers to an informal group of people with a common practice that are 'engaged in a process of collective learning' (Wenger-Trayner and Wenger-Trayner, 2015). The goals of these events were to expose participants to alternative and innovative farming practices in vegetable production and encourage peer-to-peer learning and capacity building through the creation of networks.

Extension program: The extension program for this project aimed to capitalise on existing industry investment, particularly VG15004, by linking with VegNET events wherever possible. This was also highlighted by Hort Innovation at project advisory group meetings as a key consideration when planning events. Outsourcing extension logistics to those based regionally allowed for better promotion to a local industry and avoided duplication of events. DAF, in liaison with SPAA, also coordinated separate events. Extension event presentations concentrated on sharing progress at cases study sites to highlight the evidence for change the project was generating.

Evaluation: SPAA conducted a phone interview survey with a range of project stakeholders on behalf of DAF in late 2019. The questions were designed by DAF to collect a range of feedback from 4 stakeholder groups: PA implementation grower cooperators, yield prediction site cooperators, PA service providers and project partners. SPAA was selected to undertake the interviews, in particular for grower cooperators, yield prediction site cooperators and project partners, to avoid any inhibitions interviewees may have had in providing honest feedback to DAF as the project lead. The results of the survey are presented in Appendix 9.

Other evaluation data included narratives collated throughout the project, extension event feedback and documenting grower co-operator attitudes and feedback obtained throughout the project.

Outputs

Table 2. The project outputs for VG16009 are outlined below.

Number	Description
Project Newsletters Appendix 2	
5	Issue 1 – July 2017 Issue 2 - January 2018 Issue 3 – August 2018 Issue 4 – February 2019 Issue 5 – August 2019
Literature review	
1	*'Literature review on the available and emerging precision agriculture technologies for the Australian vegetables industry.'* 2018. Angelica Suarez, John McPhee, Julie O'Halloran, Celia van Sprang and Andrew Robson. A review of international PA systems and technologies and the potential and opportunities for application in Australian vegetable systems was undertaken as part of the project by UNE, UTAS and DAF. https://www.horticulture.com.au/growers/help-your-business-grow/research-reports-publications-fact-sheets-and-more/literature-review-of-adoption-of-precision-system-technologies-in-vegetable-production/
Yield prediction outputs	
44	Each yield prediction site had multiple image captures and field events across multiple fields. A summary of the yield prediction output was developed for each field with total of 44 yield prediction outputs produced. An example is in Appendix 3.
8	Data packages for each yield prediction site were collated by DAF. An example of a data package is presented in Appendix 4.
Yield maps	
>100	Yield monitors were installed at 3 sites across Australia, with a fourth existing site also included. In total over 100 carrot yield maps were processed and generated across the 4 yield monitoring sites.
Factsheets Appendix 5	
8	• Remote sensing to predict yield of vegetable crops • Soil mapping in vegetables using EM38 • Yield monitoring in vegetables using load cells • Automated plant counts in broccoli using UAV imagery • Soil sensing in vegetable systems. Soil mapping technologies • Getting started in PA in vegetables • Practically applying drones in vegetables • Variable rate technologies in vegetables
Case studies Appendix 6	
12	Using innovative technologies to develop drainage models Using PA technologies to manage salinity and sodicity

	Using VR technology to manage within-field variability Soil grid mapping and VR application of lime and nutrients Yield and profitability mapping in carrots Soil mapping for farm development and infrastructure Precision technologies for drainage design Understanding irrigation requirements with EM38 soil mapping and soil moisture monitoring technology Practically applying drones in vegetables EM38 soil mapping as the basis for understanding and managing soil variability (In final design, layout and approval) Using precision soil mapping technologies to understand variability (In final design, layout and approval) Using soil SIS mapping to understand crop variability (In final design, layout and approval)
Webinar	
2	2nd August 2017 organised by VegNET (RMCG), 42 attendees. • ‘Precision agriculture technology in vegetable production systems’, presented by Julie O’Halloran, DAF. • ‘Precision agriculture; the what, why, how and when’ presented by John McPhee, Tasmanian Institute of Agriculture (TIA). 24th March 2020 organised by DAF, 33 attendees • ‘Practically applying PA technologies and approaches in vegetables’ presented by Julie O’Halloran, DAF. • ‘Remote sensing of root crops: an alternative for yield forecasting’ presented by Dr Angelica Suarez, University of New England. • ‘PA technologies in vegetable production systems’ presented by John McPhee, Tasmanian Institute of Agriculture (TIA).
Training events/ capacity building	
4	Bowen Drone Training (6 participants) 21-22nd November 2019 Bundaberg Drone Training (3 participants) 8-9th April 2019 and 6-7th June 2019 Werribee South Drone Training (2 participants) 23-24th August 2018 Landforming technology late 2018
Videos	
4	Precision drainage technology in vegetables Using drones in vegetables Variable rate technologies Getting started in PA in vegetables
Podcasts	
2	Growers/agronomists coordinated by DAF, interview questions developed by DAF and podcasts in progress by Ausveg communications team.
Industry magazine articles and other media Appendix 7	
15	*Vegetables Australia*

	Vegetables Australia May/June 2019 Automating plant counts using drone imagery. Pages 42-43. Vegetables Australia September/October 2018 – Optimising yield prediction in vegetable crops. Pages 12-13 *SPAA Precision Ag News* SPAA Precision Ag News Winter 2017 Volume 13 Issue 3 project introduction SPAA Precision Ag News Spring 2017 Volume 14 Issue 1 project article – Veggie variation SPAA Precision Ag News Autumn 2018 Volume 14 Issue 3 – PA enabling intensification Pages 7-9 SPAA Precision Ag News Spring 2019 Volume 16 Issue 1 - PA Tackles yield prediction Pages 22-23 *WA Grower magazine* WA Grower - Winter 2017:Adoption of precision systems technology in vegetable production WA Grower – Spring 2017: Can precision agriculture add value in vegetable production systems? WA Grower – Summer 2017: Adoption of precision systems technology in vegetable production; Capel Farms trial location (distribution 1,300 vegetable, potato and pome growers) WA Grower – Autumn 2018: Mapping variation at harvest; yield monitors on carrot harvesters - Allan McKay, Julie O'Halloran, Celia van Sprang and Ian layden Page 40-41 (distribution 1,300 vegetable, potato and pome growers) WA Grower - Winter 2018: Yield prediction of vegetable crops - Julie O'Halloran, Celia van Sprang and Angelica Suarez Page 63-64 (distribution 1,300 vegetable, potato and pome growers) WA Grower - Summer 2018: Automated plant counts from UAV imagery - Julie O'Halloran and Celia van Sprang Pages 52-53 (distribution 1,300 vegetable, potato and pome growers) WA Grower - Summer 2018: Vegetables WA Industry Summit & Grower Group Tour by Rebecca Blackman, Pages 8-9 WA Grower - Summer 2018: Vegetables WA Extension Officer Update by Sam Grubisa, Pages 42-43 WA Grower - Winter 2019: Advert in WA Grower magazine: Page 7 – Expressions of interest Grower Tour *Vegetables WA* vegetablesWA E-News – Expressions of Interest grower tour appeared in on 6th June 2019 & 31st May 2019 vegetablesWA Website – Blog post https://vegetableswa.com.au/eoi-grower-study-tour-precision-systems-technology/ *Radio* ABC Country Hour interview, John McPhee, TIA. 8th November 2019 – yield prediction in carrots
Industry updates/ workshops	
23	Project team members have presented at 23 extension/communication events throughout the

duration of the project. Where possible these events obtained attendee feedback.

22nd June 2017 Soil borne disease field walk, Bathurst, NSW. (approximately 15 attendees) Project update presented by Julie O'Halloran, DAF.

8th August 2017 Grower update Kalbar, QLD. (25 attendees) Project update presented by Ian Layden, DAF.

5th September 2017 (8 attendees) Project update at Gatton, QLD agronomist update, presented by Celia van Sprang, DAF.

11th September 2017 Project overview and update to VegNET meeting, Townsville, Queensland.

27th October 2018 Vegetables WA grower forum Perth, Western Australia. (90 attendees) Project update by Rachel Lancaster and Allen McKay.

17th November 2017 Hort Innovation and Bundaberg Fruit and vegetable Growers AGM, Bundaberg Queensland. Project update presented by Celia van Sprang, DAF.

27th April 2018 Gippsland Grower forum, Lindenow, Victoria. (11 attendees) Project update presented by Julie O'Halloran, DAF.

27-28th April 2018 Agrotrends, Bundaberg, Queensland manned by Celia van Sprang and Rhianna Robinson, DAF.

5th June 2018 PA workshops, Mannum, SA. (18 attendees) Coordinated by SPPA, presenters Celia van Sprang, DAF, Angelica Suarez, UNE, Mel Fraser, PIRSA.

5th June 2018 PA workshop Virginia, SA. (11 attendees) Coordinated by SPPA, presenters Celia van Sprang, DAF, Angelica Suarez, UNE, Mel Fraser, PIRSA.

15th August 2018 Lockyer Valley Growers update, Gatton, Queensland. (approximately 44 attendees) Project update presented by Julie O'Halloran and Celia van Sprang, DAF.

25th October 2018 Vegetables WA Grower Tour, Woodridge, WA. (approximately 47 attendees) Project update presented by Julie O'Halloran, DAF, Celia van Sprang, DAF and Angelica Suarez, UNE, NSW.

26th October 2018 Vegetables WA Grower Summit, Perth, WA. (115 attendees) Project update presented by Julie O'Halloran, DAF Qld and Angelica Suarez, UNE, NSW.

20th February 2019 (approximately 24 attendees) Farm walk at Rob Tole's farm, 'Greenvale', at Cressy, Tasmania to demonstrate the use of an iGrade controlled land plane to undertake land forming for improved surface drainage.

21st February 2019 (12 attendees) Farm walk at Rob Tole's farm, 'Greenvale', at Cressy, Tasmania to demonstrate the use of an iGrade controlled land plane to undertake land forming for improved surface drainage.

17th April 2019 Tasmania PA expo (approximately 250 attendees), Hagley, Tasmania presented by Celia van Sprang, DAF Qld and Angelica Suarez, UNE.

3rd April 2019 SPAA PA workshop Bowen, Queensland (36 attendees) presented by Julie O'Halloran, DAF Qld.

6th November 2019 VegNET update Forthside, Tasmania (15 attendees) presented by John McPhee, TIA.

23rd October 2019 VegNET update Virginia, South Australia (41 attendees) presented by Celia van Sprang, DAF Qld

25th November 2019 VegNET field walk Werribee, Victoria (17 attendees) presented by Celia van Sprang, DAF Qld and Stu Grigg, Ag-Hort Consulting

26th November 2019 VegNET update Gippsland, Victoria (11 attendees) presented by Celia van Sprang, DAF Qld

6th December 2019 VegNET update Richmond, NSW (35 attendees) presented by Julie

	O'Halloran, DAF Qld 5th February 2020 SPAA PA event Gatton, Queensland (32 attendees) presented by Celia van Sprang and facilitated by Julie O'Halloran
Conference presentations	
13	SPAA symposium, 'Practically applying PA technology in vegetable production', 7-8th August 2017, presented by Celia van Sprang, DAF Qld TropAg17, 'Remote sensing applications for agricultural and horticultural crops: From the individual tree to whole of industry', 20-22nd November 2017, presented by Luz Angelica Suarez, UNE Australian Society of Horticultural Science, Future of Horticulture, Brisbane, 18th June, "Precision systems technology in vegetable production' presented by Julie O'Halloran, Qld DAF. Hort Connections 2018, 20th June 2018, Brisbane, QLD. *How can I make better decisions using data?,* Angelica Suarez, UNE SPAA Symposium, 11th September 2018, Adelaide, 'Precision agriculture technology in vegetable production' presented by Julie O'Halloran, DAF Qld. SPAA Symposium, 9th September 2019, Launceston. 'Innovation in vegetables: putting PA into practice' presented by Julie O'Halloran, DAF. SPAA Symposium, 9th September 2019, Launceston. A vegetable growers' journey with PA, presented by VG16009 grower tour participant Andrew Johansen, Mulgowie Farming Company. SPAA Symposium, 9th September 2019, Launceston. A vegetable growers' journey with PA, presented by VG16009 grower tour participant Troy Walker, Phantom Produce. SPAA Symposium, 10th September 2019, Launceston. 'Root crop yield forecasting using satellite remote sensing' presented by Angelica Suarez, UNE. Tasmanian Spatial Information Council Executive Forum (TASSIC) 7th November 2019, Hobart presented by John McPhee, TIA Trop Ag 2019, 12th November 2019. Horticulture symposium 'Using precision information systems for advanced decision making in vegetables', chaired by Julie O'Halloran. Presentations included: • 'Yield forecasting using remote sensing in vegetables', Angelica Suarez, UNE • 'Using precision information technologies to understand crop variability', Celia van Sprang, DAF. • 'Application of precision agriculture techniques and variable rate technology in horticultural production in north Queensland', Chris Monsour, Prospect Agriculture • 'Drones for more vegetables – pathways to a commercial reality', Nathanial Parker, Airborn Insight. • 'Challenges and opportunities for PA adoption in vegetables', Julie O'Halloran, DAF.
Grower tour/cross learning experiences	
2	The VG16009 Grower Tour ran from the 4th to the 10th of September 2019 with 16 grower participants. The objective of the tour was to facilitate peer to peer learning and expand the current community of practice. Site included vegetable growers in South Australia, Victoria and Tasmania who have implemented PA practices into their businesses. The tour report is included in Appendix 8. Case study growers Val and Sam Micallef from Alandale Farms requested a site visit and discussion with Fresh Select and Stu Grigg, Ag-Hort Consulting. This was facilitated by DAF and held in January 2019 at Fresh Select's Werribee facility. The aim of this visit was to learn more from Fresh Select and Stu about their adoption of soil mapping technologies (EM38 and grid

	soil mapping) and variable rate applications.
Project reference group meetings	
4	Reference Group Meeting, 7-8 February 2017, Melbourne. Reference Group Meeting, 10-11th July 2017, Brisbane. Reference Group Meeting, 20th June 2018, Brisbane (to coincide with Hort Connections). Reference Group Meeting, 26th February 2019, Sydney.
End of project survey	
1	An end of project phone survey was conducted in late 2019. The survey targeted four stakeholder groups: grower cooperators, yield prediction site cooperators, PA service providers and project partners. The survey report is presented in Appendix 9.
Social media	
52	Social media post were comprehensively confined to Twitter. Over the course of the project there were 52 tweets distributed by the project team and participants. Tweets focused on field work activities, extension and training events. These are listed in Appendix 10.

Outcomes

The key objective of this project was to increase the adoption of precision agriculture technologies and approaches within the Australian vegetable industry. Project activities and outputs facilitated a range of outcomes as per the project MERI plan and Program Logic (Figure 2) that contributed to this objective. These outcomes are:

- increasing the awareness and knowledge of what precision approaches can offer vegetable production systems (Changes in knowledge)
- increasing precision technology skills in the vegetable supply chain / amongst service providers (Building capacity)
- increasing adoption of precision agriculture technologies by vegetable producers (Changes in practice)
- Increasing and improving networks and relationships to better position the industry to adopt new approaches

Changes in awareness and knowledge

- Given previous examples of precision technology implementation in vegetables were limited, a key outcome of this project has been the development of evidence base to engender change more broadly across the industry. From project activities, over 20 demonstrations of PA technologies on commercial farms, 12 case studies, 15 industry magazine articles and four 'You tube' style videos have been developed. The key 'take home' message of these products is that there is a suite of soil and crop variability, yield measurement and management tools available to producers and agronomists for implementation
- Five vegetable businesses (4 x carrot and 1 x sweet corn) provided field trial sites for the yield prediction component. Due to the grower contracting operating model of Harvest Moon and Kalfresh, more growers were involved in this R&D through the provision of crops for field work, than the 5 cooperating businesses. This work achieved the development of accurate and reliable yield prediction capabilities from remotely sensed satellite imagery in carrots and sweet corn. Overall accuracy of the forecasted yields were 82% (Tasmania) and 91% (Western Australia), and ranged from 74-99% accuracy. Note that whilst strong relationships were also achieved between measured yield and canopy reflectance for crops sampled in Queensland and South Australia, final commercial yields could not be obtained (due to shed operational design) and therefore compared to predicted total yield. Nonetheless, these businesses have sought to expand and improve their pack-house measurements to include tracking harvested product from the field to the packing shed which will include measurement of total tonnages harvested.
- Project activities were instrumental in increasing awareness and knowledge of available PA technologies and how they can be applied to vegetable production systems. Over 900 vegetable industry representatives were connected to the latest application of PA technologies in vegetables through project updates at 23 extension events across Australia. Content at these events focused on case study/demonstration site activities, including PA technologies applicable to vegetables, PA technologies implemented on commercial vegetable farms, on-farm trial results, management outcomes and costs benefit analysis. Event feedback (not all events) demonstrated that in terms of increasing awareness and knowledge, an average of 71% (actual number that % represents) of evaluation respondents indicated that their knowledge of PA technologies and approaches in vegetables was increased. The PA component at these events always ranked highly in terms of interest and usefulness of the information.
- Narratives documented by the project team supported this quantitative data in that the project had successfully increased awareness of PA technologies, however, these narratives did also highlight that some growers were still working through how these technologies could be applied to the vegetable crops they grow and integrated within their production systems.
- Active participation in the project by co-operators increased PA knowledge significantly (greater than 7 out of 10) for 50%, moderately (4-6 out of 10) for 20% and to a small (1-3 out of 10) degree for 30% of co-operators who had some previous experience with PA approaches.
- Key areas of knowledge gains and benefits reported include:
    - Quantification /visualisation of spatial variability one of them
    - Awareness of available PA technologies and adaptation to vegetable systems
    - Greater knowledge of the soil asset and target applications to manage constraints
    - Better forecasting
    - Economic assessments compared with current practices
    - Yield and productivity efficiencies with optimal placement of inputs
    - Mapping for drainage benefits

- Challenges with integrating technology
- The need for groundtruthing and in field data to interpret spatial mapping layers and relate to management outcomes
- The need for high resolution and accurate data

Increasing precision technology skills in vegetable systems

- ***Grower co-operators:*** Grower co-operators gained skills in precision technology as PA approaches were implemented within their farming system. These include: precision technology implementation for management practices such as variable rate applications, precision drainage development, spatial data interpretation, field sampling strategies to ground truth imagery, use of data platforms and mobile applications including prescription map development.

- ***Project partners:*** Some project partners had limited understanding of crop variability and the precision technologies and approaches to address it at commencement of the project. In some cases the greatest learnings came from where things did not work. This was certainly evident in understanding timing of crop sensing applications and strategies for groundtruthing spatial data including use of geo-referencing sampling points.

- ***Commercial service providers:*** Of the commercial PA service providers engaged through the project, 38% had not previously provided any services to vegetable production systems. The intensiveness of vegetable systems has implications for service providers in delivering quality data in terms of technology specifications for vegetables, timeliness of data collection and processing. While there were issues with the quality and timeliness of data from these service providers, it did provide an opportunity for improved understanding of applying PA technology to vegetable production systems.

- The project has achieved increased capacity in drone technologies and applications. This includes:
    - Increasing numbers of agronomists and growers have purchased drone technology and while they have sufficient knowledge and skills in flying the drone these technologies are underutilised and there has been frustration in terms of getting useable data. DAF coordinated four capacity building events focused on data processing, analytics and applications relevant to vegetable production. The groups were deliberately kept small as training was practical from flight planning to drone imagery capture and processing. These events had 12 attendees in total and included both commercial and on farm agronomists in Queensland and Victoria. Evaluation of one of these events highlighted the most valuable learnings from the training as increased understanding of image and data processing, applications for drones in vegetables and the reality of drone capabilities. All respondents confirmed that the training had changed how they would use drones in their businesses, primarily around possible applications for benefits to growers.
    - The validation of various drone analytics and applications that had not previously been utilised in vegetables such: as automated plant counts for yield forecasting in crops such as lettuce and brassicas; and flowering area estimation to monitor maturity variability in sweet corn crops.
    - There is an ongoing need for more of these events with further growers and agronomists identified late in the project.

Increasing adoption of precision agriculture technologies by vegetable producers

- The project has successfully increased the number of vegetable growers adopting and trialling precision technologies and approaches. Ninety per cent of project grower co-operators reported that they will continue to use the PA approaches implemented through the project. These include:
    - Soil mapping including EM38, Veris®, grid sampling and analysis
    - Yield monitors
    - Application of drone technology to vegetables
    - Precision drainage technologies
    - Variable rate applications of soil amendments (lime, gypsum) and nutrients.
- Additionally, 72% reported that they will explore the implementation of additional practices. Key areas where PA adoption is likely to expand for project participants include:
    - Drones applications e.g. plant counts
    - Internet or Things sensors for continuous sensing of irrigation and automation

  - Access and interpretation of satellite imagery
  - Soil mapping for VR applications and variable rate seeding
  - Yield monitoring and mapping
  - Robotic weeders, spraying and harvesting
  - Soil moisture sensing
- Participation in the project accelerated the adoption of PA practices for 70% of grower co-operators. These growers indicated that adoption was accelerated by up to 12 months (27%), by 1-2 years (18%) and by greater than 2 years (27%).
- Evidence for change has been critical in achieving increased adoption. The 2019 Grower Tour respondents reported that they were 'Very Likely' (50%) or 'Somewhat Likely' (35.71%) to implement or change practices based on what they observed on the tour. These changes include possible implementation of yield mapping and monitoring, strip tillage, using existing data and using drones for agronomic practices. Extension event feedback highlighted that there was an intent of attendees to make some changes on farm including mapping technologies and yield monitors (30% of attendees at 2019 SA workshop indicated intent to make on farm changes).
- There has been increased use of drone service providers (for both data processing and imagery capture) following drone training and on farm PA demonstrations. This data is based on feedback from services providers and discussions with project co-operators.

Networks and relationships

- *Community of Practice:* The project has significantly expanded the Community of Practice of vegetable growers implementing precision agriculture technologies by approximately 3 fold (n=45). This includes project co-operators but also growers that were not actively involved in the project but through project networks have been identified as early innovators in the implementation of precision systems. Continuing to develop a community of practice is seen as critical for the advancement of the vegetable industry, particularly where technology is concerned. Ninety per cent of the grower co-operators felt that networks developed through the project improved their PA outcomes.
- *Study tour:* In September 2019, 14 vegetable growers and 2 potato growers participated in a study tour to observe and discuss various innovations and applications of precision agriculture (PA) technologies within vegetable systems. This exploited existing knowledge that innovation adoption involves social processes and is enhanced through shared and peer-to-peer learning experiences. Over 90% of respondents rated the networks facilitated through the tour as 'Very Valuable' (57.1%) or 'Extremely Valuable' (37.5%) with fifty per cent (50%) of survey respondents indicating future contact with others in the group. The tour was successful in facilitating networks with like-minded growers and further developing the Community of Practice in precision agriculture in vegetables. Given the level of interest in the this tour study tours continue to be a valuable way to engage growers
- *Extension pathway:* Project co-operators highlighted the need for a more rigorous extension pathway to continue to support PA adoption in vegetables and continued investment in collaboration with growers to implement PA technologies on farm and link growers adopting PA. This was supported by project partners in that extension deliverers within the industry needs to also have basic knowledge and understanding of PA technologies and approaches.
- *Linkages:* The project facilitated improved linkages between grower co-operators and a range of PA service providers. Innovation support was one of the strongest themes arising from industry consultation in development of the Vegetable Strategic Investment Plan 2017-2021. This was reiterated in narratives and feedback collected throughout the project and the lack of support through limited skilled support and service providers was highlighted across all regions.

Figure 2. VG16009 Adoption of precision system technologies in vegetable production Program Logic Model

Objective

Adoption of precision systems technology in vegetable production

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Longer term outcomes

- Increase the number of vegetable producers using precision technologies and practices for improved efficiencies, productivity and profitability.

- Increase the awareness of what precision systems can offer to vegetable production systems

- Increase in precision technology skills in the vegetable supply chain

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Intermediate outcomes

Changes in knowledge/ awareness

- Increased awareness of precision technologies and their application
- Capacity in the use of associated tools and technologies
- Protocols for groundtruthing precision technologies
- Understanding of cost benefits of precision technologies

Changes in practice

- Increased adoption of precision system technologies
- Increased use of tools associated with precision technologies including groundtruthing protocols
- Adoption of intermediate steps to technology adoption
- Use of information from precision technologies in decision making

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Project activities and outputs

Literature Review

Cost benefit analyses

Demonstration Sites

- Farm action plans
- Installation and optimisation of technology
- Testing and monitoring of technology applications
- Groundtruthing, data collection and analysis
- Case study reports

Communication and extension events

- Training events and capacity building
- Field days
- Case studies/ factsheets
- Industry magazines and newsletters
- Community of practice
- Social media
- Cross learning experiences/ field tours

Foundational activities

Reference group established

Communication plan

Project partner agreements

Staff recruitment

Project planning and evaluation

Demonstration site establishment

Stakeholder engagement

Monitoring and evaluation

Effectiveness and Impact

The project was effective in achieving: increased awareness and knowledge of what precision approaches can offer vegetable production systems, increased precision technology skills in the vegetable supply chain and increased adoption of precision agriculture technologies by vegetable producers.

Key learnings given the national scope of the project include:

- A national perspective facilitated insight into PA adoption levels across the country. Significant variability in PA adoption was evident between states and regions. Tasmania and Queensland would appear to be more advanced in implementing PA technologies and approaches than other states. Tasmania in particular exhibited higher PA adoption involving multiple PA technologies integrated into the farming system.
- The lack of precision technologies in some states/regions did not appear to be related to a lack of willingness to innovate as many businesses with low precision technology uptake have demonstrated significant innovation in other areas of their business. However, without more insight into learning styles, networks and barriers or enablers of technology uptake at the regional level then adoption is likely to remain unchanged. While some of these were apparent through the project it was beyond the scope and resources of the project to explore the gamut of these factors within each region.
- The project identified that there is a current cohort of growers with a high level of interest in PA who have been unsure where to commence PA implementation and hesitant to adopt with limited evidence of success and outcomes from PA in vegetable systems.

Key learnings for vegetable production systems include:

- Variability with sufficient yield and maturity penalties to warrant precision approaches exists within vegetable production. Multiple case studies have used precision approaches to quantify this yield and maturity variability. For example, yield mapping and forecasting technologies, crop sensing and groundtruthing approaches, with obvious impacts on profitability at the field level.
    - 22% and 33% yield reduction in underperforming areas in sweet corn and green beans, respectively
    - Variability in carrot yield mapping data from 25t/ha up to 130 t/ha, a five-fold difference
    - Profit loss maps generated from yield mapping data
    - Six day earlier harvest advantage in more mature areas of broccolini compared with later maturing areas
    - Maturity variation in sweet corn identified through drone imagery and flowering area analytics at tasseling with 40% of the field maturing in advance of the rest of the crop.

  There is substantial opportunity for improved productivity and returns if this variability can be managed.
- While PA is not a solution where basic agronomy is not optimal, precision approaches were successful in understanding and managing productivity constraints through improved agronomy at a higher resolution than the whole field level. These include within field management practices such as:
    - Ynderstanding variability through soil mapping and groundtruthing with identification of salinity, sodicity, pH variability, nutrient variability, drainage constraints and soil types
    - Strategic sampling procedures for groundtruthing crop imagery and soil sensing
    - Reduced waterlogging events through drainage modelling and precision drainage works with an estimated break even return on investment if the waterlogged area achieved 30% of the average yield where previously there was total crop loss
    - Targeted placement of crop inputs such as lime and nutrients (P, K) following variable rate applications for and improved uniformity in soil characteristics e.g. soil pH with VR lime improved from a range of 5.7-6.3 (pre-VR) to 6.5-6.8 (post-VR) with average soil pH increased by 0.35 units from 6.19 to 6.54
    - Depending on the situation VR soil applications have: saved inputs sufficient to offset mapping costs; input budget has remained stable but targeted to those areas needing it; inputs have exceeded the input budget but targeted where needed.
- Precision tools have been used for tracking field recovery and waste. If the where and why of these losses can be clarified then this is yet another opportunity for improved productivity and profitability.
    - Comparison of accurate automated plant counts (100% accuracy validated against manual counts) with pack out data revealed discrepancies (and crop loss) of up to 40% in broccoli and lettuce.
    - Yield forecasting comparison with pack out data indicated crop losses of up to 45% in carrots.

- Accurate yield forecasting from remotely sensed satellite imagery has achieved accuracies between 74-99% highlighting the potential for this technology where yield monitoring capability does not exist.
- The intensity of vegetable production created challenges with scheduling technology applications and groundtruthing operations. Additionally, nearly all case study sites expanded their PA implementation beyond the initial scope outlined in farm action plans. These factors delayed finalising outcomes and case study development until the final few months of the project. A 4 year timeframe for the project would have allowed for a dedicated industry communication program around the project outputs.
- While every effort was made to report cost benefits on PA in vegetables, many of the benefits are longer term and could not be realised within the timeframes of the project. The benefits of management options such as precision drainage works and variable rate applications will only be fully apparent over time. The time for realisation of PA benefits could also limit adoption as growers look for a faster return on their PA investment, both cost and time.
- Technology on vegetable farms is increasing, much of which is currently underutilised for PA approaches. This includes drones, VR capable spreading equipment and tractor guidance. Similarly, imagery analytics that could be applicable to vegetables are continually developing at a global level.
- Use of data storage and management platforms such as PCT/agcloud and commercial imagery platforms (e.g. DataFarming, Irrisat) mobile applications and software is increasing on vegetable farms.
- There are low cost starting points for PA implementation in vegetables which could assist in alleviating widespread perceptions that PA implementation is cost prohibitive.

Key learnings for the pathway of adoption in vegetables:

- The need for a more effectual adoption pathway for PA in vegetables, particularly at a regional level, was highlighted by both project partners and grower co-operators. While linkages with the VegNET program facilitated a range of communication events (over 50% of project events), there did not appear to be any regional adoption pathway for PA beyond knowledge change.
- Lack of experienced PA service providers to support growers was repeatedly identified as a limiting factor for PA adoption even in states/regions with higher PA implementation. This dearth of support impacted on understanding and knowledge acquisition for project partners and grower co-operators as well as achieving meaningful application of technology on farm. Where project partners, had previous understanding of and experience in precision agriculture there were fewer issues and challenges with demonstration sites. Provision of basic PA training for project partners would have been beneficial at the start of the project.
- Lack of service provider experience in applying PA technologies specifically to vegetable systems impeded the quality and usefulness of data in some cases. The intensive nature of vegetable production is unique compared with other agricultural industries with a history of PA implementation. PA service providers need to understand this to deliver useable and timely data.

Appropriateness

Given the status of PA in vegetables at commencement of the project, generating locally and regionally relevant examples of technology implementation with clear reporting of outcomes and benefits to production was a necessary first step. On farm collaborative (growers, project partners and PA service providers) validation and optimisation of PA technologies was a successful approach as indicated by outcomes and grower co-operator feedback. In addition to the approach used, the PA technologies applied to vegetable systems through this project were appropriate in achieving outcomes at the farm/field level (see Effectiveness and Impact section).

Project activities were effective in achieving adoption of PA technologies and approaches. Over 90% of grower co-operators indicated they will be continuing with their current PA approaches with 72% expanding their technology adoption. Case study activities and outcomes were consistently highlighted as the most valuable aspect of extension events, particularly towards the end of the project where more comprehensive case study outcomes demonstrated practical implementation of PA technologies and approaches at the farm level. For example the case study 'Using VR technology to manage within-field variability' provided the Whishaw's with improved soil pH uniformity arising from Veris® soil mapping and variable rate lime applications; or where a range of different imagery analytics have been trialed in vegetables by Mulgowie Farming Company in the case study 'Practical applications for drones in vegetable production'; or where yield monitor data collected by Harvest Moon was used to develop profit loss maps in the case study 'Yield and profitability mapping in carrots'.

The project has undoubtedly contributed to accelerating the adoption of PA technologies in vegetable systems. However, it has also captured key barriers identified by co-operators and project partners through the project in addition to those outlined in key learnings above.

- Cost was repeatedly mentioned as a key barrier by growers to commence adoption of PA technologies and approaches
- The integration and compatibility of different technologies and sensors
- Integration of service provider collected data and self-collected data
- Unwillingness of industry to share data due to the competitive nature of vegetable businesses
- Need for a rigorous extension pathway for PA adoption within regions
- Rationalising and simplifying all aspects of PA implementation to minimise steps for growers to obtain, access and interpret data.

Efficiency

The project delivered planned outputs and outcomes within budget and the timeframe. In developing the project the initial contracted outcome was to develop 2 x case studies per state and while the project produced 12 case studies overall given the variability in adoption levels only 1 case study was developed in NSW, Victoria and SA. A two month extension was granted to enable final case study site crops to be harvested. Where possible the project engaged and linked with activities from other Hort Innovation investments. In particular, this included the Vegetable Extension Network with provision of content for regional newsletters and communication events. Over 50% of extension events reported through this project were held in conjunction with VegNET.

Legacy

The project produced a number of products and outcomes that will provide ongoing project legacy. The literature review is the first review of global and domestic R&D of precision approaches in vegetable systems. Similarly, the remote sensing component has generated two scientific publications, one currently under peer review and the other to be submitted shortly. The yield prediction algorithm developed through the project has the potential to be further refined and developed into a commercial outcome accessible to industry.

Of the project grower co-operators, 90% will maintain current PA adoption and 72% will expand to other technologies. Growers engaged through the project and participants of the Grower Study Tour have significantly expanded the existing Community of Practice on PA implementation and approaches in vegetables. Feedback from grower tour participants highlighted that 50% would continue to make use of the networks developed through the project and had plans for future contact to continue to learn from peer experiences.

In addition to building grower networks through the Community of Practice, the project also focused on developing relationships and networks between growers and PA service providers. Twenty precision agriculture service providers were engaged through the project. Over 35% of these had not previously provided services for vegetable production systems. They will be able to use the understanding of applying PA services to vegetable systems in the future.

There is evidence that some of these relationships will endure beyond the end of the project: commercial agronomists are now using drone service providers to process their drone imagery, grower co-operators through the project are now using commercial drone services providers outside of the project, yield monitor data will require ongoing data processing services.

Recommendations

The key recommendations that have emerged from this project are outlined below.

- The extent and impact of crop variability in vegetable production systems is sufficient to warrant continued investment in PA implementation as indicated by:
    - 22% and 33% yield reduction in underperforming areas in sweet corn and green beans, respectively, quantified using crop sensing and groundtruthing
    - Variability in carrot yield mapping data from 25t/ha up to 130 t/ha, a five-fold difference
    - Profit loss maps generated from yield mapping data
    - Six day earlier harvest advantage in more mature areas of broccolini compared with later maturing areas quantified through crop sensing and groundtruthing
    - Maturity variation in sweet corn identified through drone imagery and flowering are estimation at tasseling shows 40% of the field maturing in advance of the other 60% of the crop.

  With precision management options identified to address these impacts:

    - Variable rate applications for salinity, sodicity, soil pH and nutrients (P&K) to achieve improvements in crop growth, water infiltration, crop uniformity and optimal placement of crop inputs
    - Soil pH uniformity improved with VR lime from a range of 5.7-6.3 (pre-VR) to 6.5-6.8 (post-VR) with field average soil pH increased by 0.35 units from 6.19 to 6.54
    - Depending on the situation VR soil applications have: saved inputs sufficient to offset cost of grid mapping; input budget has remained stable but targeted to those areas needing it; inputs have exceeded the normal budget but with significant uniformity improvements.
    - Subsurface drainage works based on drainage modelling would achieve a break even return on investment if yield achieved 30% of the field average in this area of previous total crop loss

- PA adoption in vegetables needs to be problem focused to address particular issues rather than implementing technologies due to hype or interest in the technology alone. For example variable rate technology garners significant interest often without any evidence that this is an appropriate management option for the situation in question.

- Given the observed disparity in PA adoption between states and regions, there is a need to understand regional enablers and barriers that could explain and if possible overcome these differences. This would also inform targeted regional RD&E programs to either address barriers or aid in developing the elements that contribute to enabling adoption. While some of these were readily apparent through the project, more detailed understanding at the regional level was beyond the scope of the project.

- The project has generated substantial evidence of successful PA technology implementation in vegetable systems. There is an opportunity to leverage these outcomes and the networks developed during the project through VG18000 'National vegetable industry communications program'. This could include further communication products on leading growers in this agtech space with grower profiles, podcasts and industry magazine articles beyond those generated through VG16009. Continued use of the social media hashtag #PA4Veg is also recommended to provide an ongoing social media presence on the progress of PA in vegetables.

- Further development of the 'Community of Practice' is critical. It's clear that producers (particularly younger industry participants) see the targeted learning, information sharing and relationships fostered through an informal community as essential. Though it's also clear that this requires co-ordination of a facilitated process or pathway for communication amongst participants to maximise the outcomes from such a cohort of peers. This would also provide an alternative means for cross regional learning which are costly events to deliver and difficult to time given regional production seasons.

- The last 3 years has seen an increase in on farm technologies such as drones that are currently underutilised for PA applications or else basic enabling technologies for PA such as GPS tractor guidance could be further utilised for precision approaches by providing elevation data. A benchmark of technology on farm (including technology that exists but is not used for PA applications) could inform PA extension activities and capacity building at a regional level.

- There is rapid development and growth of imagery analytics globally for precision agriculture applications. While the project has made significant steps in advancing the application of these for vegetable systems particularly for drone imagery such as automated plant counts, flowering estimator and 3D models, there is an opportunity to continue to assess and validate analytics as they are developed and provide feedback to developers on vegetable industry needs.
- Basic PA /ag-tech capacity building for VegNET representatives would enhance the support available for PA adoption at the regional level.
- Project activities have identified significant interest in PA approaches for vegetable growers across a broader network of growers than those actively involved in the project. The PA Grower Study tour in September 2019, resulted in numerous enquiries from tour participants as to how they could be involved in the project, however, proximity to the project's end date negated involvement of any additional growers. Consequently, there is a ready cohort of growers across Australia that are primed for PA adoption with support through future investment. Industry is advised to consider a cross-industry approach particularly with levy funded crops such as onions and potatoes.
- While the project had some demonstration site co-operators who were willing to be involved in the project not all were as motivated to continue to adopt PA technologies. This is not entirely unusual as producers test and try a mix of farm management approaches. However, future investment could incorporate a formalised process to identify co-operators and ensure they were fully engaged in implementing precision systems technology and practices. That said, certain PA approaches tend to wax and wane as producers identify and then manage spatial variability issues.
- As previously noted, PA benefits are generally only realised over the longer term. Additional activities will be required to obtain a complete understanding of the cost benefits of PA implementation at VG16009 sites. In the absence of any ongoing program, there will be no coordination and support in capturing these benefits beyond the life of the project. This would be a significant missed opportunity given the scale of investment at the industry and individual grower level through VG16009. At a basic level, engaged producers should be contacted in ~18 months to assess their level of adoption or whether any adoption barriers have emerged.
- The outcomes generated from the remote sensing for yield prediction component of this project provided a wide range of benefits to predominantly the carrot industry but also for sweet corn. It was shown that the remote satellite technologies could accurately forecast yield, which in as industry that lacks wide access to commercial yield monitors is of great benefit. An algorithm developed with Sentinel-2 sensor that can be used 50 days after sowing (of carrots) was tested providing further benefits as the early estimation of yield supports better decision making during the growing season. Further research and development is required to effectively deploy this technology as a commercial service as well as guarantee the robustness of the approach across all growing regions. Future investment in this yield prediction area would need to result in a commercial product accessible by industry.
- Early pest and disease detection is a common priority across industries. In order to successfully detect and quantify disruptions at the crop level, satellite remote sensors need be calibrated to detect that particular constraints. Whist, the scope of the remote sensing component of this project was to assess the capabilities of remote sensing in yield forecasting, there remains great potential to similarly evaluate the potential of these technologies for the improved monitoring of high risk pest and diseases, including those of high biosecurity importance.

Considerations for future precision technology adoption

As evidenced by other agricultural industries such as sugar cane, cotton and grains, a sustained investment program will be required to ensure PA (or other ag-tech) is validated and adopted. The risk of not investing further in precision approaches for the vegetable industry could be that PA adoption will be stymied. The proliferation of ag-tech investments and announcements has created a degree of 'noise' for producers. Programs that seek to validate technology and practices will be necessary.

Maintaining the producer led momentum initiated by VG16009 (and previous projects) is perhaps the strongest argument for ongoing PA investment in vegetables. Adoption of PA is occurring, though it's also clear that a sufficient proportion of producers require assistance to navigate and troubleshoot not only the technology but the accompanying practices (such as altering fertiliser / soil amendment rates or interpreting data. However, the almost 2 tiered reality of precision systems adoption in vegetables across the country raises the question on how and/or where to focus any future investment for the best adoption outcomes.

Widespread PA adoption will require a more fit-for-purpose extension pathway and this was repeatedly highlighted throughout the project. Regionally based PA approaches, focused on specific regional issues with consideration of regional demographics, learning styles and networks would accelerate regional adoption and better align with the VegNET or other investment program. This would overcome issues with larger scale national projects which can struggle to deal with complexity and timeliness requirements (critical for PA implementation) and have insufficient resolution and resourcing at regional levels. Broader industry adoption of PA will require building regional extension programs based on more than communication events as technology adoption involves a dynamic process with information gathering, learning and experience are pivotal aspects particularly in the early stage of adoption.

Support from PA service providers and skilled technical assistance has been identified as critical for PA implementation across all states and regions. This support encompasses technology suppliers, mapping service providers and data processing services. The current lack of sufficient resources in this sector reflects a lack of numbers (i.e. providers to not exist in some regions or not enough of them), lack of understanding of the unique characteristics of vegetable production when applying these technologies and a tendency to be sales focused rather than invested in achieving meaningful technology implementation for precision management outcomes at the farm level. This is a barrier for any future expectation of technology implementation and practice adoption beyond this project by not only growers new to PA but also those looking to expand their current suite of PA approaches. Improvements in this area are unlikely to occur without continued investment in PA adoption driving the demand for increased capacity in the provision of these services. Engaging service providers in the process of technology application to vegetables is an opportunity to expand these services and will also provide the impetus for technology providers to address some of the current barriers to PA adoption such as compatibility issues and improved processes to streamline data acquisition, processing, turnaround and how to apply analytics to vegetable imagery.

Technology has the highest probability of being adopted when end users are co-researchers in the design and implementation and when supported to reduce barriers. There is little evidence that this occurs across the broader vegetable industry outside of industry investment. Considering these factors, adoption of precision system technology and approaches could be substantially accelerated with a co-innovation model deployed at the regional level. This would provide the necessary collaboration with growers in developing technology and practices at the farm level, while providing the necessary regional support and capacity building across the supply chain.

Refereed scientific publications

Journal articles

Suarez, L.A., Robson, A., McPhee, J., O'Halloran, J., and van Sprang, C. 2019. Accuracy of carrot yield forecasting using proximal hyperspectral and satellite multispectral data. *Precision Agriculture Journal* Under Review

Suarez, L.A., Robertson-Dean, M., Brinkhoff, J., Robson., A. Optimising the window capture for root crop yield forecasting using satellite remote sensed vegetation indices. *In preparation for submission*

References

BRAMLEY, R. 2009. Lessons from nearly 20 years of Precision Agriculture research, development, and adoption as a guide to its appropriate application. *Crop and Pasture Science,* 60**,** 197-217.

LIMPUS, S., O'HALLORAN, J. & LAYDEN, I. A. 2016. Adoption of variable rate technology in Queensland's intensive vegetable production systems - Final report for GMX-INNOV-312. Queensland: Department of Agriculture and Fisheries.

WENGER-TRAYNER, E. & WENGER-TRAYNER, B. 2015. *Introduction to communities of practice: A brief overview of the concept and its uses* [Online]. Available: https://wenger-trayner.com/introduction-to-communities-of-practice/ [Accessed 21st October 2019].

Intellectual property, commercialisation and confidentiality

Refer to Intellectual property register.

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Fresh Select, Victoria

Covino Farms, Victoria/Queensland

Alandale Farms, New South Wales

Simplot, New South Wales

Kalfresh, Queensland

Kengoon Farming, Queensland

Rieck Farming, Queensland

Jack Abbot, Queensland

Mulgowie Farming Company, Queensland

Qualipac, Queensland

Koala Farms, Queensland

Austchilli, Queensland

Musolino and Sons, South Australia

Samwell and Sons, South Australia

Zerella Fresh, South Australia

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Appendices