Adoption of variable rate technology in Queensland's intensive vegetable production systems

Final Report for GMX-INNOV-312

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Queensland Government

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Bundaberg Fruit and Vegetable Growers
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Executive Summary

Precision agriculture (PA) is a farming management concept based on observing, measuring and responding to inter and intra-field variability in crops. The goal of precision agriculture research is to arrive at a whole-of-farm management system that optimises returns on inputs while preserving natural resources. Precision agriculture aims to optimise field-level management by:

- Matching farming practices more closely to crop needs
- Reducing environmental risks and farming footprint
- Boosting profitability through more efficient practices and improvements in yield and/or product quality.

Despite a significant increase in the installation of machine guidance systems in Queensland horticulture over the last decade, evidence indicates that very few producers have been employing this technology and precision agriculture methodologies beyond basic guidance (auto-steer) activities. The scale and intensity of modern vegetable production creates substantial challenges for producers wishing to progress beyond machine guidance into other precision applications such as soil nutrition and irrigation, crop sensing, variable rate inputs and yield monitoring. The tangible but unrealised opportunities offered by precision applications combined with farming system and agronomic challenges were the catalyst for this project.

The project '*Adoption of variable rate technology in Queensland's intensive vegetable production systems'* (INNOV-312) commenced field activities in April 2014, and represented the first dedicated project to develop precision systems in intensive horticulture (vegetables) in Queensland and possibly Australia. The project sought to implement, develop and optimise a range of precision technologies across demonstration sites in the four major vegetable growing regions of Queensland.

Precision approaches implemented include:

- Soil mapping (EM38) and strategic soil sampling programs
- Remote and proximal biomass or crop sensing (multi-spectral)
- Yield monitoring load cells on root crops (carrots, potato and sweetpotato)
- Variable rate input programs (nutrients, soil ameliorants, irrigation)

The key areas of investigation 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?

A major component of the work has been to develop adoption pathways and processes that address producer needs, which required a substantial focus on implement retro-fitting, crop sensing timing, data acquisition platforms, producer and agronomist capacity building, data analysis and dissemination.

Given the project had a limited two year time frame to generate outcomes it has achieved a number of important outcomes:

- ~5000 hectares of intensive cropping under some form of precision management

- Located and quantified within block variability in vegetables systems

- Installation and optimisation of the first yield monitors in Queensland
- The first prescription (VR) fertiliser and soil amendment maps used in Qld horticulture
- Increased awareness and improved knowledge of within–field variability and precision technology including an increase in producer knowledge and capacity to identify variability and use a range of technology
- On-ground demonstration of a range of technologies which improved producer understanding and knowledge of equipment and operational issues
- A diverse range of media including being featured on Australia's premier rural television program 'Landline'
- Addressed market failure that existed between what technology was available and producer opinion of the technology
- Secured further investment in precision agriculture projects

The value of implementing precision technologies in vegetable systems has firstly been to establish that crop variability does occur, that the variability typically does incur a yield or product quality penalty and more importantly it can be quantified and treatment options developed and executed. Secondly, working in intensive cropping has led to other horticultural industries (tree crops, turf) to also undertake investment in precision technology. The project employed commercially available technology, thus the innovation hasn't been hardware but the development, optimisation and capacity building of the farming systems, producers and broader agri-businesses involved in the project. Importantly, this project has been the catalyst for further investment into precision systems in horticulture. It is expected that further adoption and customisation of variable rate approaches will now occur across vegetables and into other cropping systems.

However, given the relative complexity of optimising precision technologies across a broad range of farms and producers, and the lack of time to truly assess economic impacts there are a number of RD&E areas that will require further work and investment, such as:

- Implementation of processes that include clear steps for timing of data and technology, support for data collection and interpretation – support at the farm level to ensure that precision becomes a standard practice
- Capacity building of producers, agronomists and equipment dealers through on-farm support, training and mentoring opportunities
- Pre/post assessment data in order to create whole-farming systems with integrated approaches – mobile data analytics platforms to exploit the valuable data collected
- R&D into the development of 'next generation' yield monitors and advancing multi and hyper-spectral sensing applications that are fit for purpose.

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Project background

Adoption of variable rate technology in Queensland's intensive vegetable production systems (the project) aims to increase incremental change by introducing innovative practices and technology into vegetable production systems. The project addresses the natural resource management issues of improving soil condition and water quality. Soil is the key natural resource for agriculture as well as a range of ecosystem services and the loss of soil through water erosion and structural decline is a significant environmental and agronomic issue. Improving soil condition and water quality remains an area where vegetable systems are able to improve these resource conditions. Queensland has in excess of 30,000 hectares of vegetable production, characterised by high cropping frequency, intensive tillage and high nutrient and water use.

Standard practices in intensive vegetable production involve fertiliser and soil ameliorant (lime, gypsum, composts) applications across a field regardless of soil and nutritional variability. Variable rate (VR) technology coupled with precision practices allows nutrient, soil ameliorant and irrigation applications to match spatial soil and/or crop requirements within a field. This leads to a more efficient and effective use of inputs and reduces the risk of losses to the environment. The effective and precise management of in-field variability in vegetable systems requires knowing both the location and understanding the reason for sub-optimal crop performance and addressing the cause of the variability.

The use of VR technology has been adapted to varying extents in other Australian agricultural industries (e.g. grains), and internationally in broad acre cropping and European horticulture. While the technology is readily available, significant adaptation and optimisation is still required for tropical and sub-tropical horticultural operations. Robertson *et al* (2007) reported up to $30/ha improvement in the gross margin for cropping by using a suite of PA technologies including crop sensing and VR fertiliser. With high input and high value vegetable crops it is expected that $/ha gross margins could be greater than that achieved in broad acre systems. Martin (2004) successfully employed crop sensing (NDVI) to address variability in strawberries, though was hampered by lack of real time monitoring. Roberson (2000) reported that high value horticultural systems stood to benefit from the adoption of site-specific crop management, though producers would require assistance to implement the technology. Importantly Lawes (2010) indicated that while the adoption of VR in Australian grains industry generally pays, adoption requires producers to undertake a significant amount of troubleshooting to optimise the system. This would also hold true for horticultural systems, where producers are likely to need significant assistance to fully optimise precision technologies. Taylor *et al* (2006) showed possible savings in excess of $100 per/ha on nitrogen budgets in sweet corn production and that adoption of VR is a viable option.

While adoption of auto-steer/satellite guidance is relatively high, adoption of VR technology in Queensland horticulture is extremely low. The Department of Agriculture and Fisheries Queensland (DAF), through a former Caring for our Country project on controlled traffic farming (OC1-00762) assembled a large (n=350) qualitative and quantitative dataset that indicates most producers see VR as the next step in optimising their investment in PA and that adoption is currently hampered by a lack of support and information on 'how to' implement VR in a range of crops. Reef Rescue investment legacy also indicates the wide adoption of satellite guidance though producers are yet to fully unlock the most important aspects of this technology. In essence, the adoption of VR is primed for rapid expansion.

Methodology

To increase adoption across the entire Queensland vegetable industry through cross regional learning opportunities, the project targeted the main growing regions in Queensland of the Atherton Tablelands, Bowen, Bundaberg and the Lockyer /Fassifern Valleys in south – east Queensland (**Figure 1**). Crops in these regions include sweet corn, green beans, potato, sweetpotato, tomato, chilli, carrots, onions, and brassicas.

Figure 1 Map of Queensland showing vegetable growing regions involved in the project (red pins)

Commercial farm demonstrations

The project established two commercial vegetable farm demonstration sites in each region, South-east Queensland, Bundaberg, Bowen and Atherton Tablelands, facilitated and supported by DAF extension staff. The demonstration sites compared (where possible) standard management practices with site/crop specific management. Regional demonstration sites and co-operators were selected following pre-project discussions with producer associations, local agronomists, and equipment dealers, and with individual producers. To ensure project goals could be realised and project momentum could be maintained after the project, typically producers who were 'innovators' and 'early adopters' of technology were selected as formal co-operators in the project. Formal agreements were established with demonstration site co-operators either directly with DAF or via regional producer /NRM organisations. These agreements outlined the roles and responsibilities of those involved and also ensured that on farm activities and involvement in extension events were linked to various milestones.

A range of activities were undertaken at each demonstration site including:

- Capture of imagery/data to identify spatial crop variability,
- Ground-truthing variability,
- Installation of VR technology,
- Variable (prescription) application maps,

- VR applications,
- Quantifying nutrient inputs,
- Yield monitoring and mapping.

Activities conducted at the demonstration sites are listed in **Table1**.

Table 1 Regional demonstration sites in Queensland and the activities undertaken

Region	Farm	Crops Grown	Activities Undertaken	VRT Assets Installed
Atherton Tablelands	Ben Poggioli	Potatoes, corn, sweetpotato	Remote (satellite) biomass mapping, yield mapping, Greenseeker installation, soil characteristic mapping/sampling	ATV yield monitor Viking 5 tonne bulk spreader RT200C Greenseeker 4 sensor crop sensing system Summit program install & training for data management
	North Qual	Potatoes, corn	Remote (satellite) biomass mapping, yield mapping, soil characteristic mapping/sampling, variable rate fertiliser and lime application, soil moisture monitoring	ATV yield monitor Variable rate application controller on existing fertiliser spreader
Bowen	Euri Gold Farms	Trellised tomatoes	Proximal (satellite) and remote biomass mapping, soil characteristic mapping	None – Producer stopped farming tomato in 2015
	Vee Jays's Tomatoes	Trellised tomato, grape tomato, chilli, capsicum, green beans	Proximal biomass mapping with Greenseeker installation, soil characteristic mapping/sampling, variable rate compost application, plant tissue sampling for disease	RT200C Greenseeker 6-sesonr crop sensing system Variable rate controller on existing bulk spreader
	Phantom Produce	Trellised tomato, capsicum, cucumber	Soil characteristic mapping/sampling, variable rate gypsum application	Bulk spreader retrofitted with variable rate control to enable VR applications
Bundaberg	Windhum Farms	Sweetpotato, melon	Remote (satellite) biomass sensing, yield mapping, soil characteristic mapping/sampling, soil moisture monitoring	Greenstar 3 2630 display Greentronics YM410-2T load cell
	Austchilli	Chilli, capsicum	Satellite and proximal biomass sensing, soil characteristic mapping/sampling	FM100 DGPS Locator RT200C Greenseeker 6-sensor crop sensing system Additional Trimble Yuma tablet for high resolution logging Farm Works program installation for data management
	Snap Fresh	Trellised tomato	Proximal biomass sensing, soil characteristic mapping/sampling	None - Not pursued
Fassifern (Kalbar) & Lockyer Valley	Kengoon Farming	Sweet corn, green beans, carrots and onions	Satellite, UAV and proximal crop biomass sensing, EM 38 soil mapping, VR applications, yield mapping	TS3000 Agrispread Landaco bulk spreader (shared) Valley Variable Rate Irrigation system (retrofitted to existing pivot irrigator)
	Rieck Farming	Sweet corn, green beans, carrots and onions	Satellite, UAV and proximal crop biomass sensing, EM 38 soil mapping, VR applications, yield mapping	ATV yield monitor Field IQ Platform kit for sharing Landaco spreader
	DJM Farms	Sweet corn, green beans, carrots and onions, lucerne	Satellite, UAV and proximal crop biomass sensing, EM 38 soil mapping, VR applications, yield mapping	Trimble FM1000 guidance screen Set of 4 RT200C proximal biomass sensors, 'Greenseekers' (shared)
	Kalfresh	Green beans, carrots and onions	Satellite, UAV and proximal crop biomass sensing, EM 38 soil mapping, yield mapping	Yield monitor sharing
	Windolf Farms	Potatoes, brassicas	EM 38 soil mapping, yield mapping	Greentronics YM2000 yield monitor plus additional sensors
	Qualipac	Broccoli, onions	EM 38 soil mapping, UAV crop biomass sensing	None
	Kluck Farms	Lettuce, cabbage, cauliflower	EM 38 soil mapping, UAV crop biomass sensing	None
	Nuendorf Farming	Sweet corn, green beans, carrots and onions	EM 38 soil mapping, UAV crop biomass sensing	None
Sunshine Coast/ Gympie	Templeton & Sons Ginger	Ginger	EM 38 soil mapping, strategic soil sampling, VR applications	None
	Carter and Spenser	Ginger	EM 38 soil mapping, strategic soil sampling, VR applications	None
	Oakland Farms	Ginger	EM 38 soil mapping, strategic soil sampling, VR applications	None
	Mellor Family	Ginger	EM 38 soil mapping, strategic soil sampling, VR applications	None

Grower association and agribusiness engagement

Engagement with regional grower associations and agribusinesses was considered key to successfully building capacity within each region that could continue to be capitalised on beyond the life of the project. Collaborative agreements were established with grower associations to facilitate greater ownership and project legacy where they were applicable.

Agribusinesses associated with this project encompassed a range of enterprises including:

- Agronomists
- Machinery sales
- Technical service providers

Grower collaborators were encouraged to include their agronomists in discussions and project activities and DAF officers worked with them wherever possible in undertaking field activities. Agronomists were also a key target audience for capacity building activities in the use of mobile platforms, interpreting mapping data and protocols for strategic soil and plant analysis.

Technical service providers were engaged through the need for their services for a range of technology installation and optimisation issues. They were also brought into discussions with co-operators to assist in building relationships between these key stakeholders as part of the project legacy. In some cases they were formally engaged in the project through third party agreements.

Farm action plans

Given most producers and/or their agronomy teams had little to no previous experience using 'advanced' precision applications, a critical part of the project methodology was to develop and discuss 'farm action plans'. Essentially, these plans provided the basis for discussions between DAF staff and the producer team. Importantly, it allowed producers to better visualise where some of the technology might fit within their farming system and where the knowledge gaps and likely points of failure might be (**Figure 2**).

Throughout the planning process a number of key questions were used to focus the discussions and the subsequent work program.

The key areas of investigation 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 and equipment suitable for addressing any variation?
- Will a precision approach elicit a yield/quality response?

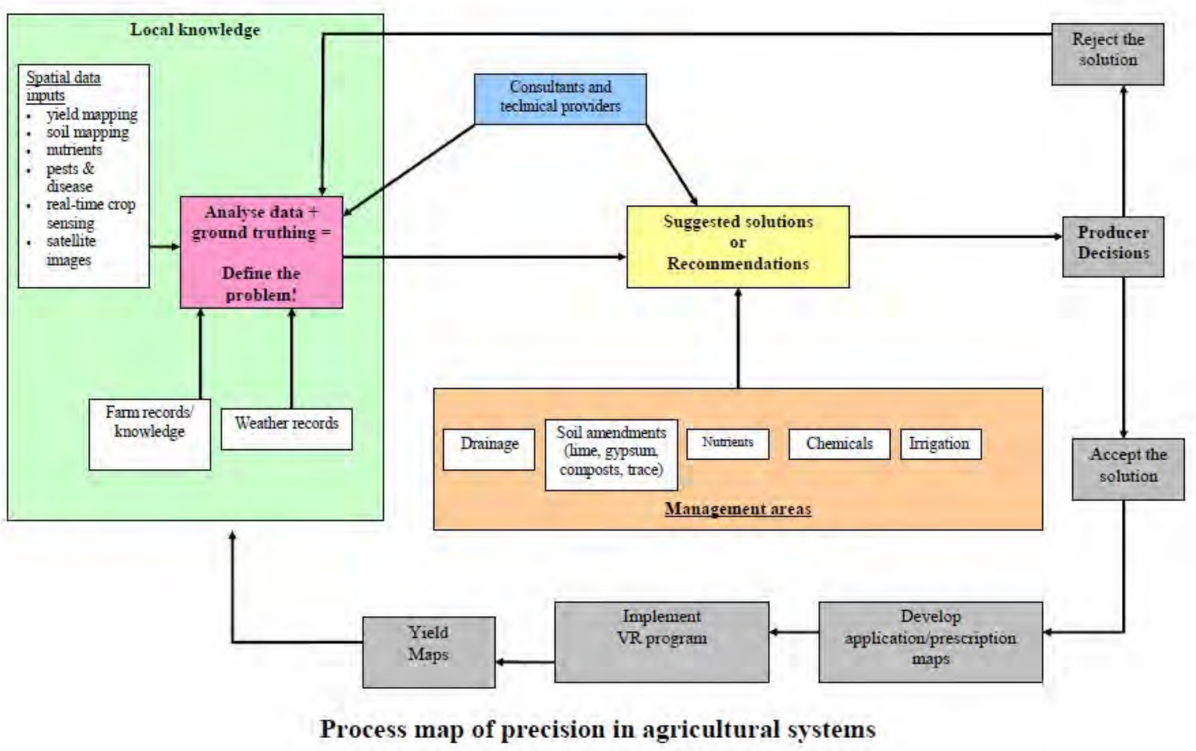


Figure 2 Process flow used with producers to illustrate the components involved in PA systems

Identifying spatial variability

A suite of precision technologies were investigated to identify spatial variability, including:

- Remote satellite biomass sensing and unmanned aerial vehicles (UAV),
- Proximal biomass sensing (e.g. tractor mounted),
- Soil electromagnetic (EMI) surveying and soil sampling programs,
- Soil moisture sensing and
- Yield monitoring and mapping.

Crop biomass sensing

The range of technologies was used to assess spatial biomass variability included high-resolution satellite (sub-metre), unmanned aerial vehicle (UAV) and proximal (in this case, tractor or implement mounted- **Figure 3**) biomass sensing technologies. These primarily rely on the vegetation index, Normalised Vegetative Difference Index (NDVI), as an indicator of crop health and vigour. NDVI is a robust and useful index for determining the apparent "greenness" of a crop allowing the user to identify areas that are not growing as vigorously and which may require ground-truthing or investigation.

Initially, high resolution satellite imagery (0.3m - 0.5m pixels) was used to collect and map NDVI variability data on large areas of horticultural crops. Satellite imagery with a 0.5 m/pixel resolution was deemed the most appropriate for vegetable crops because most of the crops were planted in fields that ranged from 2.5ha to 30ha, with bed widths of 0.8m to 3.0m wide across staggered planting dates

Satellite image captures in the Atherton, Bundaberg and Kalbar regions were scheduled to coincide with critical crop stages so ground-truthing could be conducted and if any issues that were identified could be managed in an appropriate timeframe. Timeliness of interventions or management actions to address observed variability was seen as very important in terms of validating the use NDVI imagery.

While several proximal sensing systems exist, Greenseeker™ (www.trimble.com) sensors were chosen because they were readily available, easily serviceable in all of the demonstration regions and they are active sensors that have their own light source. A Greenseeker™ 2 sensor system was initially used in a demonstration capacity by DAF staff. The successes in employing proximal sensors led to the installation of several sensor systems by co-operators onto existing farm equipment to monitor the vigour of horticultural crops. Greenseekers™ were either installed directly onto the producer's spraying equipment or a tractor used for multiple operations to maximise the opportunities to capture biomass data at no additional cost.

Figure 3 Greenseeker™ sensor and a 4-sensor system mounted on the front of a tractor.

Unmanned aerial vehicles were also used in some regions for the capture of spatial crop biomass imagery (**Figure 4**). In south-east Queensland, multispectral cameras were used to capture NDVI imagery. These cameras also provided spatial data using various other indices, however, the NDVI was the main index used to assess crop biomass and variability in growth. In North Queensland, however, the use of UAV was not as successful due to inexperience of the service provider.

What is NDVI?

"The pigment in plant leaves, chlorophyll, strongly absorbs visible light (from 0.4 to 0.7 µm) for use in photosynthesis. The cell structure of the leaves, on the other hand, strongly reflects near-infrared light (from 0.7 to 1.1 µm).

NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it, and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light.
Calculations of NDVI for a given pixel always result in a number that ranges from minus one (-1) to plus one (+1)"

– Earth Observatory (NASA)

Figure 4 UAV 6 rotor craft (left), and UAV 4 rotor craft utilised to capture NDVI data through the project (right).

Electromagnetic Induction (EM) soil mapping

Electromagnetic induction (*commonly referred to as EM or EMI*) soil mapping was used widely across each of the vegetable regions to ground-truth or identify the presence of soil spatial variability. It is a cost effective option ($35/ha - $140/ha depending on additional services involved) for detecting spatial differences in soil moisture, clay content and soil salt levels. As a result, it can be used to define soil type/textural boundaries and some soil physical constraints associated with salt levels. The resulting maps required calibration or ground-truthing to understand the actual differences between zones by conducting a series of *strategic or zonal soil sampling* for electrical conductivity, soil moisture and soil texture.

A number of providers in Queensland offer commercially available EM services which were utilised through the project. These typically feature the EM38 type sensor or the DualEM sensor, both measuring apparent electrical conductivity (ECa) of soil (**Figure 5**). Urdanoz *et.al*. (2012) summarised the differences between EM38 and DualEM sensors and concluded that both are comparable.

Strategic and zonal soil sampling

Strategic soil sampling according to soil variability data constitutes a significant practice change for the horticultural industry. Traditionally, numerous soil samples (20-30) across a field are collected and bulked to obtain a 'representative' sample from the field. This means variability within a field is diluted and analysis of the representative soil sample may not adequately describe soil condition. In this project, more strategic sampling was required to accurately assess spatial soil variability. In most cases strategic soil sampling or indeed simply increasing the number of samples per block/field was used to illustrate existing variability and often the inadequacy of 'bulking' samples.

Crop biomass imagery and/or soil characteristic mapping were used to inform and map strategic or zonal soil and plant tissue sampling programs. An example of zonal soil sampling is presented in **Figure 6**, where three distinct ECa zones were identified using an EM38 sensor. Other strategic sampling regimes involved setting up a grid-pattern for sampling soil characteristics such as pH (**Figure 6**).

Figure 5: EM38 for rapid EMI soil surveying towed in a case by a quad-bike to survey crop-land (left) and Trimble SiS DualEM sensing and soil sampling rig.

Figure 6: Soil sampling points based on EM survey perceived soil zones (left); grid-based soil sampling plan for pH (centre) and a rapid pH soil sampler mounted on a quad-bike to perform large scale pH mapping (right).

Yield monitoring and mapping

Load cell based, geo-referenced yield monitors were retrofitted to five mechanical vegetable harvesters across Queensland. Yield monitors were installed for potato crops in Atherton and the Lockyer Valley, sweetpotato in Bundaberg and a carrot harvester that services crops in the Fassifern and Lockyer Valleys (**Figure 7**). Of all cropping systems, horticulture harvest equipment lacks Original Equipment Manufacturer (OEM) yield monitoring solutions. However, after-market options are commercially available and the project installed a combination of Greentronics (x3) and ATV (x2) yield monitors across Queensland. Installation was undertaken by specialist technical service providers who also offered assistance with technical optimisation and troubleshooting.

The technology installed for monitoring yields had never been used before in Queensland and as with all the technologies implemented through this project, technical optimisation and calibration was critical to ensure the monitors operated as intended. Sweetpotato harvesters are custom built equipment and there was no prior experience that could be drawn on in terms of 'how to' fit a yield monitor. Significant modifications to the harvester were required to make the load cells operational to an appropriate level of accuracy (<10%). There were significant electronic problems associated with the potato yield monitor in Atherton, this had to be removed and repaired and reinstalled in 2015 for the subsequent potato harvest. It is important when implementing new technologies that the data capture is viewed regularly, so that discrepancies can be identified or rectified quickly. In this case, the problem was identified quickly but could not be rectified easily due to the intensive harvest operations and therefore confidence in the accuracy of the 2014 yield data is low.

Significant resources (time and labour) were required to undertake calibration of all yield monitors. All the crops to be monitored for yield required digging during the harvest process and, depending on field conditions a significant amount of soil is collected with the harvested product (**Figure 8 right**). In an attempt to take soil into account, yields were hand sampled or load-out trucks/bags were weighed to calibrate the data.

Figure 7: Producer co-operator Phil Cuda and ATV's Bernd Kleinlagel installing the load cell component of a yield monitor on a Grimme potato harvester's at Atherton (left) and ATV's Bernd Kleinlagel showing potato producer Justin Poggioli how to tare the yield monitor and interpret data from the cab-mounted control box (right).

Figure 8: Kalfresh carrot harvester operator and Bernd Kleinlagel inspecting the carrot harvester's loading arm to begin installation of the load-cell based yield monitor (left) and sweetpotato harvester installed with a Greentronics yield monitor and load cells (right).

Variable rate technologies

Variable rate spreading capability

At commencement of the project there were limited VR spreading capabilities in Queensland vegetables. Project co-operators increased capacity in this area predominantly through retrofitting VR controllers to existing granular and bulk spreaders. Two commercial spreading contractors of bulk product (lime, gypsum) were also used in the project. For examples of equipment used see **Figure 9**.

Figure 9: VR ready bulk spreader assets purchased for soil amendments in crops including sweet corn, green beans, carrots and onions, and potato production.

Variable rate irrigation

A variable rate irrigation (VRI) system was retrofitted to an existing centre pivot in south-east Queensland. This VRI system forms one demonstration site for a University of Southern Queensland (USQ) investigation into the potential application of real time soil moisture sensors it inform VRI programs.

The pivot block selected had visible soil type variability between and within the pivot quarters. EMI soil mapping was undertaken to characterise soil type differences that could influence irrigation requirements, e.g. Sandier soils are more freely draining, requiring more frequent irrigation of lower amounts compared with higher clay soils which have greater water holding capacities and need comparatively longer irrigation intervals. Real time soil moisture sensors were developed by USQ mechatronic engineers and installed in the pivot quarters. Catch can assessments of sprinkler outputs were carried out prior to evaluation of different irrigation strategies.

Prescription mapping

Where variable rate applications were identified as an option for improving crop uniformity; soil and plant tissue analysis data in conjunction with agronomic recommendations were used to generate a prescription map. Additional data layers such as EMI, crop biomass sensing, cut and fill works, and topography, and producer knowledge of how crops performed were incorporated into the development of prescription maps.

Prescription map development was undertaken by specialist service providers initially. However, as producers became more comfortable with the technology, some commenced utilising commercially available software (PCT software) that facilitated the producers themselves generating their own prescription maps. Prescription maps are then loaded directly into VR ready spreaders via the USB port in their guidance equipment. The majority of VRT asset purchases during the project life related to either retrofitting existing, suitable spreading equipment with variable rate capability, or purchasing VR capable equipment (**Figure 9**).

Data Processing

Data cleaning and post-processing into spatial maps was undertaken by specialist service providers. Service providers were chosen according to their experience, existing relationship with producers and their willingness to assist the project and producers in achieving the goals of the broader project. In some cases, formal agreements were developed to ensure that all parties understood their role in the project.

Mobile mapping applications

Mobile mapping platforms were utilised widely by project staff to carry out a range of activities including:

- Sharing of mapping data with project staff, service providers, growers and agronomists
- Directing zonal and strategic soil and plant sampling processes
- Targeted crop scouting
- Recording and mapping of in crop activities

The applications that proved the most valuable to project activities were Google Earth, Dropbox and Sirrus (SST software), although a range of others were also utilised.

Extension

The extension program comprised a range of activities delivered by DAF project staff and regional grower groups. These include:

- Media – regional and national
- Video case studies
- Workshops and training events
- Field days
- Factsheets
- Conferences and symposiums
- Grower association (Bundaberg Fruit and Vegetable Growers, Bowen Gumlu Growers Association, Lockyer Valley Growers Association) newsletters and networks for communication of project events

Video case studies were developed in liaison with DAF information development officers. Project staff developed the video storyboard to outline the objectives, messages and footage required. Scenes and interview footage was filmed and narrated and professionally edited. The videos are accessible on YouTube or through other DAF Corporate Communication media.

A range of social media were also used to send notification and alerts related to project activities e.g Twitter, Facebook, see **Communications, Social media updates**.

Monitoring and evaluation

The monitoring and evaluation plan and outcomes are detailed in the accompanying Final Report MERI Template and discussed further in the Results section of this report.

Predicting adoption

It's difficult to predict the future particularly where technology, agriculture and producer population characteristics intersect, nonetheless it's important to try and understand the timeframes associated with technology adoption and to better ascertain what the critical components are to maximise adoption or to overcome barriers to adoption.

The project team employed an adoption tool developed by CSIRO. ADOPT (Adoption and Diffusion Outcome Prediction Tool) is an MS Excel-based tool that evaluates and predicts the likely level of adoption and diffusion of specific agricultural innovations with a particular target population in mind (see https://research.csiro.au/software/adopt/). ADOPT predicts practice adoption levels using a structured set of questions based on well-established understanding of the socio-economic factors influencing adoption of agricultural innovations (**Figure 10**).

Given the nature of the innovation and the low starting point (e.g. no vegetable producers practicing advanced precision prior to project), ADOPT allowed the project team to develop a clearer understanding the likely adoption levels and timeframes associated with the technology in the target population.

The project team used knowledge and experiences developed throughout the project in conjunction with the results obtained from other benchmarking activities (see below) and entered responses to the 22 questions posed in the ADOPT tool, responses were based on:

- Knowledge of the target population
- Level of producer support across the regional footprint of the project
- Level of complexity in optimising the range of technologies
- Knowledge of likely timeframes required to realise any benefits
- Financial and risk management impact
- Formal and informal producer feedback received since project commencement.

The results were pooled and the median was calculated to arrive at a predicted adoption time across the population.

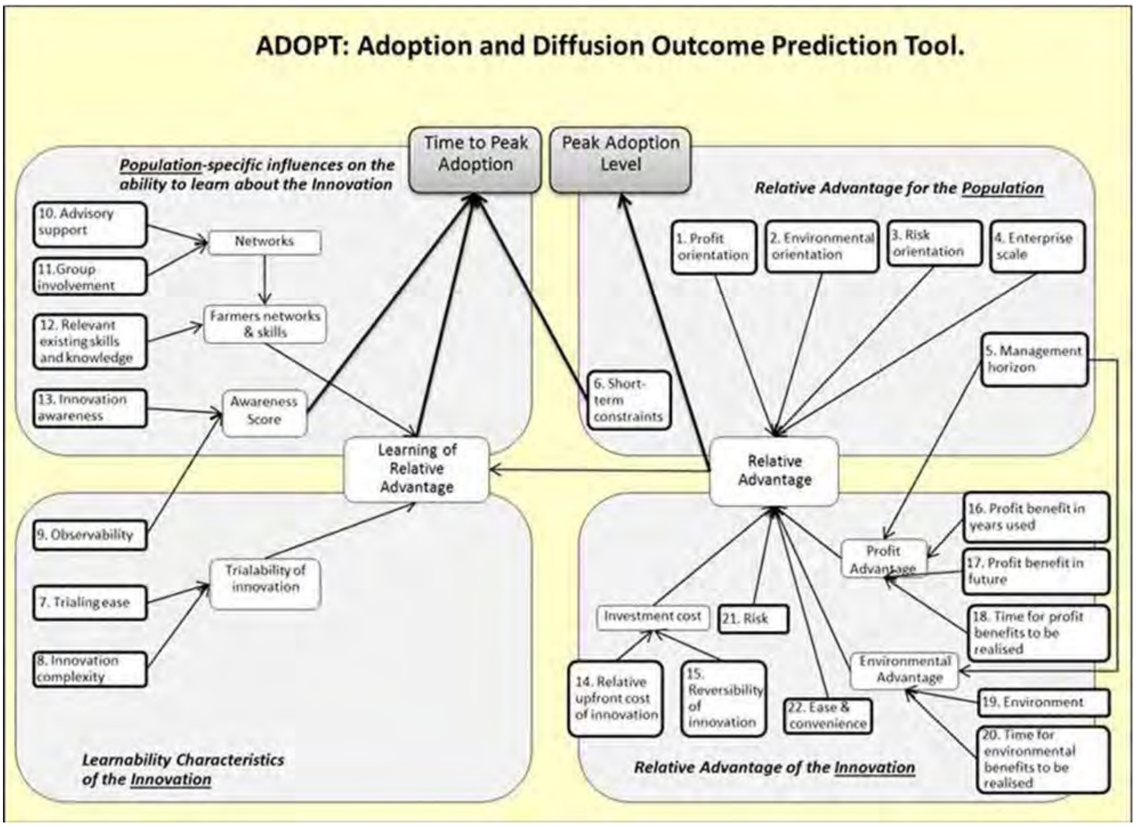


Figure 10: The ADOPT process developed by CSIRO (Source: https://research.csiro.au/software/adopt/)

Adoption and Project Impact Study

DAF engaged Central Queensland University (CQU) to undertake a practice adoption and project impact study. Through a series of one-on-one discussions with producers and consultants the study aimed to:

- Assess producer and consultant attitudes to the adoption of precision systems in vegetables
- Assess the impact the project had in progressing the adoption of VR approaches and technology
- Examine the methodology/ governance model used and identify improvements for future projects.

Results

The project employed a number of tools and approaches that allowed producers and their agronomy teams to ascertain field and crop variability, identify underlying causes and implement management interventions where possible.

Importantly, within block spatial variability in vegetable cropping was successfully identified and quantified through the project and this alone represents a major outcome in terms of crop management approaches and producer knowledge. Collaborator responses to successfully identifying spatial variability were mixed. In some cases identification and mapping of spatial variability confirmed and allowed for accurate definition of variability they were already aware of. For other co-operators, the identification of soil and crop variability tested long held assumptions that their production areas were relatively homogenous and challenged the efficacy of existing management practices.

The following section provides an overview of the results achieved with the technologies employed in the project. Individual farm and application results are presented through a series of case studies.

Crop biomass sensing

Satellite

The range of technologies was used to assess spatial biomass variability included satellite, UAV and tractor mounted crop sensing imagery. In large areas, >20ha, satellite derived NDVI was a useful indicator of crop vigour and did provide information that could be actioned via ground-truthing (see **Table 2** for a list of farms and imagery capture dates). The satellite imagery/data allowed project participants to view biomass data in very high resolution and compare areas of low biomass on a whole-farm scale (**Figure 11**). However, most horticultural crops in Queensland are grown in coastal areas and cloud cover can often be a limiting factor. Satellite images were generally scheduled four weeks in advance of a critical crop stage (e.g. post – establishment and pre-harvest), which meant that the capture had to be rescheduled, delaying critical management opportunities. During peak growth periods in many districts, a number of capture windows were missed due to weather conditions.

As the project progressed, it was clear to both the producers and project staff that satellite imagery, while useful in identifying issues (e.g. irrigation uniformity and weed pressure) over large farms it could not give producers all of the information they required. While the imagery was useful to achieve ‘buy-in’ from producers and their teams, the time delay between the image capture and the processing time was generally too long (1-2 weeks), to be of value.

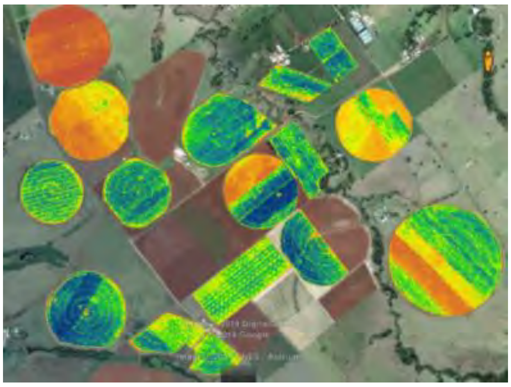


Figure 11: NDVI satellite imagery of potato crops planted under pivot irrigation in Atherton

Table 2 Satellite imagery used for identifying spatial variability in crop biomass based on NDVI (including non-demonstration site collaborators)

Farm	Crop	Satellite imagery date	Comments on imagery
Poggioli	Potato	12 October 2014 21 February 2015	Imagery indicated irrigation uniformity problems, soil nutrition vs. potato variety effects
Cuda	Potato	16 October 2014 7 November 2014 26 August 2015 23 October 2015	Imagery indicated irrigation uniformity problems, pivot gun efficacy, aerial spray and nutrient application uniformity, soil nutrition vs. potato variety effects
Moore	Beans, carrots	15 March 2014 11 May 2014 10 August 2014	
Sutton	Broccolini	17 July 2014	Irrigation issues able to be identified
Kengoon Farming	Sweet corn, green beans, carrots and onions	15 March 2014 11 May 2014 10 August 2014	Irrigation uniformity, possibly some soil type differences affecting irrigation/nutrition/amendment effectiveness
Reick Farming		15 March 2014 11 May 2014 10 August 2014	
Kalfresh	Carrots	17 July 2014 10 August 2014	Plant establishment and disease pressure identified
Windhum Farms	Sweetpotato	25 January 2015 5 September 2015 10 November 2015	Irrigation uniformity, underlying landscape features, such as drainage lines that have been cultivated for cropping, variety differences, some features are unexplainable based on cropping history and will be investigated
Austchilli	Chilli, capsicum	25 January 2015 18 September 2015 14 October 2015 10 November 2015	Helped identify areas that were requiring additional irrigation and areas that were disease affected.
Euri Gold Farms	Trellised tomato	25 May 2014	Weed pressure, soil type changes affecting irrigation/nutrition/amendment effectiveness

Proximal sensors

Proximal sensing refers to the measurement of attributes of the canopy or fruit using sensors mounted on vehicles or close to the object being measured. Proximal sensors (e.g Greenseeker™) for collecting biomass data, specifically near-infra red (NDVI) data, were tested alongside satellite imagery and proved a more robust tool for identifying variability at a resolution sufficient for horticultural production.

In Bowen, satellite imagery was compared to a single quad-bike mounted Greenseeker sensor to measure NDVI of trellised tomato. The 0.8m resolution satellite imagery measured a small portion of the trellised tomato canopy, about 20 cm, with the remainder of the frame experiencing interference from external influences such as soil, plastic mulch bedding and weeds. An example of this is shown in **Figure 12**, where a satellite image was ground-truthed only to find that spatial NDVI variability was actually being influenced by weed presence in the inter-row area and did not correlate well to the tomato crop. The same crop was monitored two weeks later using a single Greenseeker™ sensor mounted on a quad bike on an altered angle discussed previously. The single NDVI sensor was better able to discern crop variability as it only measured the trellised canopy and not the soil or weed interference. In this case, plants that were suffering with disease symptoms, that went unrecognised when ground-truthing the satellite image, were clearly seen in the low biomass (red) areas of the mapping.

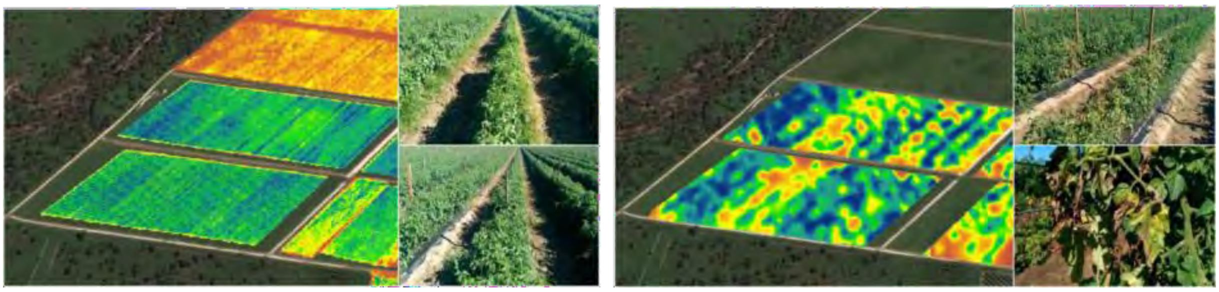


Figure 12: NDVI satellite image (0.8 m/pixel) of a tomato crop. High biomass indicated by blue colours, correspond to high weed presence in the inter-row while low biomass indicated by green/yellow areas had been cleared of weed (inset), left.

Tractor mounted crop sensing technology**,** was increasingly used as the project progressed. This approach proved to have a much better fit for crop sensing in intensive vegetable systems, as producers were able to view variability in real time on the screen and weren't hampered by weather conditions. The tractor mounted system also allowed producers to map crop growth any time they were undertaking a field operation without the potential for lengthy delays that could be associated with satellite imagery, an important consideration for short growing season crops.

To test Greenseeker technology, a quadbike mounted with a single Greenseeker sensor was used to survey a field of tomato on the March 31, 2015. The Greenseeker was able to distinguish the differences in canopy vigour of the trellised tomato plants, See **Figure 12**, with canopy NDVI values ranging from 0.55, lowest vigour, to 0.85, high vigour. At the time of ground-truthing, irrigation issues were recorded with localised waterlogging within the crop and low vigour areas corresponded to these waterlogged areas. The root systems of the waterlogged plants was very shallow to 10 cm in soil with a measured volumetric water (VWC) content of 24%, compared to the high vigour areas with root systems to 30cm and 10% WC. The waterlogged plants also exhibited symptoms of bacterial spot, *Xanthomonas campestris pv. vesicatoria* and bacterial wilt, *Ralstonia solanacearum*. Both pathogens thrive in warm, wet environments and can be transported in infected soils and water runoff (Persley *et.al*, 2010). As the site had been recently laser-levelled, it was concluded that waterlogging is an effect of differing soil types in the area and / or irrigation uniformity issues.

Some consideration of crop architecture and planting systems was also required when using the Greenseeker™ proximal sensors. For example where they were used to monitor trellised tomato fitting the sensors at an altered angle to view the side of the trellised tomato crop rather than the top of the canopy of the crop provided a better indication of crop growth (**Figure 13**).

Figure 13: A six-sensor Greenseeker™ array installed at an altered angle to view the side of trellised tomatoes, left

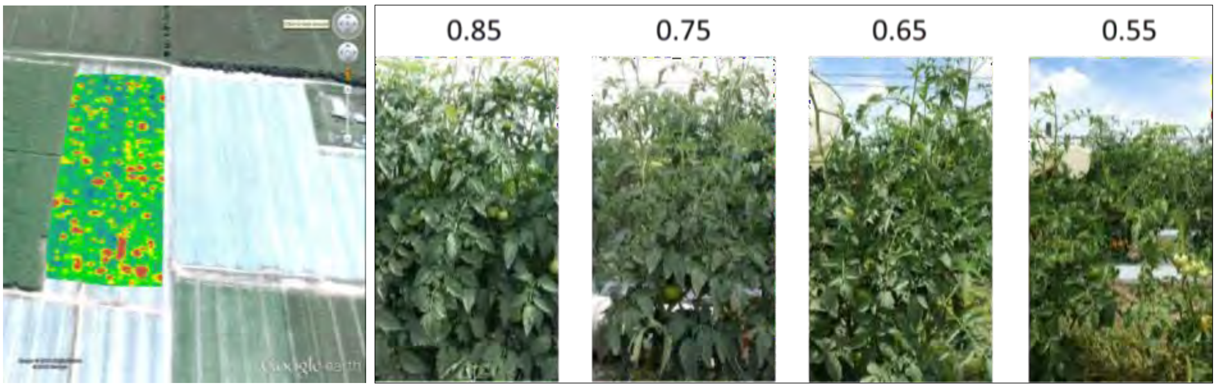


Figure 14: Bundaberg tomato biomass assessment using quad-bike mounted NDVI on March 31, 2015. The red areas of the crop indicate low vigour while the blue and green areas are highly vigorous, left.

Although proximal sensors were much more efficient at detecting variation at a very high resolution, and even individual plants, the methodology or technique used when collecting crop sensing data could also be a source of variability. In trellised tomato, an exercise using a quad-bike mounted with a single Greenseeker™ sensor found that the faster the sensor travelled through the crop, the less sensitive it became to individual plants. The operator set the data logging interval to 1 m/second, and by varying the speed of forward movement from 5 km/hour up to 20 km/hr resulted in very different NDVI readings from the same length of trellised tomato row (**Figure 15**). At 5km/h, the sensor was able to collect higher resolution data along the same length of trellised tomato. This indicates that operators need to have the skills and knowledge necessary to collect high quality data and alter logging speeds in response to ground speed. As a result, speed restrictions needed to be set while logging data and operators were advised to reduce rapid speed changes as much as possible.

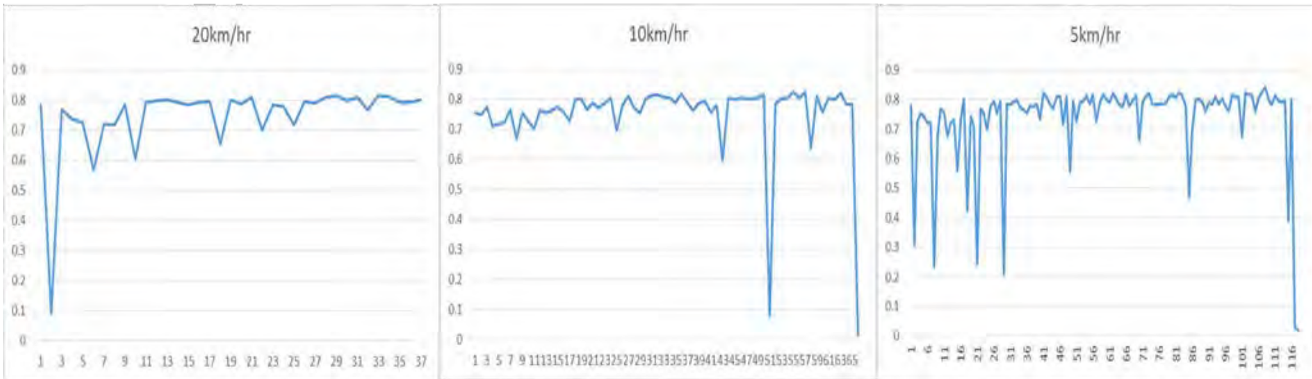


Figure 15: Greenseeker™ NDVI readings vs forward speed of a quad bike with 1m/1 second logging interval.

Unmanned aerial vehicles / systems (UAV - UAS)

Remotely piloted aircraft or UAVs certainly seem to offer great potential for producers and crop consultants to obtain accurate and timely crop sensing data and simple RGB photos and are destined to play an important role in crop management and precision farming approaches. Given the potential benefits to vegetable producers, the project sought to exploit this technology; but the reality at the time the project commenced there were very few commercial operators (particularly in regional locations) that could deliver a high quality product in the timeframes that are meaningful to vegetable producers, at a price that was competitive with other capture technologies.

Despite the service limitations, during 2014, as part of an ongoing R&D collaboration, carrot and onion crops were regularly monitored throughout the growing season by **Boeing 'Phantom Works'** using UAVs (**Figure 16**). This resulted in the development of a crop sensing system that is capable of delivering high resolution imagery to producers in less than 24 hours to mobile platforms. Following the results of 2014, crops (predominantly onions) continued to be monitored crops throughout 2015 with the aim of developing specific analytical algorithms that could be used in a predictive sense. An additional 3 producers became involved in these crop sensing activities. Monitoring of onion crops using UAV technology in the Kalbar region continued as part of an ongoing collaboration between DAF and Boeing Australia. The aim has been to use the UAV crop biomass imagery to develop specific algorithms for predicting disease. A range of technical difficulties with Boeing's aircraft and processing limited the extent to which accurate data was obtained and also how it could be interpreted, which further highlights that unmanned aerial applications beyond simple photographs is can be difficult. This work remains ongoing as several producers are keen to pursue UAVs as a crop monitoring tool.

In Atherton, a UAV was used to test their capability for effective monitoring of potato crops. UAVs were the preferred method in this region due to cloud cover causing satellite capture interference during the peak potato growing season. At the time, the information considered in the decision to use the UAV was sound, it could deliver NDVI data on crop biomass and this could be spatially mapped, the result however was a simple false-colour photograph that could not be manipulated or used to ground-truth the crop as the data contained no geo-referenced locations to create a spatial map. This was a lesson in skilling collaborators in understanding the technology and critical thinking to sort the genuine technical service personnel from 'novice' operators.

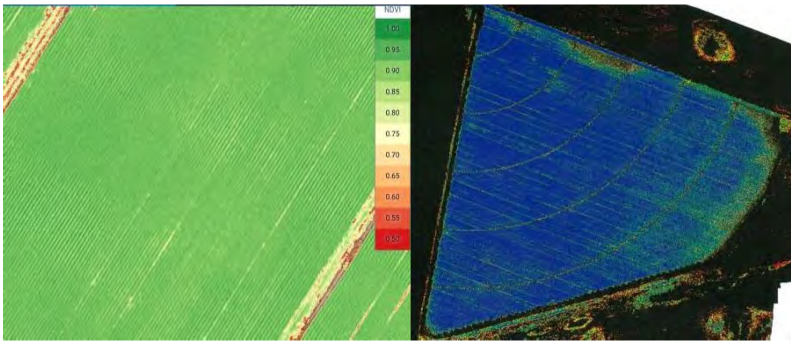


Figure 16: UAV (Boeing Phantom Works) captured crop biomass imagery in green beans (left) and carrots (right)

Yield monitoring

Yield mapping is the ultimate measure of spatial variability and a necessary data layer to undertake cost benefit analysis of the impact of spatial variability and management interventions. While a single yield map offers the producer a snapshot in time of a blocks yield, continual or further yield monitoring and mapping will allow the producer to track yields temporally and spatially, and measure the impact of any interventions. The majority of collaborators believe that it will be the ability to monitor temporal yield variability that will provide significant value in terms of the yield monitoring systems. As many of these crops are grown as part of a whole farming system rotation individual fields have not yet been planted back into the yield monitored crop. For example, carrots are planted into the same block once in 3 years. As the project was for 2 years, those fields initially yield mapped will still have another 1-2 years before they are planted back into carrots. This has limited the collection of temporal data through the project.

Installation of the yield monitoring systems required some modification and optimisation. This impacted early yield mapping data in that while it provided a good indication of spatial variability it did not accurately reflect absolute yield tonnages. This was further complicated by the very nature of harvesting root crops in that soil and mud comprise a component of the harvested tonnages. Various methods of calibrating the yield monitors were undertaken in an effort to account for this soil component. How this was done and to what extent, varied depending on the layout and capability of the packing shed. In mechanically harvested carrots, this dirt and mud component was measured in samples taken directly from the harvester and was found to vary from 10-20% across the field (**Figure 17**). Despite the conveyors assisting in the removal of dirt and mud, it is estimated that under wet conditions the soil component could account for up to 50% of the load-out weight.

Figure 17: The mud and dirt component recorded by yield monitors of mechanically harvested carrots can be significant, up to 50% in wet conditions.

As with many vegetable crops, yield is only one component of profitability. The ability to provide product within a customer's market specifications is also critical. The quality of the product (marketability) also needs to be considered and this is the data layer that is currently lacking and would complement the yield mapping layer.

Soil mapping (EM38)

Electromagnetic induction (EMI or more commonly referred to as EM38) soil mapping sensors have been commercially available for use in agriculture for over 30 years. Despite the low costs and benefits of undertaking soil mapping activities; very few of the project collaborators (including some crop consultants) were even aware of it let alone had used it prior to the project. EM38 soil mapping was used both as a tool to identify spatial variability and to better understand through comparing data layers any variability identified through other mapping layers such as crop sensing imagery or yield mapping.

In some cases, EM38 mapping was closely correlated with spatial variability. This would be expected where variability was due to inherent soil characteristics such as textural differences (**Figure 18**). In this example soil analysis of texture reveals significant differences in sand and clay content between these areas, with the red areas (pale areas in google earth image) having significantly lower clay content and sandier soil type. Where EM38 was not closely correlated to spatial variability, then further groundtruthing activities were undertaken. In terms of this project, in these examples spatial variability tended to be due to pH issues, soil moisture or the influence of 'cut and fill' for land levelling.

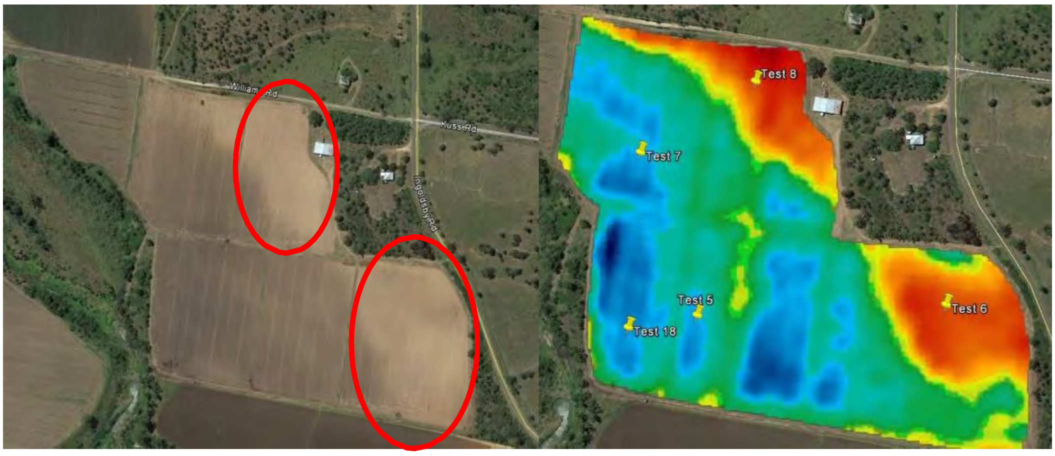


Figure 18: Google earth image indicating differences in soil type as indicated by differences in soil colour (left) and EM38 mapping which shows similar patterns (right) where red areas indicate a lower EMI.

Groundtruthing

Once evidence of variability was detected and mapped, ground-truthing is then required to determine the cause of variability. Ground-truthing is critical because without ascertaining the causes of variability it cannot be understood or indeed managed. Ground-truthing activities involves significant time commitments (and expense) from project staff, producers and consultants through field visits to assess and undertake sampling whether identified variability was caused by:

- Pest and disease impacts,
- Irrigation issues,
- Soil and nutrient variability
- Sensing artefact or error (bare soils, plastic mulch, weeds)
- Seasonal or varietal differences

In the absence of any obvious pest and disease problems or irrigation issues, further sampling and mapping was undertaken. Ground-truthing primarily involved strategic and zonal sampling of soil and plants, and EM soil mapping. Where possible, existing data layers were used to help understand variability, such as cut and fill maps or previous EM soil mapping. The majority of variability detected throughout the project was due to soil type variations (with possible nutritional and irrigation influences on crop growth), cut and fill land levelling and pH related issues. The use of mobile devices was an essential element of ground-truthing by project officers and/or crop consultants enabling accurate spatial sampling and mapping as part of ground-truthing activities.

One example of zonal soil sampling (**Figure 19**), where distinct ECa zones were identified using an EM38 sensor. These zones were processed into three distinct zones and investigated using a mobile device with location positioning to find and take soil samples from the zone of interest. The geo-location of the soil sample was recorded via geo-positioning applications on a mobile tablet. Other strategic sampling regimes involved setting up a grid-pattern for sampling soil characteristics such as pH (**Figure 20**). A mobile application called Sirrus (www.sstsoftware.com) was used to deploy a grid-based sampling regime and the application was used to find the centre-point of each grid location to take and record the location of soil samples.

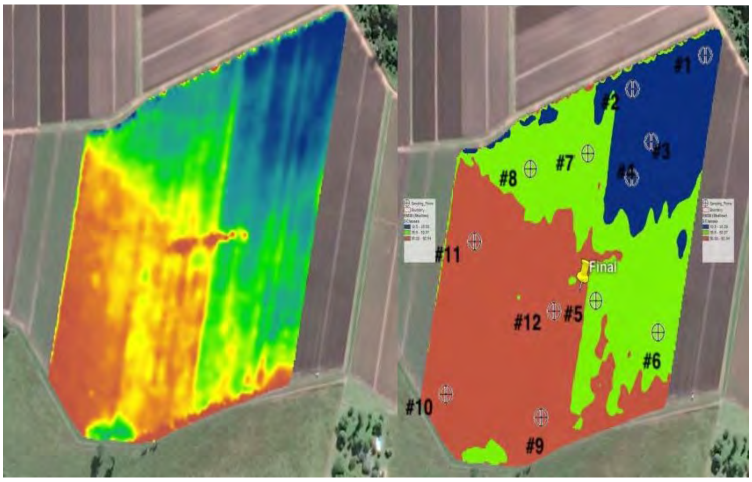


Figure 19: EMI soil mapping (left) and zonal map (right) used to record soil sampling points.

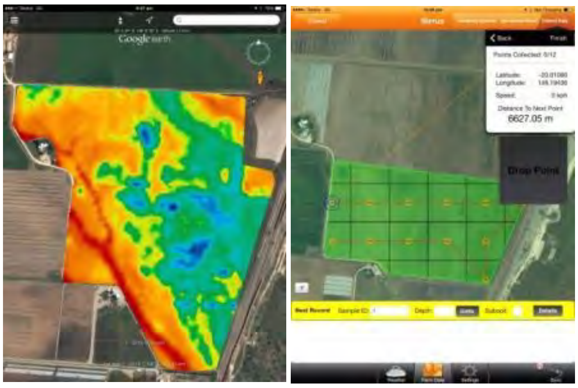


Figure 20: Using a mobile device and crop scouting software Sirrus by SST (centre), for zonal or grid based soil sampling to ground-truth EM soil data.

The sampling methodologies associated with ground-truthing spatial variability have resulted in two major paradigm shifts within the producers and consultants engaged in the project. There has been a quite significant change to how producers understand the role and indeed the power of increased rigour towards soil sampling and how agricultural consultants undertake soil sampling and recommendations. In one example, an agronomist was asked to give a recommendation for fertiliser rates based on 26 soil tests. Traditionally, a single soil test would be used to make a recommendation for this entire 26ha of vegetable crop under pivot irrigation. Alternately, here each soil test had to be treated as a separate field in order to develop a logical recommendation, complete with geo-referenced coordinates to map the prescription (**Table 3**). Generally recommendations are based on the most limiting factor to crop growth and in this instance it was phosphorus. Each zone in the prescription map was allocated a rate in 5% increments based on the soil test results (not shown). This adjustment in methodology for producers, agronomists and DAF officers did cause problems with early ground-truthing efforts, resulting in missed opportunities for prescription mapping due to incomplete data sets, delays in processing data or missed production windows.

The physical and timely sampling of soils and crops to unlock mapped data from sensing activities can be both onerous and costly and often producers were not able to commit adequate resources to this component, with consultants also reluctant if a suitable return-on-investment (ROI) isn't obvious.

Table 3 An example of fertiliser recommendations for developing a variable rate prescription map comparing traditional and new VR application rates

Sample ID	Location Latitude ('S)	Location Longitude ('E)	Rate 1 (-20%) kg/ha	Rate 2 (-15%) kg/ha	Rate 3 (-10%) kg/ha	Rate 4 (-5%) kg/ha	Rate 5 (STD) kg/ha	Rate 6 (+5%) kg/ha	Rate 7 (+10%) kg/ha	Rate 8 (+15%) kg/ha	Rate 9 (+20%) kg/ha	Rate 10 (=25%) kg/ha	Rate 11 (+30%) kg/ha	Rate 12(+35%) kg/ha	Rate 13 (+40%) kg/ha
21388850	-17.336866	145.529966									2,520				
21388751	-17.336929	145.531111								2,415					
21388752	-17.336373	145.531764					2,100								
21388753	-17.335829	145.532809								2,415					
21388754	-17.335356	145.5345							2,310						
21388755	-17.335107	145.534375										2,625			
21388756	-17.334682	145.535149													2,940
21388757	-17.334299	145.536009									2,520				
21388758	-17.333511	145.535585								2,415					
21388759	-17.333932	145.534704											2,730		
21388760	-17.334238	145.533933										2,625			
21388761	-17.334669	145.533051							2,310						
21388762	-17.335026	145.532158								2,415					
21388763	-17.335343	145.5313								2,415					
21388764	-17.335875	145.530215							2,310						
21388765	-17.336195	145.52966		1,785											
21388766	-17.334964	145.530148								2,415					
21388767	-17.33464	145.531033							2,310						
21388768	-17.334298	145.531862							2,310						
21388769	-17.333866	145.532684											2,730		
21388770	-17.333414	145.533391													2,940
21388771	-17.333021	145.534079								2,415					
21388772	-17.332922	145.532157													2,940
21388773	-17.333362	145.53134													2,940
21388774	-17.333963	145.530544													2,940
21388775	-17.334514	145.532115											2,730		
Total kg			0	1,785	0	0	2,100	0	11,550	16,905	5,040	5,250	8,190	0	14,700

Total kg/26ha pivot	Avg VR kg/ha of 26ha pivot	Traditional kg/ha
65,520	2,520	2,100
P kg/ha VRA	252	210
N kg/ha VRA	18	15

Turning data into knowledge and management actions

Investing in precision systems often runs the risk of generating an abundance of data without reward or a satisfactory ROI. In addition, turning complex datasets into actionable items and farming knowledge isn't necessarily a straightforward process. Firstly, the project sought to focus on elements that made sense to producers, such as soil and yield maps, crop biomass and simple VR inputs (lime). Secondly, if variability could be viewed, quantified and understood then it was highly likely that if suitable equipment (or agronomic approaches) and adequate support mechanisms were available to assist with validation, then producers would seek to treat or reduce the variability.

Precision in agriculture typically involves the creation of management zones for intervention and strategies to address areas of concern (for example soil nutrition and structure, irrigation, pest and disease programs). Information is optimised when multiple data layers are utilised to develop strategic management zones.

Ideally a project of this scope and complexity would be delivered over a 3 to 4 year (or possibly longer) timeframe; this would allow more time and confidence to turn data into useable producer knowledge, particularly as more crop rotations would increase the validation of the technology and interventions. Nonetheless, in a relatively short time the project was instrumental in achieving (from a relatively low base) some compelling outcomes.

Presenting the entire body of work and individual activities undertaken across Queensland is not possible in this report. Therefore, the following series of case studies are intended to provide the reader with a deeper understanding of both the benefits and the complexity of adopting precision management approaches in a range of commercial vegetable production systems.

Case Study 1 – Vee Jay's Tomatoes, Bowen

Operations

Key outcomes

- Improved knowledge and management of soils and disease
- Variable rate equipment operational
- Variable rate compost application completed
- Crop sensing of biomass health now a farm practice

Vee Jay's Tomatoes produce trellised gourmet (round) tomatoes and trellised roma (or egg) tomatoes, grape snacking tomatoes, specialty chilli lines and specialty coloured mini-capsicum lines. Vee Jay's Tomatoes is a family owned business that aims to reduce their farm's reliance on inorganic fertilisers and chemicals. The majority of the crop's nutrition is supplied via a pre-plant compost application. This compost or "ash" as it sometimes referred is a composed mixture of sugarcane mill by-product, chicken manure and fruits rejected by marketing standards waste from the packing shed. The compost enhances the microbial activity of the soil via the high carbon content of the sugarcane by-product, sometimes referred to as mill mud or mill ash. Their VR objectives are to understand the causes of variability in their crops by strategically sampling soil and crops, apply VRA amendments where they can modify soil variability and to work towards delivering precise applications of nutrition to boost low productivity areas via foliar sprays.

Activities

1. EM soil survey
2. Strategic soil sampling
3. VRA compost amendment
4. Proximal (Greenseeker™) NDVI mapping

Vegetable crops are only grown in Bowen between the months of March and November, with the summer months characterised by high temperatures and high rainfall. In 2014, a 57ha block was surveyed by EMI sensors and this indicated that the farm had apparent soil variability. In February 2015, further mapping using EMI technology was carried out. From a total area of ~200ha, an area of 57ha was soil sampled using a 2 ha grid-pattern to determine nature of spatial features indicated by the EMI mapping. When analysed, soil chemical properties were found to be well correlated with calcium (R^2= 0.8), magnesium (R^2= 0.73), pH (R^2= 0.9) and sodium (R^2= 0.95) levels, indicating that soil type is influencing EMI zones rather than EC (or water). As a result a compost recommendation was developed to supply the crop with the desired levels of potassium, phosphorus and calcium, see Table 6. A prescription map was developed and subsequently applied by a bulk spreader retrofitted with variable rate control on the 8th of May 2015, to supply compost rates to the area to meet these requirements with rates ranging from 5 t/ha to 20 t/ha (**Figure 21**). A basic chemical analysis of the compost contains 0.6% N, 1% P, 0.4% K, 0.4% Ca and 21.6% total carbon. The highest rate of 20 t/ha of compost was applied to areas that were severely lacking in calcium, see **Table 4**.

Analysis using EM, soil samples and Greenseeker data indicated that the areas where the highest rate of compost was added was affected by low crop biomass(**Figure 22 - 23**), where crops were barely half the NDVI biomass rate than crops that grew in areas spread with 5 and 15/ha compost rates. Further analysis of this relationship showed that disease and soil type factors were at play as the highest rates of compost were applied to areas of the field that had the highest clay percentage and therefore highest at risk of waterlogging and root diseases.

Analysis of Greenseeker™ data show (**Figure 24**) that trellised tomato and chilli crops can be effectively monitored using the technology. Ground-truthing the data has identified numerous causes of low biomass areas including, native and feral animal damage, harvesting damage, herbicide damage and disease. Early disease detection in horticultural crops could have the largest impact on crop management strategies and this data shows disease can be identified early in trellised tomato using angled proximal, Greenseeker™ sensors. Low biomass readings were evident in the crop as early as July 28, 2015 while ground-truthing on August 4, 2015 only identified a mildly symptomatic area with suspected *Fusarium sp*. infection of a susceptible egg tomato variety, Site 4 (not shown) while other areas of low biomass on the data layer did not necessarily correspond to low biomass in the crop. These low biomass trends continued to be investigated and samples were collected on August 19, 2015 for laboratory testing.

By August 19, 2015 Site 4 had been devastated by disease and plants had begun to collapse with stems showing signs of vascular discolouration of the stem well above the crown, an indicator of *Fusarium oxysporum* f.sp*. lycopersici* infection (**Figure 25**). Ground-truthing on August 19 using Greenseeker™ data layers dated August 13-15, 2014, showed the infection had possibly spread from the highly susceptible neighbouring crop to a resistant gourmet tomato crop at Site 5 and 6. Although resistant, disease pressure was high enough to cause yellowing symptoms in some plants (**Figure 26**)**.**

After August 27-30, those plants that were exhibiting yellowing symptoms were now in a state of collapse. The pathogen *Fusarium oxysporum* (race not confirmed by laboratory testing) was successfully isolated and identified via molecular sequencing by the DAF Grow Help Laboratory in samples taken on August 19, 2015. *Fusarium oxysporum* is a soil-borne fungus that enters the root reducing the effectiveness of the water conducting tissue of stems. This causes stunting, yellowing, wilt and eventually death (Persley *et. al*, 2010). This infection cannot be treated with chemicals or pesticides and prevention is the best practice using resistant cultivars and good farm hygiene.

A secondary infection of *Fusarium falciforme*, which is not a known pathogen of tomato, was also isolated from the samples taken from Site 5. This could indicate that the pathogen pressure had weakened the plant to the point where secondary invaders could infect the plants. When locations of these plants were compared to maps from the previous months, a disease pattern emerges well before advanced physical symptoms certainly resulted in yield losses.

Fusarium oysporum f.sp. lycopersici is host specific, only attacking and penetrating the vascular tissue of tomato (*Solanum lycospersicum*) specifically. Race 1 and 3 of the pathogen are widespread in Queensland with Race 2 being only found in the Bowen district (Persley at al, 2010) and are very difficult to control once agricultural soils have been inoculated. Conventionally, management practices include: long rotation cycles with non-host plants, resistant cultivars, quarantine and soil fumigation (Fravel *et al*, 2003), however Borrero *et al* (2006) states that there is no effective chemical control of *F. oxysporum* f.sp *lycopersici*. The authors also state, that while Race 1 and 2 resistant cultivars have been available for many years, the constant development and discovery of resistant forms of the pathogen, with over 200 forms now recognised (Fravel *et al*, 2003; Borrero *et al*, 2006; Persley *et al*, 2010), means that the development of new resistant cultivars, and particularly Race 3 resistance, and maintenance of soil health must be a priority.

Veejay's are impressed by the technology's ability to detect poor performing areas of tomato crop before visual symptoms emerge and will train a dedicated officer to collect and analyse their own Greenseeker NDVI data via specialised software. The data will be used by the producer and agronomist to develop crop monitoring schedules and will reduce manual crop checking times. Although the data does not indicate causes of variability, agronomists will be able to pinpoint key sampling locations to accurately determine pest and disease pressure and make more targeted recommendations.

Table 4 Elemental requirements for tomato based on gridded soil sampling and rate of compost required to supply soil requirements (data provided by Bowen Crop Monitoring)

Sample #	Latitude ('S)	Longitude ('E)	Sulphate -S kg/ha	Phosphorus kg/ha	Potassium kg/ha	Calcium kg/ha	Compost t/ha
1	-20.04961	148.1423	71.4				**5**
2	-20.04974	148.1439	63.1				**5**
3	-20.04982	148.1449	61		15.7	332.7	**20**
4	-20.04839	148.1459	60.3		34.1		**5**
5	-20.04986	148.1457	52.4				**5**
6	-20.05099	148.1456	60.8				**5**
7	-20.05168	148.1478	59	2.6	86.5	529.2	**20**
8	-20.04983	148.1479	64.7		154.6	285.6	**20**
9	-20.04852	148.1481	60				**5**
10	-20.04849	148.149	66.5				**5**
11	-20.04979	148.1488	53.7				**5**
12	-20.0512	148.1486	48.5				**5**
13	-20.05127	148.1503	60	5.2			**5**
14	-20.04982	148.1505	71.5	15.7	117.9		**15**
15	-20.04852	148.1507	34.1	31.4			**10**
16	-20.0474	148.1506	70				**5**
17	-20.04596	148.1507	57.6	73.4	23.6		**15**
18	-20.04481	148.1507	67.6	31.4	23.6		**5**
19	-20.04498	148.1519	56.3		15.7		**5**
20	-20.04592	148.1517	60.8				**5**
21	-20.04722	148.1515	59.7				**5**
22	-20.04867	148.1519					**5**
23	-20.04974	148.1518					**5**
24	-20.05099	148.1516	71.5	55	70.7		**15**
25	-20.05001	148.1528	39	68.1	13.1		**15**
26	-20.0489	148.1528	61.6	44.5			**15**

Figure 21 Compost (referred to as ash) rates based on soil test data was poorly correlated to EM perceived zones but both layers assisted agronomists and GIS specialists to meet the tomato crop's nutrition needs recommended by agronomists (left) and final compost VRT prescription application based on soil properties and EMI mapping (right).

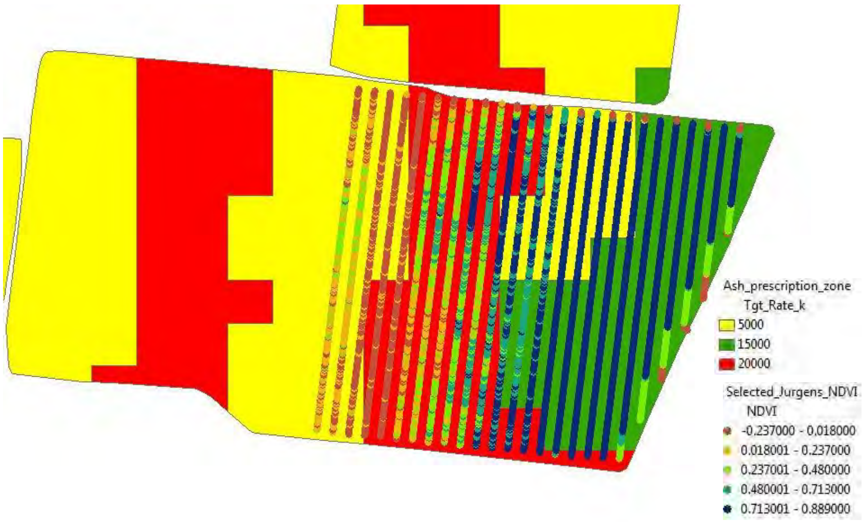


Figure 22: Greenseeker data collected on the August 29, 2015 overlaid with the compost prescription map shows low NDVI ranges of crops correlate with the area that received the highest rate of compost, 20/ha.

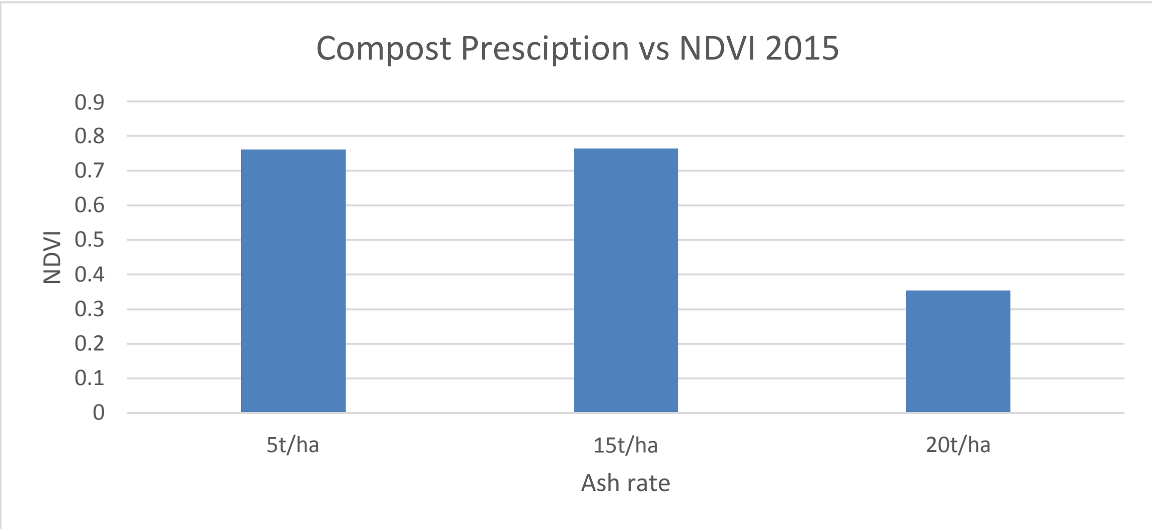


Figure 23: Compost (ash) prescription and NDVI data shows that the area that was treated with the highest rate of compost had crops that exhibited the lowest NDVI readings for biomass.

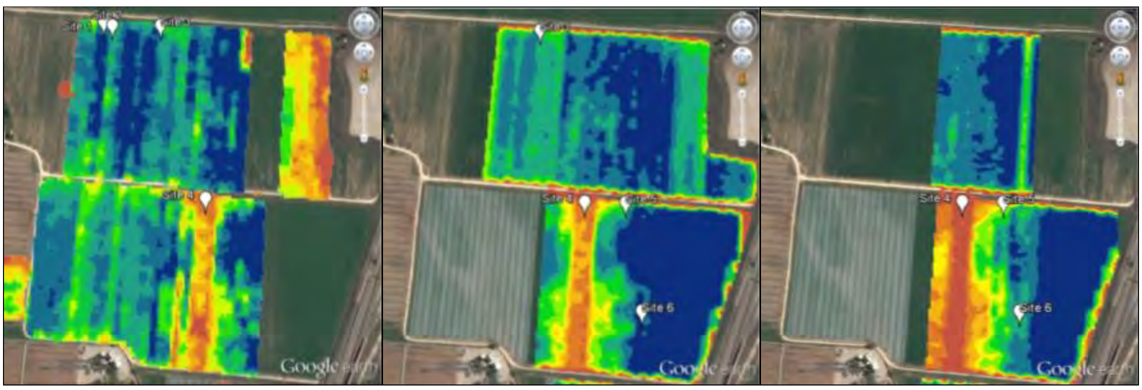


Figure 24: Using Greenseeker™ for early disease detection and tracking disease progression in trellised tomato.

Figure 24 notes - Left: July 22-28, 2015 ground-truthing identified a number of areas affected by disease, Sites 1-4, characterised by yellowing and wilting leaves. **Centre**: August 19, 2016 Sites 5 and 6 showed symptoms of Fusarium sp. (later confirmed as *F.oxysporum*) infection and were sampled, while Site 4 crops, a susceptible egg-tomato variety, had completely collapsed. **Right**: By August 27-30, 2016 Site 5 and 6 plants showed advanced signs of infection and plants at Site 5 were collapsing.

Figure 25: August 4, 2015: Site 4 low biomass area identified using Greenseeker™ data corresponded to an egg-tomato variety susceptible to *Fusarium sp*. Presence (left) and August 19, 2015: Site 4 presented vascular tissue discolouration of the lower stems when inspected (right).

Figure 26: Physical symptoms of Fusarium sp. detected by Greenseeker® proximal sensors on August 19, 2015 at Site 5 and 6 (left) and by August 30, 2015, Fusarium sp. symptoms on trellised tomato were severe (right).

Case Study 2 - Phantom Farms, Bowen

Operations

Phantom Farms, owned and operated by Carl and Trudy Walker is located 3.2 km from the mouth of the Don River north-west of the Bowen township. The primary vegetable crop is capsicum, including yellow, green and red types with some specialty cucumber and tomatoes. The farm acquired GPS Guidance and auto-steer technology in 2010 after receiving a Reef Rescue grant to improve soil health and management. At the time, Mr Walker also had the foresight to install flow rate control on a fertiliser spreader knowing that this would help him to more evenly distribute fertiliser across the farm and avoiding fluctuations in rates caused by traveling speed changes. Basic operations include, controlled traffic farming, traditional "representative" soil sampling on a block-by-block basis, basal fertiliser and gypsum application (1 t/ha standard). Crop seedlings are transplanted into plastic mulch with drip irrigation to conserve moisture and create ideal growing conditions during the winter growing months.

Key outcomes

- Improved knowledge and management of soil and soil sodicity
- Variable rate equipment operational
- Variable rate gypsum application completed

Activities

1. EM mapping using Trimble developed SIS method
2. Variable rate gypsum application to 25 ha of sodic to highly sodic crop land

The soil can be characterised as a fine-sandy-clay-loam and due to the proximity of the Don River there is a shallow aquifer; groundwater levels are highly variable in the area. In 2011, groundwater levels rose to within 0.3 m, of the soil surface causing salts to be deposited into the active rootzone of the crop and over subsequent years, crops have suffered as a result. However the extent of the problem was not well understood prior to this project which undertook EM mapping and strategic soil sampling at Phantom Farms. Variability across the farm had not been assessed and soil sampling using traditional bulk sampling methods had not adequately identified the extent of soil sodicity. As a result, an inadequate gypsum application/s were being applied. In March 2016, a local precision agriculture contractor undertook EM mapping and soil sampling to 1 m depth using the Trimble SiS (Soil Information System) www.trimble.com/Agriculture/sis.

The mapping and sampling test results show that a significant portion of the land's topsoil (0-0.5) and subsoil (0.5 m-1.2m) is affected by salinity with EC (1:5) ranging from 0.09 to 0.66 dS/m and 0.02-1.24 dS/m respectively. Hardie and Doyle (2012) state soil salinity restricts plant growth due to toxicity via an increased uptake of concentrated toxic ions, such as sodium and chloride, and reducing the uptake of water and nutrients. Capsicums are shallow rooted crops, taking 70-80% of their water requirement from the top 0.3 m of soil (Ben-Gal *et al*, 2012), fortunately in the Phantom Farms case study the highest levels of salinity were found below 0.5 m. However, the more extreme salinity figures fall into the moderate and high levels of salinity (**Table 5**) and therefore have the potential to cause yield declines

The results also show that of the 32 ha mapped, 53% of the cropping area had an exchangeable sodium percentage (ESP) of over 6%, with some areas having an ESP as high as 20.5% within the top 0.5 m of soil, this is considered sodic to highly sodic (**Figure 27**). Sodic soils are prone to dispersion, hard setting and surface crusting, reducing infiltration of water. Where the EM mapping results were highly correlated to adverse soil conditions and showed spatial variation across the farm, variable rate amendments, particularly using gypsum used as an ameliorant is warranted.

A gypsum prescription map/program (**Figure 28**) was developed using agronomist expertise and a gypsum calculator (such as Back Paddock's Sodicalc, see www.backpaddock.com.au) to address the farm's salinity and sodicity. Rates ranged from 0 t/ha on 16 ha to 10 t/ha on 7.18 ha on the highly sodic portions.

In April 2016, an existing bulk spreader was fitted with variable rate control to service the VR gypsum application. The equivalent of 6 t/ha (average rate used) was spread across 20 ha to ameliorate the effects of high salinity and sodicity on the farm. While the rates varied from 0 t/ha to 10 t/ha, due to the way the land is utilised, this rate was halved (0 t/ha to 5 t/ha) as it was applied only to the bed that the crop was grown in and incorporated, and not applied onto the permanent controlled traffic wheel-tracks (e.g. not broadcast spread).

Over the coming months/years, soil salinity, and crop heath and yield will need to be monitored using sites and data identified during this project to validate the effectiveness of the prescription map and track the farm's progress in reducing the effects of salinity and sodicity. These results are not reported here due to the project's close in June 2016, however an outcome in terms of a yield improvement is expected based on comparing crop yield in current and ideal soil conditions via a gross margin reported in the economics section.

Table 5: Australian soil salinity class based on saturated paste equivalent (ECsp(eq)) and corresponding 1:5 dilution values, (Source: Hardie & Doyle, 2012, pp 424)

Salinity class	Saturated paste extract (EC_{eq} or EC_{se})	1:5 Dilution ($EC_{1:5}$)		
	All soils (dS/m)	Sand (dS/m)	Loam (dS/m)	Clay (dS/m)
Non-saline	0–2	0–0.14	0–0.18	0–0.25
Low	2.0–4.0	0.15–0.28	0.19–0.36	0.26–0.50
Moderate	4.0–8.0	0.29–0.57	0.37–0.72	0.51–1.00
High	8.0–16.0	0.58–1.14	0.73–1.45	1.01–2.00
Severe	16.0–32.0	1.15–2.28	1.46–2.90	2.01–4.00
Extreme	>32.0	>2.28	>2.90	>4.00

Figure 27 Location of Phantom Farms owned (blue) and leased (red) crop land. Arrow shows the salt scalds in uncultivated land

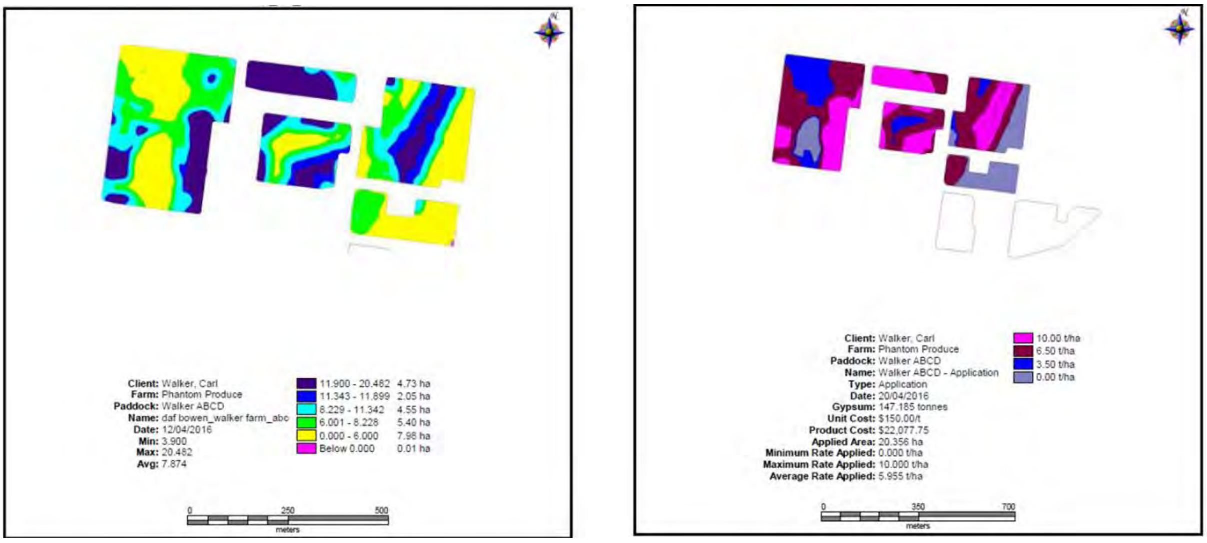


Figure 28: ESP% ranging from 0 to 20% at Phantom Farms (left) and a prescription application map for VR gypsum amendment to address soil salinity, gypsum rates range from 0 to 10 t/ha across 20 ha (right).

Case study 3 – North Qual Produce, Atherton Tablelands

Operations

North Qual Produce, managed and owned by the Cuda family, manage a group of producers located in the Atherton Tablelands west of Cairns. The producer group produces up to 14,000 tonnes of fresh and processing potatoes. Having already invested in GPS auto-steer systems, North Qual pursued precision technologies to assist them to efficiently manage the large area of land (300ha) used to grow potatoes under the eleven centre pivots that are used for irrigating and nutrient applications. The main focus of the business is to improve yields through better soil management and targeted inputs.

The majority of pre-plant activities are performed by tractors and equipment in the field, a combined fertiliser and planter operation plants the crop and post-planting the crops are managed for pests using aerial (light aircraft) applications. The crop is harvested mechanically using a Grimme GB1700 potato harvester.

Key outcomes

- Improved knowledge and management of soils and soil moisture
- Local contractor now operational in delivering prescription mapping
- Variable rate lime application completed
- Yield monitoring operational with yield performance analysed
- Local agronomist undertaking a range of precision practices.

Activities

1. Remote (satellite) NDVI mapping
2. EMI soil survey
3. Strategic soil sampling
4. VRA lime amendment and fertiliser
5. Yield monitoring

Initial high –resolution satellite mapping (NDVI) of the potato crop in 2014 indicated that a number of crop performance issues could potentially be addressed using VRT, particularly soil ameliorants, fertiliser and irrigation. A number of large pivot irrigators (up to 26 ha each), showed that irrigation efficacy was not as high as desired and some of these issues could be rectified by general maintenance of the equipment. EM soil mapping of several pivot fields also indicated that there were some significant soil characteristic changes that should be investigated. These EM data sets were incomplete therefore a sampling program using soil zones was not possible, so grid sampling soil physical and chemical properties was performed across three pivot fields. These fields were Pivot **4**, **8** and **10**, however Pivot 10 was not cropped in the 2015 season and was therefore the project concentrated on Pivots 4 and 8.

A load-based yield monitor was installed on a Grimme potato harvester in 2014. The purpose of the yield monitor is to record yield data during harvesting and to give North Qual a better indication of the extent of crop variability. The yield monitor installation represents the first one installed in Queensland. During the 2014 potato harvest, a logging fault was detected and the yield monitor computer and logging interface unit was replaced. More recently a wireless upgrade was carried out, this will enable yield data to be transmitted via mobile network connection directly to the data processor, negating the need to manually retrieve data from the unit.

Example 1 – Pivot 4 (26ha)

Soil results for Pivot 4 were developed into a prescription map to apply VR lime, the goal was to increase pH to 5.5 (CaCl) of a loam-clay-loam soil across the block as well as address phosphorus nutrition. The lime rates/areas ranged from 0 t/ha for 8 ha of land that did not require a lime application, to 4.5 t/ha on 3 ha of very acidic soil. Unfortunately, the application timing window in June 2015 was rapidly closing before the project team and producer could secure a VR ready lime spreading contractor and the traditional 2.5 t/ha had to be applied. If this lime VR lime amendment had been achieved, 40% of the total lime used could have been saved by using VR technology and processes. Basal fertiliser rates were adjusted to supply adequate phosphorus nutrition to the potato crop by -5% up to +40% of the standard rate of 2.1 t/ha custom N:P:K fertiliser blend with Entec®, a nitrification inhibitor reducing leaching risk. This VR prescription would have increased fertiliser application by 17% however the fertiliser would be applied in a more strategic way to boost the productivity of low production areas. Despite a successful test application the week before, as with the VR lime, problems were encountered on the day of application and the VR retrofitted fertiliser box was manually overridden to prevent double the desired rates being applied. This installation error has now been rectified.

EM soil mapping, soil samples and satellite NDVI captures in 2014 indicated some differences in soil texture across the 26ha. The texture contrast was slight and partially influenced by past management practices but was visible in numerous layers of spatial data including EM and NDVI (**Figure 29**). Historically, the crop planted in the south-eastern side of the pivot suffered from moisture stress earlier and the producer also observed that the dominant wind direction (south–easterly) during the growing season had an influence on plant productivity. These observations indicated that there was potential for variable rate irrigation and to confirm this, two soil moisture monitoring stations were installed in the eastern and western sides of the pivot to record soil moisture and electrical conductivity at depths ranging from 15cm - 85cm. Irrigation was manually adjusted based on feedback from the soil moisture sensors that can be viewed online and mobile devices regarding water percentage at critical root zone depths. As a result, the eastern half of Pivot 4 received approximately 11% more water than the western half of the pivot.

Based on soil moisture data (**Figure 30**), and the EM mapping the western side of the pivot has slightly sandier soil which drained irrigation water faster than the western side. The western crop also appeared to have a shallower active root zone, as it utilised moisture at higher rates in the 15-35 cm zone than the crop on the eastern side. In this case there is an indication that due to slight soil textural differences and aspect, crops planted on the western side of the pivot should be irrigated more frequently in smaller volumes to potentially increase yields.

Soil salinity (EC) was also monitored by the MEA soil monitoring stations. Measuring salinity can be an indicator of fertiliser (salts) extraction or leaching in soils. The salinity profile on the eastern side showed that EC was highest in the 25 cm depth while on the western side, EC is high at both 15 and 25 cm depths with a steady increase in EC at the 35 cm depth, indicating some leaching may be occurring to this depth. Salinity in terms of crop limiting toxic salts, such as sodium, chloride and aluminium, is low indicating that the soil salinity sensors are likely to be detecting high fertiliser concentrations in the surface layers of soil, particularly phosphorus and potassium (**Table 6**). What is clear from the salinity sensor results (**Figure 30-31),** is that removal of nutrients, or salts, is highest early in the crop's growth period and there is minimal leaching, despite the addition of 11% more irrigation on the eastern side of the pivot. This suggests that irrigation strategies could be improved further to increase productivity on the eastern side of the pivot with low risk of fertiliser leaching past the root zone.

Yield monitoring data indicated that yields in Pivot 4 ranged from **32 t/ha to 46 t/ha** (average of zones) in the 2015 season, with a single variety planted in the eastern side of the pivot, as indicated in **Figure 29**, producing a much higher yield (49.5 t/ha). When this higher-yielding variety was separated from the rest of Pivot 4 yield data, it revealed that it in fact produced 27% more than the average yield (**Figure 32**).

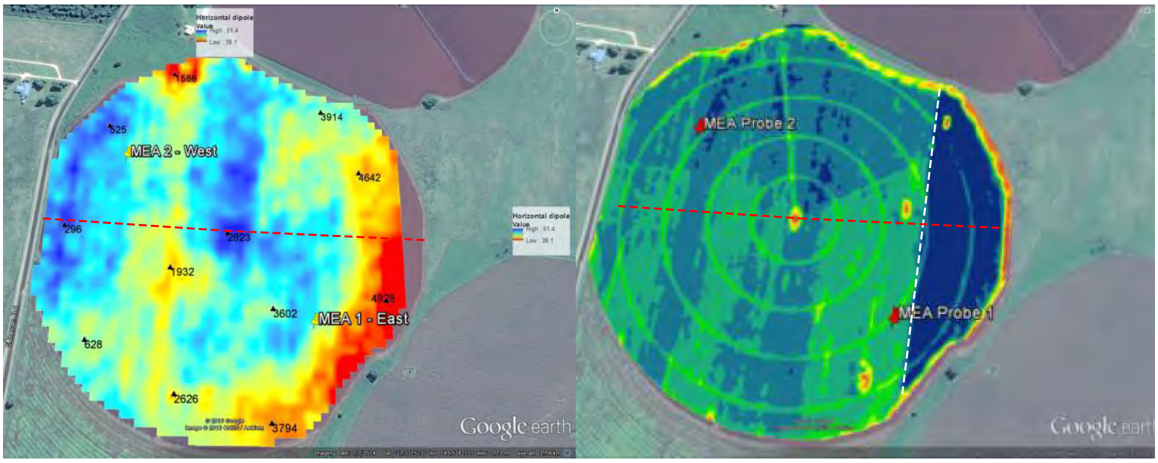


Figure 29: (left).Location of soil sample sites (▲) and MEA capacitance soil moisture probe locations in Pivot 4. The area north of the red dotted line was once a fenceline between two different fields, the northern side was once grazed while the southern was potato cropping.

Figure 29 (right) Pivot 4 potato crop NDVI satellite image showing higher biomass areas north of the red dotted line, in younger cropping land. The dark blue area east of the white dotted line is a more advanced potato crop that has reached maximum biomass earlier (full, closed canopy with no soil surface to reflect red light).

Table 6 Soil samples taken at soil moisture monitoring stations on 4 September 2015 show decreasing EC and nutrients from 15 cm to 65 cm, reflecting the data collected by the salinity sensors

Site	Depth (cm)	pH (1:5 CaCl2)	Elect. Conductivity dS/m	EC (Sat. Ext.) dS/m	Organic Carbon (OC) %	Phosphorus (Colwell) mg/kg	Available Potassium mg/kg	Calcium (Amm-acet.) Meq/100g	Sodium (Amm-acet.) Meq/100g
East (1)	15	5.10	0.32	2.00	1.20	356.67	586.67	4.07	0.04
	25	5.40	0.27	1.70	1.23	236.67	333.33	5.03	0.04
	35	5.37	0.17	1.07	0.76	89.00	210.00	3.53	0.03
	45	5.60	0.14	0.87	0.47	52.33	150.00	3.13	0.03
	55	5.77	0.12	0.80	0.45	56.33	153.00	3.13	0.02
	65	5.93	0.12	0.73	0.39	41.67	130.00	3.03	0.02
West (2)	15	5.27	0.47	2.93	1.27	376.67	720.00	5.37	0.05
	25	5.67	0.25	1.57	1.27	223.33	356.67	5.50	0.04
	35	5.70	0.15	0.93	1.06	146.67	280.00	4.57	0.03
	45	5.73	0.13	0.80	0.58	67.00	203.33	3.33	0.02
	55	5.83	0.12	0.73	0.46	45.67	150.00	3.10	0.02
	65	5.90	0.12	0.70	0.38	37.33	120.00	2.93	0.03

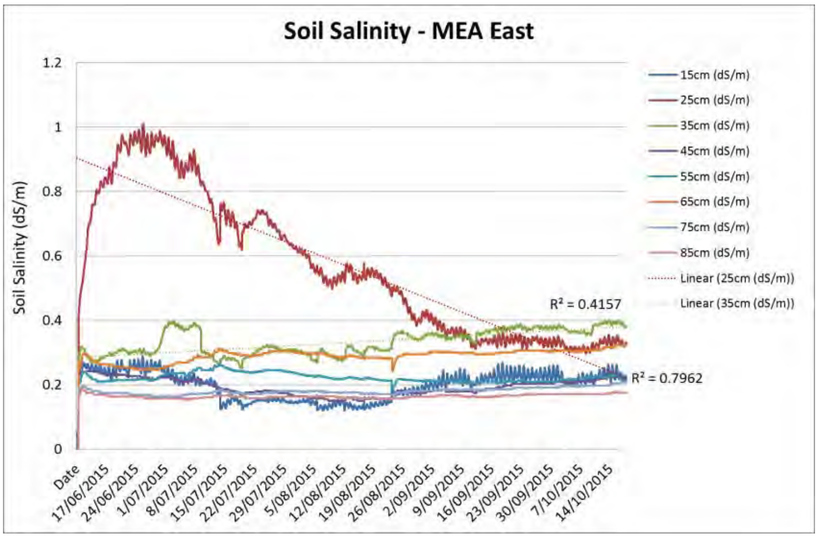


Figure 30 Soil salinity at Pivot 4's east monitoring station. Trend lines indicating salinity (or nutrients) is restricted to the upper, active root zone with only slight leaching into 35 cm soil profiles.

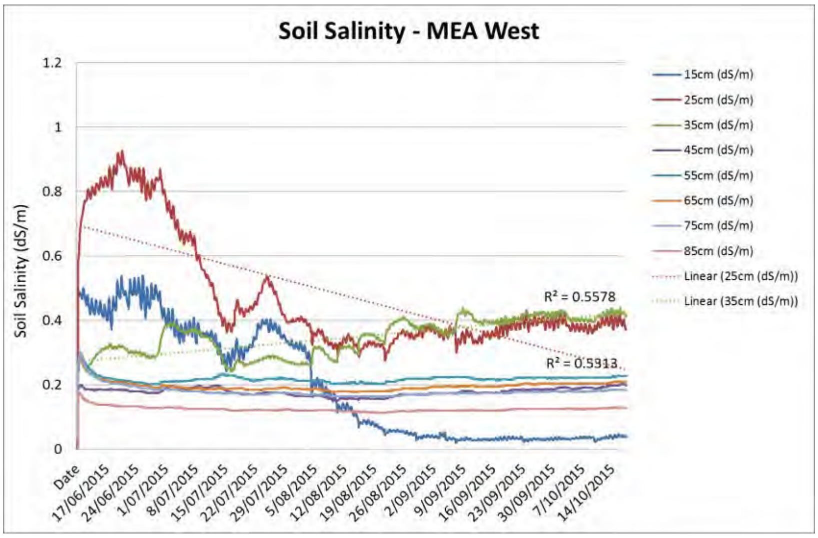


Figure 31: Soil salinity at Pivot 4's west soil moisture monitoring station at depth. Trend lines indicate that it shows a similar trend in the 25-35 cm zones however the western crop accessed more nutrition from 15 cm depth than the eastern crop, and higher leaching potential as salinity 25-35 cm depths increase slightly nearing the end of the season**.**

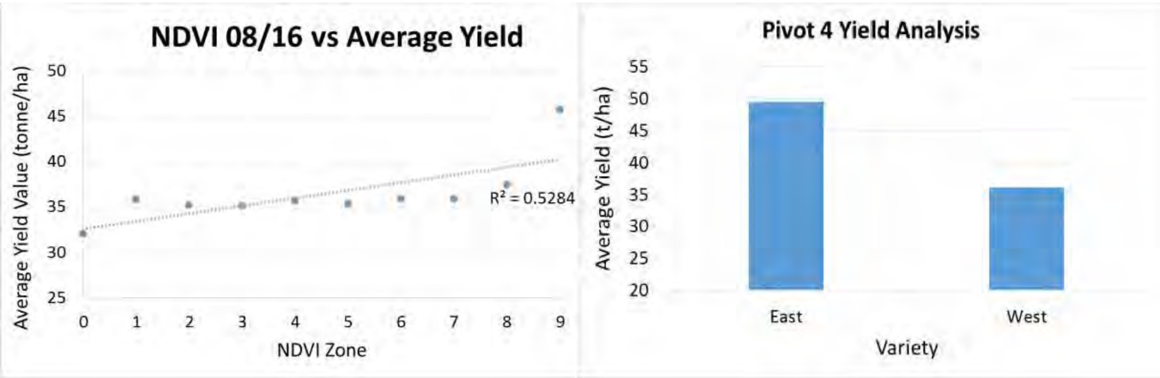


Figure 32: Correlation between yield monitor data and NDVI sattelite imagery (left) and yield differences between potato varieties seen in Pivot 4 (right)**.**

Example 2 – Pivot 8 (24.8 ha)

The results from grid based soil sampling showed the crop would benefit from a VR lime application to address pH levels (**Figure 32**)**.** The pH (CaCl) ranged from 4.7 to 5.7, (**Figure 33**) and a total of 34.9 t of lime was applied to address a target pH of 5.5.

When compared to the traditional blanket rate of 2.5 t/ha (a total of 62 t), a saving of 44% was made by adopting a VR based amendment on this field (see **Table 7** for detail). The cost of additional soil samples has been taken into account to compare traditional practices vs. VRT practices. In future, the producer and agronomist may want to reduce sampling cost by only sampling "zones".

Pivot 8 was monitored via NDVI satellite imagery and yield monitoring during harvest, however due to market restrictions only a small portion of the field was planted. This data set was limited and was unable to be correlated to pH, lime application, yield or NDVI. Follow-up soil samples were performed after the crop had been harvested however the pH range showed little variation when compared to the previous soil samples collected in 2014 indicating that it may take numerous years of targeted lime applications using VR to achieve pH uniformity in this red-clay soil type.

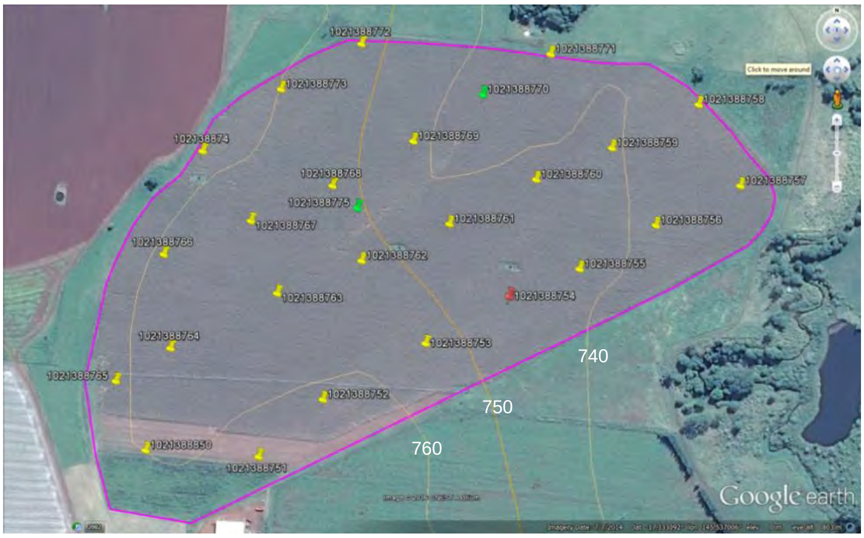


Figure 33: Grid sampling Pivot 8 (showing contours) for strategic VRT lime application, locations of soil samples were recorded and plotted using Google Earth's desktop application.

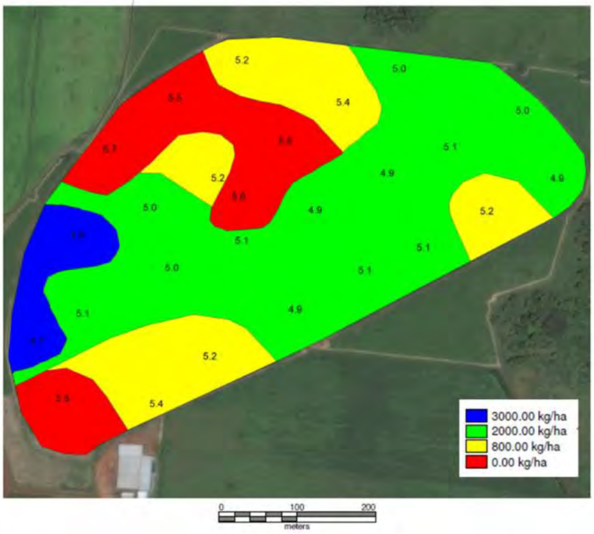


Figure 34: Grid based pH sampling of Pivot 8, a 24 ha potato field to produce a variable rate lime prescription map for Pivot 8 showing pH (CaCl) and lime rate zones 0-3000 kg (or 3 t/ha).

Table 7 : Lime rates and costs comparing VRT to traditional rates for Pivot 8

pH Zone	pH (CaCl)	Area (ha)	Lime Required (t/ha)	Total Lime (t)	Cost of Lime Spreading $160/t
Normal	5.5 – 5.7	4.6	0	0.0	$0
Moderate	5.2 – 5.4	5.8	0.8	4.6	$736.00
Low	4.9 – 5.1	12.9	2	25.8	$4,128.00
Very Low	4.7 – 4.8	4.8	3	4.5	$720.00
VRT Lime Cost		*24.8*	*1.4 (average)*	*34.9*	*$5,584.00*
Cost of soil sampling (24 samples only)					*$2,487.20*
Traditional Lime Cost		*24.8*	*2.5*	*62*	*$9,920.00*
VRT saving (Approx.)					*$1,848.80*

Figure 35: Panoramic photograph showing lime distribution after VR spreading on Pivot 8, note the areas that have received lime compared to those that have not.

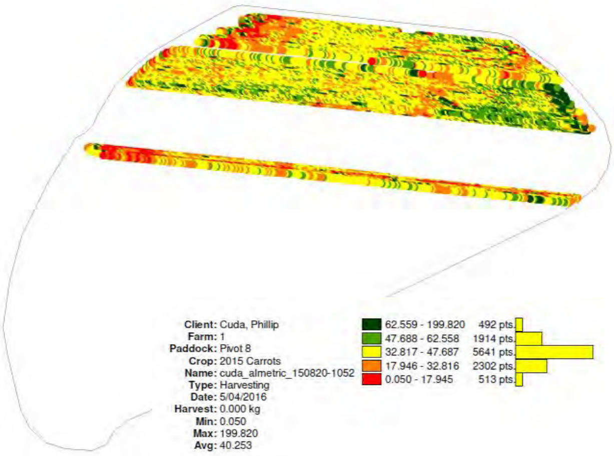


Figure 36: Pivot 8 yield data transposed into a map for easy viewing. The distribution table shows the crop produced a mean yield of 32-47 t/ha.

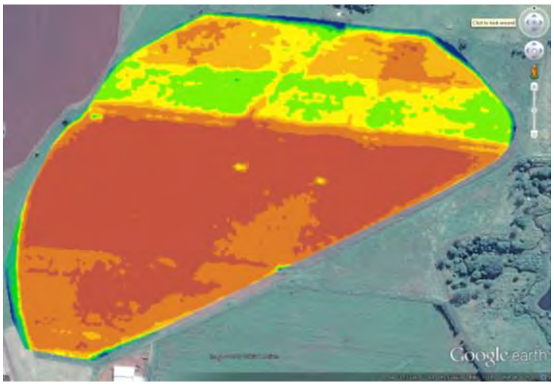


Figure 37: NDVI of Pivot 8 crop in August 2015 showing low NDVI (yellow/orange, top) of a young potato crops and very low (red/orange, bottom) of the uncropped section of the pivot with partial weed cover.

Further Yield Monitoring

Yield analysis on other fields on North Qual has showed similar correlations between yields vs. NDVI (**Figure 38-39**). Pivot 5 and 7 yields displayed the best correlation with NDVI data and these fields also had a relatively low variability in yield, from 5% to 7% respectively. These fields were otherwise not monitored in terms of identifying the cause of variability, but it does indicate that in-field variability across this potato farm can be quite low and that NDVI crop sensing is a valid tool for assessing yields. Gross margin analysis would help the producer determine if employing VR practices to address a yield variation of 5-10% would be economically beneficial.

Overall North Qual is satisfied with the data they have generated from the project. With some obvious productivity barriers now identified and understood, the producer is interested in pursuing VR programs in the two fields, Pivot 4 and 8, identified to be the most variable in this study. The producer and agronomist are now looking to appropriate software that could be utilised to streamline the data processing procedure and VR prescription map development. Now that a wireless upgrade has been made to the yield monitor, the data collection process will be less onerous and data will be available much sooner.

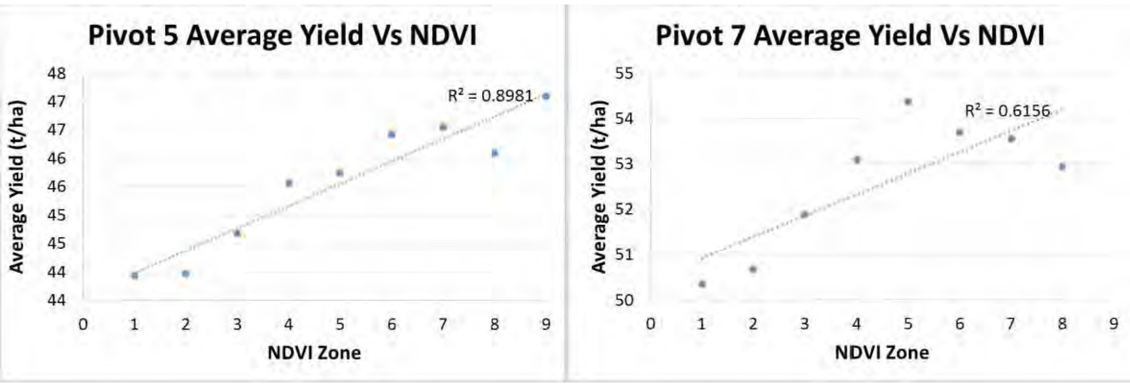


Figure 38: Pivot 5 yield vs. NDVI correlation shows good correlation between the two measurements and low variability across yield data sets.

Figure 39 (right) Pivot 7 yield vs. NDVI correlation shows good correlation between the two measurements and low variability of yield.

Case Study 4 – Poggioli Farms, Tolga, Atherton Tablelands

Operations

Ben and Justin Poggioli farm potatoes, irrigated peanuts and dryland seed-corn in rotation with grass and sugarcane at Tolga on the Atherton Tablelands. Ben takes on the majority of the crop management processes and has adopted a controlled traffic, strip tillage system to conserve soil and water resources. By adopting this farming system, Ben has reduced his tillage operations from four passes to one, saving up to 1.5 hours/ha of machinery use. Ben has observed variability on his farm for a number of years during spraying and harvest operations and went looking for technology that he could potentially use to find out what is causing yield variability and the extent of its effect on profit. Ben aims to improve poorly performing areas, increase productivity and reduce the cost of inputs such as soil amendments and fertilisers.

Key outcomes

- Improved knowledge and management of soils and crop health
- Proximal crop sensing adopted
- Variable rate equipment in operation
- Yield monitoring operational with yield performance analysed
- Producer engaged with farm software provider to develop precision data management.

Activities

1. Remote (satellite) and proximal (Greenseeker™) NDVI mapping
2. EM soil survey
3. Strategic soil sampling
4. VR lime amendment and fertiliser
5. Yield monitoring

Satellite NDVI imagery obtained in 2014 indicated that some fields exhibited variability as a result of seed issues, poor irrigation uniformity and poor biomass areas, which were leading to lower than expected yields. This confirmed what Ben had observed during the previous year's harvest.

Two satellite images were successfully captured for Ben's property; more were scheduled but were abandoned due to cloud interference. A four sensor Greenseeker™ sensor array was installed on existing spraying equipment to monitor crop biomass directly without the problems associated with satellite imagery and cloud cover (**Figure 40**). The spraying equipment traverses the field every 7 to 10 days and is the ideal tool to give producers information in real-time as well as creating layers of information to build an accurate picture of the farm productivity and problem areas. Ben says that viewing the Greenseeker™ in real-time has been one of the greatest benefits so far as he has been able to identify areas of crop that are suffering moisture stress due to irrigation uniformity and identifying the extent of reduced seed potato viability, usually due to old seed.

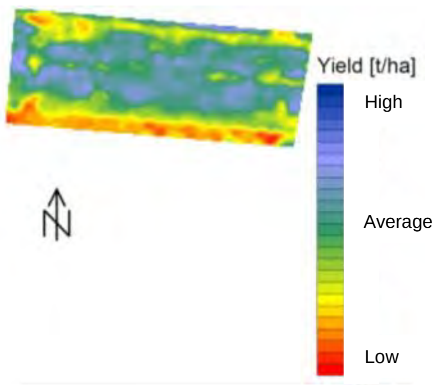
Figure 40: Greenseeker™ sensors mounted to spray boom

A load-based yield monitor (http://www.atv.net.au/ATV_YM2.html) was installed on a Grimme potato harvester in 2014 and data from the harvest that year confirms Ben's observations of the satellite imagery. In 2014, the yield monitor collected data on two blocks and the data revealed that yield had been adversely affected by the age of potato-seed that was purchased that year (**Figure 41**) and irrigation uniformity (**Figure 41 right**).

In early 2015, some EM mapping was performed on a 17 ha block at the Poggioli Farm. The mapping results indicated that there were areas that had highly compacted surface layers (0-20 cm) due to soil textural differences and nutrient availability as a result to pH. (**Figure 42**) This field was subsequently left out of the sweetpotato/corn rotation and planted with a cover crop in an effort to improve soil organic matter and structural condition. There is the potential to use a VR prescription or cultivation map to cultivate areas where high compaction was a problem. Developing cultivation prescription maps or excluding fields with high yield limiting conditions out of the cropping rotation is a previously unconsidered benefit of using precision approaches in vegetables. There is also the potential for remediation of pH and calcium via varying rates of gypsum application (**Figure 43**).

In 2015, market restrictions meant that the farm could only grow a small amount of potato and subsequently, a 7.5 ha block was planted. Yield monitoring of the block showed that a maximum yield of 73 t/ha (uncorrected) was achieved (**Figure 44**). Packing shed data was unavailable at the time of writing this report, however the developer of the particular yield monitor used here factors in a variation of 10% and discussions with producers suggest that a mean of 10% of the yield logged bythe monitor is soil or mud, depending on conditions.

Unfortunately, a number of factors prevented us and the producer from gaining really good outcomes in this particular case study. Ben has since stopped producing potatoes and will move onto other opportunities in vegetables and tree crops; however he is one of the most enthusiastic producers that volunteered to be demonstration farms and plans to continue with this work after finalising this project. Ben plans to move the yield monitor to a bulk vegetable harvester for melons and pumpkins and has taken on the task of developing his own VRT system using SST Software's 'Summit' desktop and 'Sirrus' mobile applications for VR amendments, foliage spray applications and yield mapping.



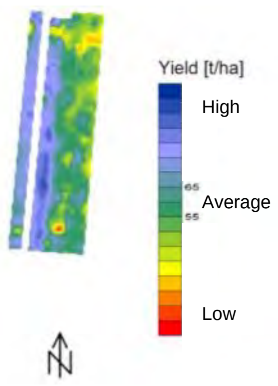


Figure 41: (left) 2014 Yield monitoring in potato block E-W revealed that seed viability and subsequently yield, had been compromised on a large area, shown in red as lower than average yield, due to old potato seed that was purchased and sown in 2014 and (right) yield monitoring shows the extent of irrigation variability on a 2014 potato crop and demonstrates the importance of regular maintenance of equipment.

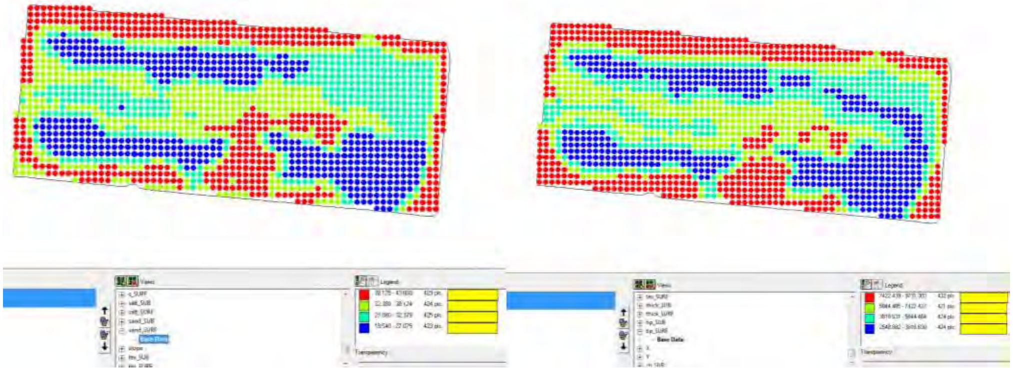


Figure 42: EMI SiS soil mapping surface layers viewed in Farm Works shows a relationship between sand percentage (left) and compaction in kPa (right) shows that VRT can not only be used for amendment application but also tillage operations.

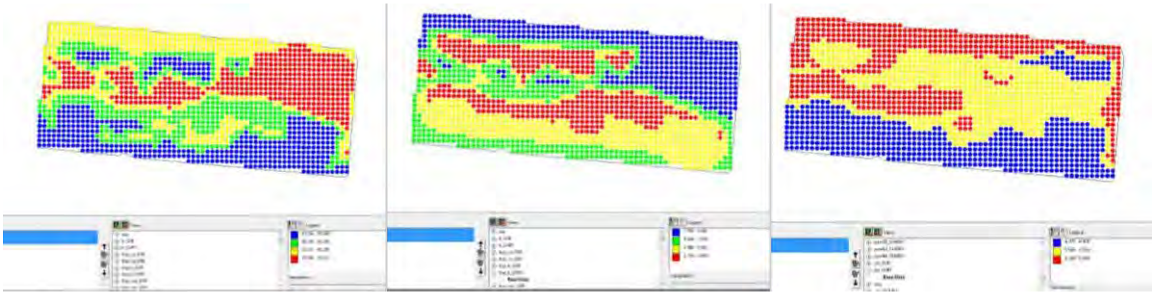


Figure 43: Calcium and potassium availability appear to be in response to pH (far right) and this combination can be used to develop pH and gypsum VRA maps in the future.

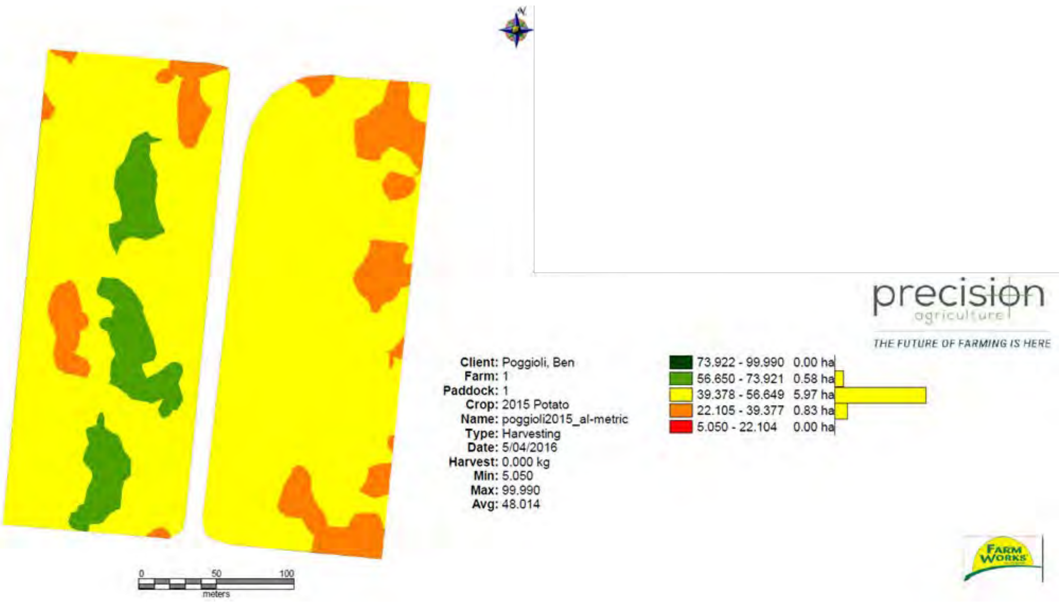


Figure 44: 2015 yield mapping at Ben Poggioli's potato farm, yield distribution shows 81% of the potato crop achieved a yield of between 39 t/ha and 57 t/ha.

Case study 5 – Kengoon Farming, Kalbar, SEQ

Operations

Kengoon Farming is a small family operation located just out of Kalbar in the Fassifern Valley, South-east Queensland. This farming operation produces green beans, sweet corn, carrots, onions and some fodder cover crops e.g. barley. They primarily produce crops under contract to larger packing operations. Green beans, sweet corn and carrots are all mechanically harvested crops so uniformity is of paramount importance to optimise marketable yield. This family has been working towards PA practices since they installed GPS guidance in 2009. Kengoon owned a VR capable speeder but had not used the VR capacity prior to the project.

Key outcomes

- Improved knowledge and management of soils and crop health
- Variable rate fertiliser and bulk spreading equipment in operation
- Yield monitoring operational across contract operations with yield performance analysed
- Proximal crop sensing now standard practice across farm
- Producer engaged with farm software provider to better utilise farm data

Kengoon have readily adopted VR applications through the project and it has become standard practice across the farm to improve the uniformity of crops, particularly where there has been significant variability due to land levelling activities. To date the various VR applications they have undertaken have had some benefit to the farming operation in improved uniformity, yield and cost savings.

Example 1 – Field 7

Satellite crop biomass imagery captured across this farm in March, May and August of 2014 revealed variability consistent with previous 'cut and fill' mapping for land levelling and producer experience with how the block performed (**Figure 45 and 47**). A targeted soil sampling program revealed that the poorer performing areas (Zone 1 – yellow and red areas in the satellite image) were typically associated with areas of lower nutrient status (**Table 8**) compared with Zone 2 (green areas in the satellite imagery), in particular nitrogen, phosphorus and potassium.

In the absence of VR capability, this field would have received 650kg/ha of an N, P and K granular fertiliser blend across the field, however a prescription map was developed based on the satellite imagery, cut and fill mapping, soil sampling results and producer knowledge of how the crop grew spatially. The prescription map resulted in 300kg/ha of fertiliser applied to 50% of the block (Zone 2) and 400kg/ha to the other 50% (Zone 1) using a VR-ready granular spreader (**Figure 46**). An additional 250kg/ha was top dressed on Zone 1 to give a total of 650kg/ha on only 50% of the block. This equates to a saving of 350kg/ha on Zone 2 and an overall 25% fertiliser saving across the block (>$1500 cost saving in fertiliser).

Table 8 Field 1 soil test results showing differences in nutrient availability between the two zones that can be addressed by VRT

Mg nutrient /kg of soil	Zone 1	Zone 2
Nitrogen (N)	13.3	31.0
Phosphorus (P)	76.8	125.0
Potassium (K)	332.0	507.0
Sulphur (S)	12.0	18.1
Boron (B)	0.65	1.0
Iron (Fe)	105.5	156.7
Zinc (Zn)	2.5	3.6

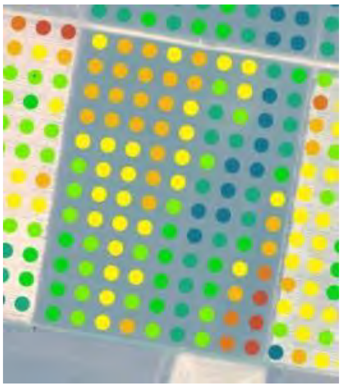


Figure 47: Field 7 cut and fill map, the coloured dots indicate the amount of 'cut' or 'fill' with red representing the greatest 'cut' areas and blue-green the greatest 'fill' areas.

Figure 46: VRT ready granular fertiliser spreader used to deliver a VRA prescription map to Field 7.

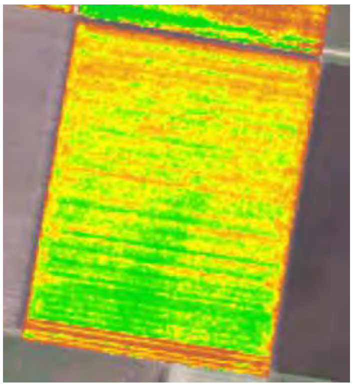


Figure 45: Field 7 satellite NDVI imagery; red to orange colours indicate low biomass or poorer growing areas while green indicates high biomass and better crop growth.

Example 2 – Pivot 1.

Identifying variability may not always require specialised technology such as EM soil surveying or satellite images, in Pivot 1 visible differences in soil type were evident using Google Earth (satellite view) images (**Figure 48**). According to producer experience, crops situated in the paler soil type, visible in the north and extending into the east of the block, consistently performed significantly lower than the rest of the field. EM soil mapping confirmed the visible soil differences (**Figure 48**).

Strategic soil sampling of this pivot quarter detected low pH (not critical but low enough to have a potential impact on nutrient availability). These results were mapped spatially and used to develop a prescription map for future lime applications. Rates were assigned based on a targeted pH increase from 5.5 to 6.5. Traditionally, a fixed rate of lime (approximately 1- 3 tonnes/ha) would have been applied across the whole field, however using VR, up to 6.5 tonnes per hectare of lime was applied to the poorer performing area and a reduced rate of 3 t/ha of lime applied to the remaining area.

As with some of the previous examples of VR lime, this particular prescription did not result in a saving in lime or cost of spreading, however it did result in noticeable yield improvements. In the subsequent green bean crop, there was a **75% yield response** across the poorer area, which equated to approximately **28%** of the field. The VR lime prescription used 14% more lime, which equated to an additional $300 in lime costs, but it was applied in a more targeted manner and achieved a yield result which more than offset the cost of additional lime. Yield mapping of carrots 18 months after the initial VR lime application indicates that there are still some issues in this area (**Figure 49-50**). Additional investigation is required to determine if this is due to different irrigation requirements with changing soil types and if it can be modified using additional VR approaches.

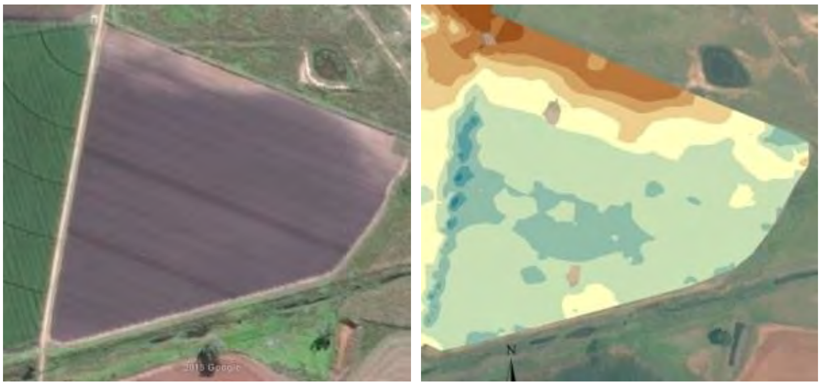
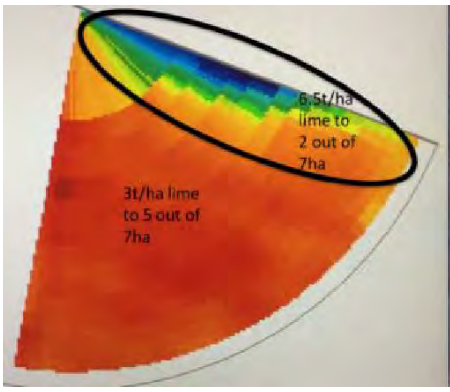


Figure 48: Real-colour Google Earth (satellite view) image of Pivot 1 quarter exhibiting soil type variability (left) and EM soil mapping of the same block, Pivot 1, confirming visual differences in soil type (right).



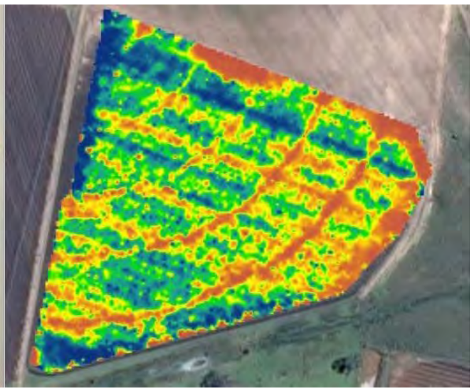


Figure 49: (left) A prescription map developed for Pivot 1 to address differences in soil chemical composition showing highlighted area of yield increase and VR fertiliser rates.

Figure 50: (right) Yield map of carrots 18 months after VR application.

Example 3 – Linton pivot 2

In 2015, Kengoon commenced using tractor mounted 'Greenseeker' sensors to map crop biomass. The NDVI data (shown in **Figure 51**) identifies spatially how variable crop growth was across the field. Two distinct growth zones are easily discernible (labelled 1 and 2). Plants sampled from each of the zones revealed significant differences in plant growth. Soil and plant tissue analysis from each zone highlighted some key differences in nutrient status (**Table 9**). The poorer growth areas (Zone 2) had significantly lower plant tissue nitrogen and potassium as well as lower nitrogen, phosphorus and potassium in the soil. As a result of this data granular fertiliser N, P and K blend was applied using VR to Zone 2 at a rate of 250kg/ha.

Following the VR application, this block also had yield mapping undertaken on the carrot crop. This yield mapping layer was consistent with the previous crop sensing imagery, in that the same patterns were evident across the field. Further analysis of this imagery indicates that the poorer performing areas yielded up to **25% less than the average block yield while the better performing areas yield up to 50% higher than the average** (**Figure 52**). From the lowest yielding to the highest yielding areas of this field represented a tripling of yield. This implies that the VR application may have been either too late in the crop to improve uniformity, or the single VR application was not sufficient to improve the nutrient status of zone 2 to the extent that it no longer impacted on crop growth. Nonetheless, the obvious field zonation discovered using crop sensing and the quantified impact on yield is compelling in terms of within block variability and the yield penalties that can occur.

Following harvest of the carrot crop, EM soil mapping was undertaken and revealed patterns that closely matched those previously seen in the crop biomass sensing and yield mapping. Further analysis of the available datasets reveals strong correlations ($R^2 = 0.96$) between the spatial layers, particularly between the crop NDVI biomass and final yield (**Figure 53**). This supports the differences in growth detected and quantified by the crop sensing data; and that undertaking crop sensing and employing NDVI data can be a good indicator of final yield performance. There was also a strong correlation (R^2=0.89) between the EM soil mapping and the NDVI biomass datasets. The relationship between the EMI and final yield was not as strong (R^2=0.67).

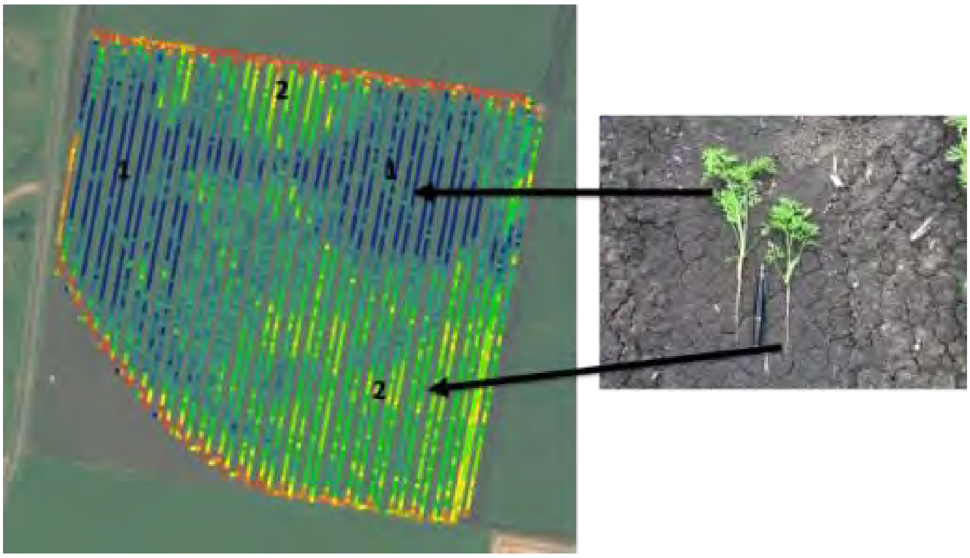


Figure 51: Tractor mounted NDVI mapping of "Linton Pivot 2", and plant samples from each of the crop growth zones. Green/yellow zones indicate poorer growth, blue indicates better growth.

Table 9 : Plant tissue and soil test comparison showing the percent (%) reduction in nutrient status between Crop Growth Zones 1 and 2.

Sample type	Nutrient	% Reduction
Plant Tissue	Nitrogen (N)	30%
	Potassium (K)	47%
Soil Test	Nitrogen (N)	66%
	Phosphorus (P)	50%
	Potassium (K)	40%

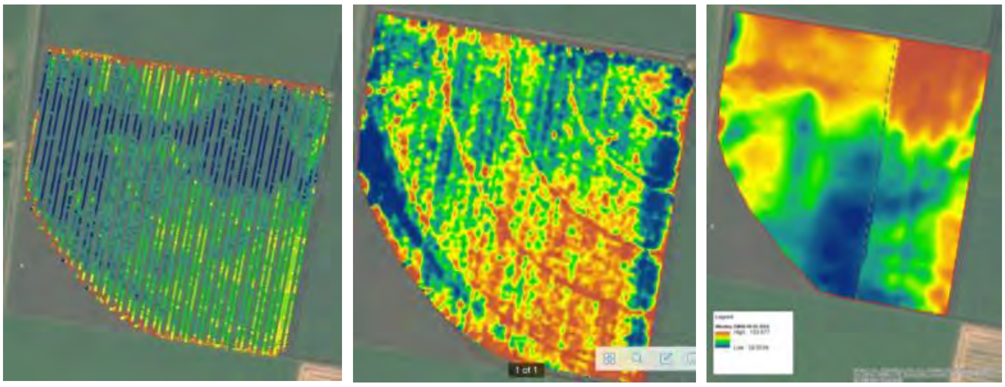


Figure 52: Greenseeker (left), carrot yield map (centre) and EMI soil mapping (right) all exhibit similar spatial patterns caused by differences in soil characteristics and show the impact on biomass and yield is consistent across layers.

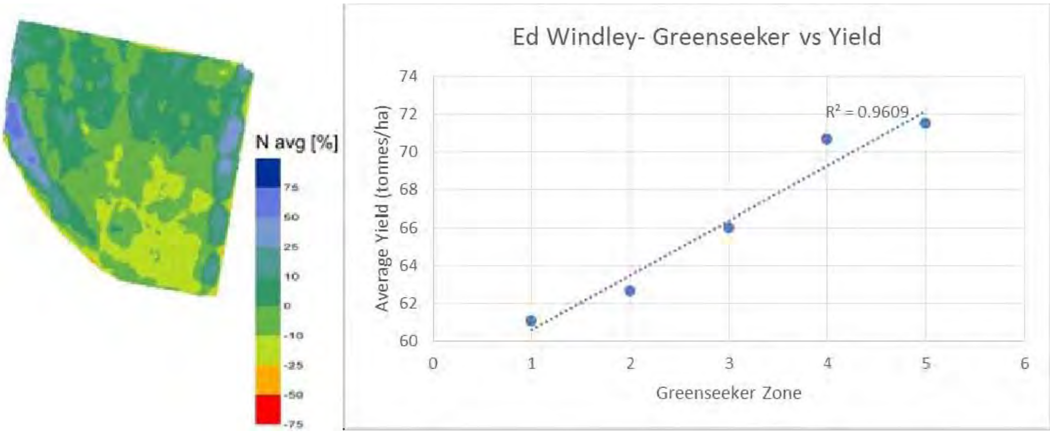


Figure 53: Yield mapping as a % of the average field yield can be used to determine the extent of yield reductions on gross margins, left. Right, the correlation between Greenseeker crop biomass mapping and yield mapping is very high at an R^2 of 0.96.

Example 4 – Field 4.

This example demonstrates how VR applications can be used to improve the spatial uniformity of vegetable crops. Biomass data obtained from Greenseeker sensors from June 2015 highlighted the variability that existed spatially across this field. From this spatial data some initial soil sampling indicated that a VR lime application could be warranted.

Based on the crop sensing data and the soil pH results a prescription map was developed to direct a VR application of lime featuring three (3) zones of different lime rates (**Figure 54 (A) and 54 (B)**). However, as the producer's confidence and skill in implementing VR technology grew, he also became more demanding in the level of detail he was seeking. At this stage he began developing his own prescription maps using commercially available software to more accurately reflect what was happening in the field, to incorporate his own knowledge of how the crop grew and also to facilitate more gradual changes in rates for the spreader. In contrast to the initial prescription map which had three zones, a finer resolution approach generated six (6) zones. This allowed for rates from **2 t/ha** on the better performing areas up to **7t/ha** on the poorer areas. Previously this block would have received a broadcast application of 3t/ha of lime across the 8.2 hectare block. Comparison of the two approaches revealed that the conventional broadcast application would have used 25.2 tonnes of lime, while the VR application used 26.9 tonnes of lime. So while the VR application used a similar amount of product it was far more targeted and an impact on crop performance could be expected.

Yield data will be obtained for this block when it is next planted to carrots. However, NDVI satellite imagery of the subsequent corn crop revealed extremely uniform production (**Figure 54 (d)**). This is supported by anecdotal evidence from the co-operator that the block has never performed so uniformly in the 10 years it has been farmed, with silking and tasselling of the corn occurring on the same day.

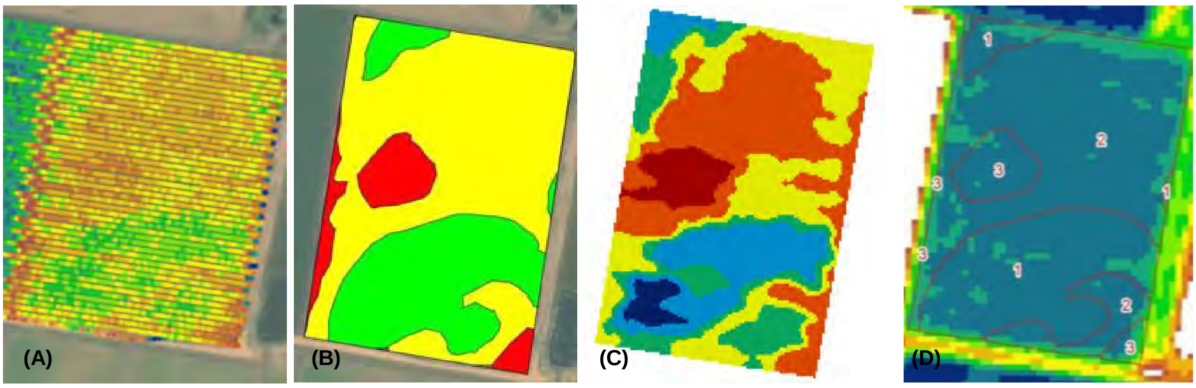


Figure 54: Field 4, (A) NDVI (Greenseeker) image showing biomass variability in June 2015, (B) – A prescription developed by an external service provider showing basic growth zones. (C) A prescription map for the same Field 4 developed by the co-operator using commercially available software to achieve greater precision in his prescription mapping, and (D) - NDVI mapping of corn crop following VR application showing the uniformity of crop biomass after a series of VR applications. Numbers represent the location of the original three prescription zones depicted in (A).

Case study 6 – DJM Farming, Kalbar, SEQ

Operations

DJM Farming is a small family operation located just out of Kalbar in the Fassifern Valley in South-east Queensland. This farming operation produces green beans, carrots, onions and some fodder crops e.g. lucerne and barley. They primarily produce crops under contract to larger packing operations. To maximise their previous investment in auto-steer technology and to improve uniformity and the most productivity from their operation, this business installed tractor mounted crop biomass sensors to assess spatial variability and are currently ground-truthing spatial variability to assess the potential for variable rate applications.

Key outcomes

- Improved knowledge and management of soils and crop health
- Variable rate fertiliser and bulk spreading equipment in operation
- Yield monitoring operational across contract operations with yield performance analysed
- Proximal crop sensing now standard practice across farm

Example 1 - Pivot 1

This field exhibits variability in crop growth as indicated by the tractor mounted NDVI data (**Figure 55 and 56 (A)**). The NDVI map indicates an area of higher crop biomass (blue) and a significant (approximately one third) of the block indicating poorer crop growth (yellow/red). The NDVI values obtained within this block range from 0.14 up to 0.75 (NDVI values only occur between 0 and 1) indicating that the variation in crop growth is likely to be substantial. Unfortunately, this mapping data was received too late to undertake any in crop ground-truthing. The variability evidenced in this crop biomass map has a similar pattern to the 'cut and fill' areas for land levelling when the pivot block was developed (not shown).

Figure 55: Tractor mounted Greenseeker crop sensors undertaking sensing (NDVI) in green beans

These mapping layers were used to assign zonal sampling points which will be completed to ground-truth the EM mapping and to identify any soil differences that may be contributing to the crop biomass variability (**Figure 56 (B) and 56 (C)**) **.** This grower has uploaded all his mapping data into PCT Gateway software for data storage, viewing and analysis, including mapping of sampling strategies, and development of prescription maps.

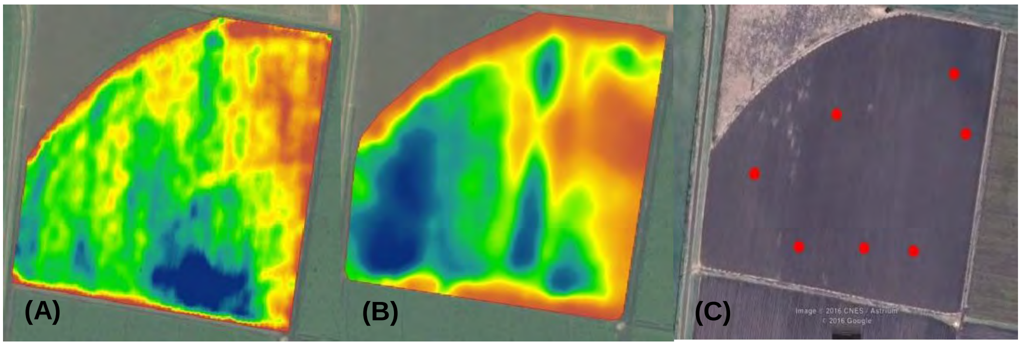


Figure 56: Tractor mounted NDVI (A), where the blue areas indicate the highest biomass areas through to the yellow and red areas which indicate the lowest biomass areas; and EMI mapping (B); and (C) sampling sites to ground-truth EMI mapping and the crop biomass mapping.

Case study 7 – Windolf Farms, Tenthill, SEQ

Operations

Windolf Farms is a family operation situated near Gatton in south-east Queensland. Windolf Farms produces potatoes, parsnips, watermelon and broccoli as well as having washing, packing and transport operations. In late 2015, Windolf Farms installed a Greentronics (www.greentronics.com) load cell based yield monitor on one of their Grimme potato harvesters (www.grimme.com) just prior to the 2015 harvest. They are interested in identifying variability to potentially implement variable rate soil amendment and fertiliser applications and variable rate planting of potatoes (e.g. adjusting the planting density based on spatial differences in performance).

Key outcomes

- Improved knowledge and management of soils
- Improved soil sampling regime
- Yield monitoring operational

Yield mapping

The yield monitor was installed immediately prior to the 2015 potato harvest. Due to the tight timeframes involved between installation of the equipment and potato harvest, there was little time to optimise the technology and undertake calibration before harvest. Consequently, these activities had to occur while harvest was in progress. This did result in limited complete field data sets for the yield mapping (**Figure 57**). Harvester operating staff also had limited time to familiarise themselves with the operation of the yield monitor and some of the missing data can be attributed to staff adjusting to the new routine of starting and operating the yield monitor. The first season experiences with the yield monitor did highlight to Windolf Farms the need to keep detailed records of field operations and crop details e.g. variety changes, to assist with ground-truthing the yield data post-harvest.

Post-harvest, approximately 150 hectares was mapped using EM soil mapping to identify any inherent soil characteristics that could contribute to yield variability (**Figure 58**). The soil mapping identified several blocks that were selected for detailed zonal soil sampling. Using the field depicted in **Figure 59** as an example, results of the soil sample analyses revealed significant soil texture differences (**Table 10**), or changes in clay and sand content. These would be associated with different irrigation requirements as sands are more freely draining with lower water holding capacity, requiring more frequent irrigation events than soils with higher clay content. Nutritional data indicates low status of some key nutrients (e.g. potassium, boron) that could be limiting to yield in these sandier soil types. Results for other fields revealed similar soil type variation and one field also exhibited high exchangeable sodium percentages (>6%) indicating potential sodicity and associated soil structural problems.

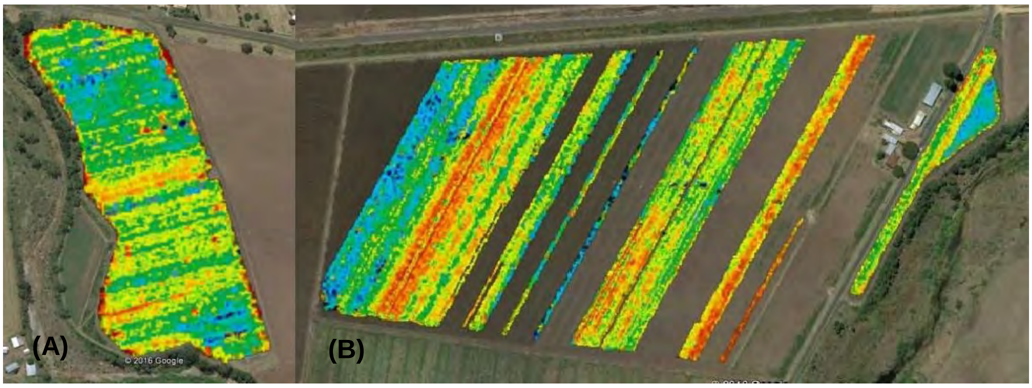


Figure 57: Greentronics yield map of a potato crop (A), with red indicating the lowest yielding areas and blue the highest and; an example of missed yield data (B)

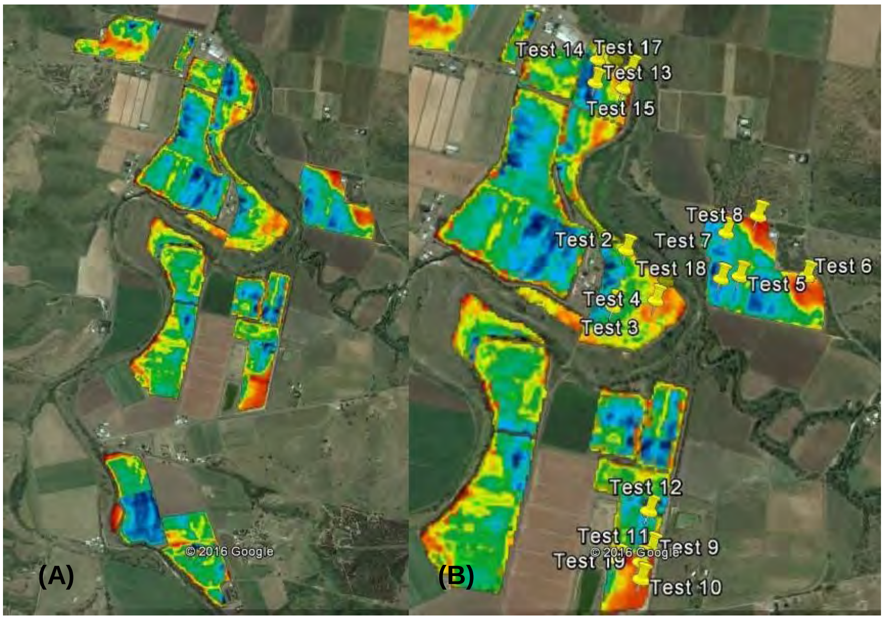


Figure 58: EMI mapping (A), colours indicate changes in clay content, soil salts or soil moisture and soil sampling sites (B) situated according to EMI mapping zones

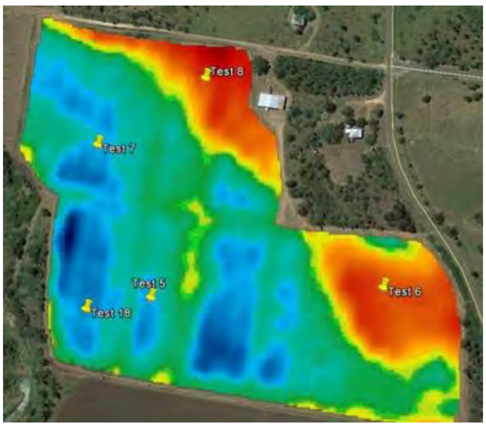


Figure 59: EM soil mapping of potato field showing different EM zones, red areas indicate lower electrical conductivity and blue areas higher electrical conductivity.

Table 10 Soil analysis results for the field depicted in Figure 58 (above).

Soil characteristic	Blue zone	Red zone
Sand %	4.5	61.7
Clay %	52.2	5.7
Potassium (cmol+/kg)*	0.68	0.29
Boron (mg/kg) **	1.1	0.5

* Critical limit for potassium in vegetables is 0.6 cmol+/kg

** Critical limit for boron in vegetables is 0.5 mg/kg

Case study 8 – Qualipac, Gatton, SEQ

Operations

Key outcomes

- Improved knowledge and management of soil types across farm
- Improved soil sampling regime

Qualipac is a large family operation based at Gatton in south-east Queensland. They farm over 1000 hectares including their own land and lease blocks. Broccoli, onions and pumpkins are the key crops produced. While the majority of production goes to the domestic market they do also export significant volumes of broccoli to Japan and other Asian markets. They have a grading and packing operation as part of their business. Qualipac became involved in the project in late 2015 and are interested in assessing what spatial variability they have across their farming country. They are particularly interested in the potential for variable rate irrigation.

Example 1

In late 2015, EM soil mapping was undertaken on 2 blocks known to exhibit spatial variability in crop growth. This identified a significant area of higher electrical conductivity as indicated by the red area (**Figure 60**). The range in EM values from 22 up to 311 indicated significant differences in some soil characteristics, however this required further clarification by soil testing. Soil testing to ground-truth the EM data was undertaken using a grid based approach (**Figure 61**).

One of the analyses undertaken to ground-truth the EM mapping is soil texture analysis, this identifies differences in the percentages of clay and sand of a particular soil location (**Figure 62**). Soil texture analysis identified variability in the percentage of clay across these blocks in a pattern very similar to the EM mapping, with the higher clay percentages in the area of highest electrical conductivity. This is consistent with what you would expect. These differences in clay content indicate that this block could potentially benefit from variable rate irrigation. The higher clay areas have greater water holding capacity while those areas of lower clay percentage are likely to drain more freely, hold less water and therefore dry out more quickly. These spatial differences in soil type likely have associated differences in irrigation requirements. This could be ground-truthed further by using the EM map in conjunction with the soil test results to strategically place soil moisture probes.

Additional soil analyses allowed a range of other measurements to be mapped. The project has identified more pH issues than co-operators would have predicted. Spatial mapping of pH (CaCl) indicates a significant breadth of pH values across this block, pH 5.76 – 7.33 (**Figure 63**). This information could be used to develop a prescription map for variable rate lime to address some of the lower pH areas. Similarly, spatial mapping of soil nitrate levels indicate a **2 fold increase in nitrate levels** across the blocks. This could be used to develop and specify prescription rates for variable fertiliser applications (**Figure 64**).

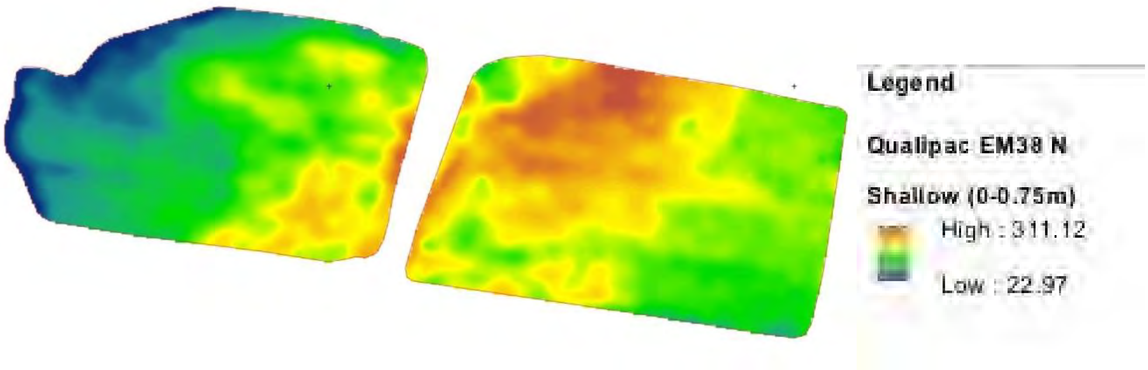


Figure 60: EM mapping indicating substantial changes in some soil characteristics (clay, salt or moisture).

Figure 61: Grid sampling points to ground-truth EM mapping results.

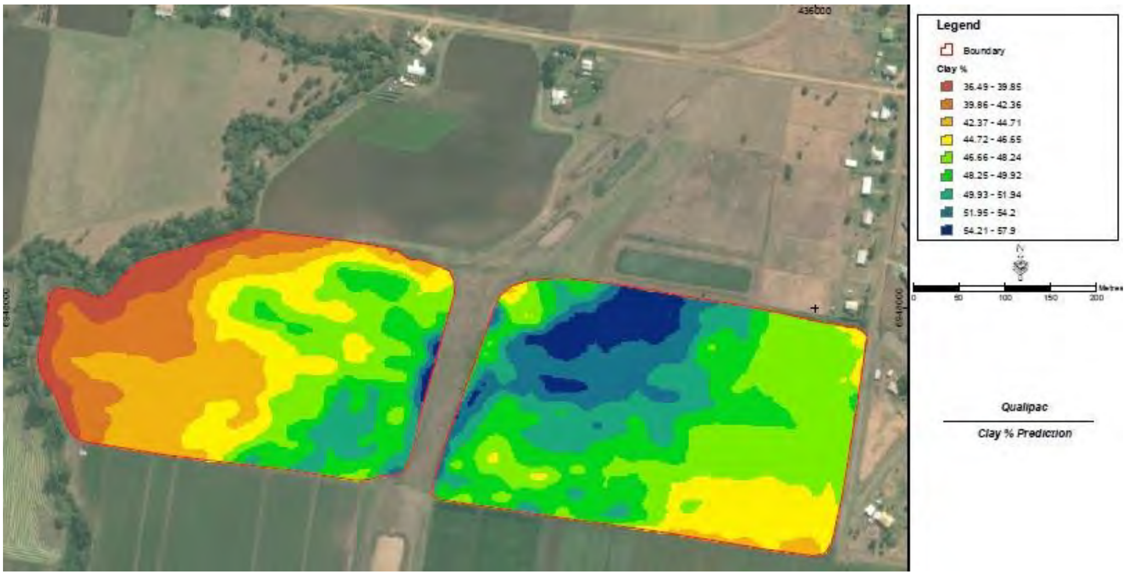


Figure 62: Clay percentage as indicated by soil texture analysis results undertaken as part of ground-truthing the EM mapping.

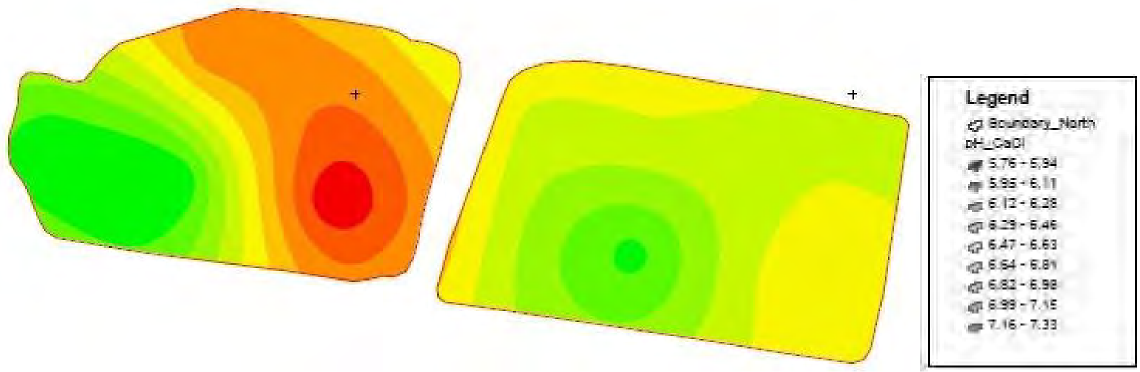


Figure 63: Spatial pH (CaCl) mapping based on grid soil sample analyses.

Figure 64: Spatial mapping of soil nitrate levels (mg/kg) based on grid soil sample analyses.

Case Study – Windhum Farms, Bundaberg

Operations

Windhum Farms is a 140 hectare sweetpotato and English potato farm owned and operated by Darren and Linda Zunker. The farm is located near 'The Hummock' in Bundaberg, an area that is locally renowned for rich volcanic red soil that is both fertile and lacking in soil variability. Darren and Linda had previously invested in machine guidance and had prepared some equipment to undertake VR applications, though apart from machine guidance they hadn't progressed into other precision farming technologies.

Key outcomes

- Improved knowledge and management of soils and block variability
- Irrigation according to soil type
- 1st yield monitor and maps for sweetpotato
- Variable rate applications of lime/gypsum according to field variability

Darren is an active member of the Australian Sweetpotato Growers Association (ASPG) and is a strong advocate of 'soil health' and practices cover cropping rotations to reduce soil pest and disease pressure. The interest in the project was to better understand or quantify yield variability at the block scale and over time be in a position to better manage variability in yield and quality.

Windhum Farms have a close relationship with Vanderfield (the regional John Deere™ dealership) and the project used this relationship to assist achieve the goals of the project and Windhum Farms. Similarly, the farm uses a consultant agronomist and including and supporting the agronomist was an important factor to progress the adoption of precision applications.

Activities

1. Soil EM mapping and sampling
2. Remote (satellite) biomass sensing
3. Yield monitoring and mapping
4. Soil moisture monitoring

In 2014, EM soil surveying of a 7.5ha trial block (*Boundary Block*) was carried out using a Dual EM 21S sensor to collected ECa readings from 0-25cm, 0-75cm, 0-125cm and 0-275cm before planting of the sweetpotato. Conductivity zones were ground-truthed and EM perceived "zones" were soil sampled for analysis (**Figure 65-66**). In collaboration with Central Queensland University, the zones identified through EM mapping were also analysed for crop pathogen incidence and found that there was some variation in nematode species between the different sites and this may have an effect on yield (**Table 11**).

Elevation data from the field was collected using RTK GNSS hardware to extract Topographical Derivatives. Drainage simulations were carried out using 3D modelling software to ensure the field had no depressions (that may affect yield through waterlogging). The elevation and EM data was also used to assist in drip irrigation design for uniform emissions. This was to eliminate the potential effect on yield from variability in applied irrigation and nutrition through fertigation. The existing irrigation design had a water pressure variability of 16% in the northern half of the Boundary block, while the southern section was higher at 17%, where less than 10% variability is desired while using drip tape to maintain irrigation uniformity. The resulting irrigation system reduced irrigation variability to 5.5% in the northern and 7.7% in the southern blocks, well below the desired range of 10%.

To manage irrigation application in this block and further reduce the risk of yield variability, PCT VA Gateways software was used to analyse the data collected by the EM survey and topography to identify a suitable site for installing soil moisture sensors (**Figure 67**). The total water use of the crops in Boundary block was recorded as 6.18 mega litre/ha (ML/ha), with irrigation making up 45% of the total at 2.8 ML/ha. The water use efficiency of the crop is discussed later in this case study.

In 2014, the yield monitoring system (Greentronics YM410-2T) was installed on the farm's sweetpotato harvester and used load cells to measure the weight on the unload elevator. Load cell readings are logged with a GPS position were field calibrated by comparing harvested yield per bin, to actual yield per bin measured on scales in the packing shed. One load cell reading per second was recorded in *.csv format along with corresponding GPS position and tilt compensation sensor data was is used to remove error when operating on undulating terrain, see **Table 12** for an example of the data logged. After initial testing, redesign of the elevator was required, with a short length of conveyor fitted at the bin delivery point. This independent section of conveyor eliminated changing belt tension, and was used as the weighing span section reducing error to approximately 5%.

A major challenge in recording accurate yield data was daily changes in the amount of soil being measured by the system with changing soil moisture conditions. Although a large amount of this error could be overcome by performing tare calibration of the load cells at the end of each row, a process was developed to accurately measure all soil (measured as yield) being delivered to the packing shed. By comparing harvested weights versus washed sweetpotato weights, the amount of soil harvested each day was calculated (**Figure 68**). This allowed post-calibration of the yield map values and for accurate gross margin analysis.

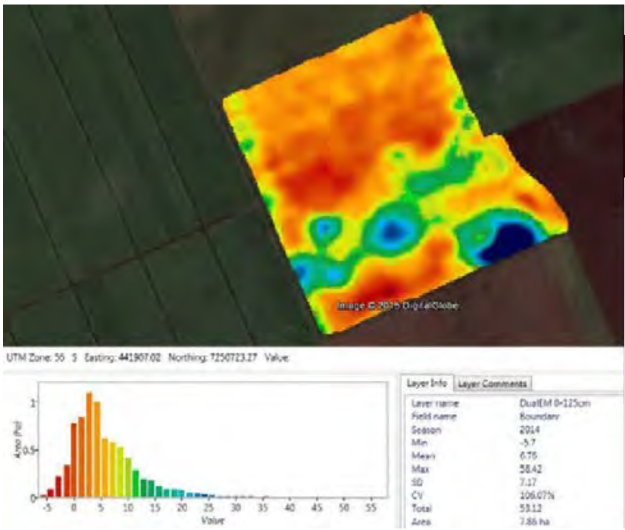
In March 2015, yield data from "Boundary" was analysed and found that the northern section of Boundary block yielded 13% higher than the southern section (**Figure 69**). This result surprised the producer as in the previous year, the northern section was rotated from a forage sorghum green manure break crop, while the southern section had not and sweetpotatoes had been grown in successive years. This is not normally their best management practice as it increases the potential for yield limiting populations of soil borne disease and pests, particular nematode, to be maintained. Darren had previously committed to reduce the farm's reliance of nematicides to control root knot nematode (*Meloidogyne sp.*) and improve general soil condition and microbiology, and was astonished that only one year of successive cropping could cause such significant yield penalties. It was a costly lesson, with gross margin analysis suggesting that this resulted in reduction in returns by up $255/ha.

Some correlation was noted between this first year of yield data and soil EM (**Figure 70**), but the cause remains unknown requiring further investigation and additional (temporal) yield maps will allow for normalisation of yield data to be carried out.

Water use efficiency of the crop harvested from boundary, based on 90.8 t/ha average was 14.6t/ML, while the northern section of Boundary produced a higher yield at 96.3 t/ha and a WUE of 15.6 t/ha, 13% higher in yield and WUE than the southern section.

A single year of data has confirmed that there is significant variability in sweetpotato yields, even in what are considered relatively uniform soil and fields. After gross margin analysis of the yield data, the co-operator and their agronomic consultant can see potential for significant return on investment from implementation of precision practices.

While initially sceptical about the level of soil and crop variability on their farm; the project work has convinced Windhum Farms that greater accuracy through strategic soil sampling, monitoring of block yields and variable rate soil ameliorants will provide productivity benefits to their operation. Since the trial work, Darren and Linda at their own expense have commissioned additional EM soil mapping / sampling and a variable rate application of lime and gypsum on a new farm; indicating that since becoming aware of soil and crop variability precision practices have been adopted.



Soil sample locations for 176 Windemere Road

	Decimal Degrees	Degrees Minutes Seconds
Point # 1	-24.8562 152.4248	24°51'22.32" S 152°25'29.28"E
Point # 2	-24.8552 152.4256	24°51'18.72" S 152°25'32.16"E
Point # 3	-24.8555 152.4237	24°51'19.8" S 152°25'25.319"E
Point # 4	-24.8555 152.4249	24°51'19.8" S 152°25'29.64"E

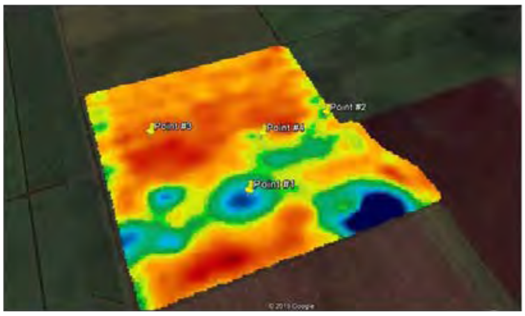


Figure 65(right) EM soil surveying of "Boundary" block reprisentation at 0-125 cm depth highlighted high variation in EM percieved soil properties indicated by the coefficent of variatiton (CV= 106%) derived via PCT VA Gateway software**.**

Figure 66: Soil sample locations were used to target EMI percived zones to determine the causes of EM variability. These locations are geo-referenced so that agronomists can return to their exact locations for temporal comparisons.

Table 11 Nematode numbers/200ml soil (corrected for extraction efficiency) by Central Queensland University.

Sample ID	Root-knot	Spiral	Root-lesion	Free-living
1	74	101	0	4073
2	0	36	0	4905
3	0	146	11	3128
4	0	56	5	1553

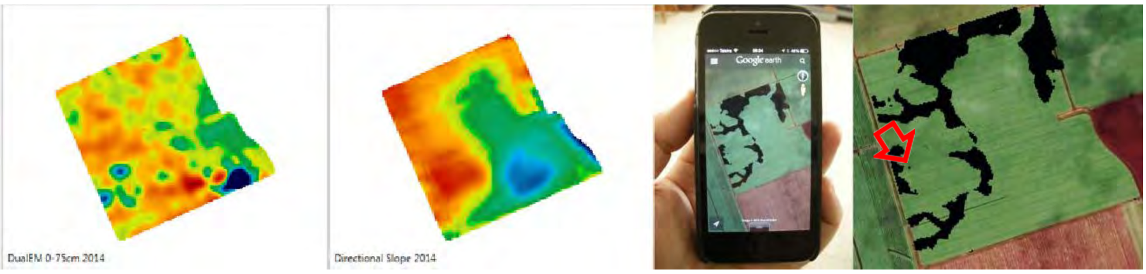


Figure 67 Using EMI surveying and slope data to determine soil moisture sensor locations in PCT VA Gateway and mobile devices for installation at a suitable location in the field (red arrow).

Table 12: An example of the data that is logged during an active yield monitoring operation via load cells and Greentronics YM410-2T.

Latitude	Longitude	Yield(kg /ha)	GroundSpeed(kph)	SwathWidth(cm)	Weight(kg)	Active	RPM	Sats	Date	Time
0	0	0	0	148	2.955	1	62	0	15/03/2015	20:19:28
0	0	0	0	148	2.153	1	62	0	15/03/2015	20:19:29
-24.856171	152.426578	130013.6	0.59	148	3.154	1	62	10	15/03/2015	20:19:30
-24.856171	152.426576	125177.6	0.57	148	2.933	1	62	10	15/03/2015	20:19:31
-24.856173	152.426575	92798.17	0.59	148	2.251	1	62	10	15/03/2015	20:19:32
-24.856173	152.426573	58829.67	0.78	148	1.886	1	62	10	15/03/2015	20:19:33
-24.856175	152.426571	16389.92	0.85	148	0.573	1	62	10	15/03/2015	20:19:34
-24.856175	152.426568	100533.5	0.87	148	3.596	1	63	10	15/03/2015	20:19:35
-24.856176	152.426566	79196.46	0.84	148	2.735	1	62	10	15/03/2015	20:19:36
-24.856176	152.426565	14477.54	0.84	148	0.5	1	63	10	15/03/2015	20:19:37
-24.856178	152.426563	59834.14	0.81	148	1.992	1	62	10	15/03/2015	20:19:38
-24.856178	152.42656	90410.23	0.89	148	3.308	1	62	10	15/03/2015	20:19:39
-24.85618	152.426558	61861.47	0.88	148	2.238	1	62	10	15/03/2015	20:19:40
-24.85618	152.426556	52090.07	0.85	148	1.82	1	63	10	15/03/2015	20:19:41
-24.856181	152.426553	77204.7	0.89	148	2.825	1	62	10	15/03/2015	20:19:42
-24.856183	152.426551	64952.27	0.87	148	2.323	1	62	10	15/03/2015	20:19:43
-24.856183	152.42655	36339.28	1.04	148	1.554	1	63	10	15/03/2015	20:19:44
-24.856185	152.426546	67888.27	1.1	148	3.07	1	63	10	15/03/2015	20:19:45
-24.856185	152.426543	76812.06	0.97	148	3.063	1	63	10	15/03/2015	20:19:46
-24.856186	152.426541	31003.7	0.97	148	1.236	1	63	10	15/03/2015	20:19:47
-24.856188	152.42654	56605.15	0.97	148	2.257	1	62	10	15/03/2015	20:19:48
-24.856188	152.426536	28062.77	0.95	148	1.096	1	63	10	15/03/2015	20:19:49
-24.85619	152.426535	18379.93	0.93	148	0.703	1	62	10	15/03/2015	20:19:50
-24.856191	152.426531	25279.92	0.99	148	1.029	1	62	10	15/03/2015	20:19:51

Packing Shed

Block Number Boundary Block
Date 23/03/15
Bins Harvested 63 Bins 7Rows (63)

Cartons Packed

Small	56 + 54	110
S/med	56 + 56 + 3 + 24 + 2 + 2	143
Medium	64 + 64 + 64 + 64 + 64 + 64 + 64 + 64 + 64 + 38	614
L/med	56 + 56 + 37 + 32	181
Large		
No. 2	56 + 56 + 56 + 56	224
½ Bin	557 + 591 + 539 + 546.5	2233.5
1/3 Bin	393	393

1272 + 441

658 Cartons @ 18.7 kg	12304.6
614 Cartons @ 15.7kg	9639.8
1/2 Bulk Bins	2233.5
1/3 Bulk Bins	393
Rubbish 473 + 480 + 995	1948
Left in shed 306.5 + 66.52	373.02
Total	26891.92
Less carry over in shed	365.98
Total	26525.94
Harvester Weight 25637kg	
Difference	888.94

Figure 68: Example of the data collected in the packing shed to post-calbrate the yeild data. The post calibatration process can be time consuming due to the variety of different packing specifications. This highlights that tonnes per hectare (t/ha) while useful in terms of overall yield variance does not reflect actual packout.

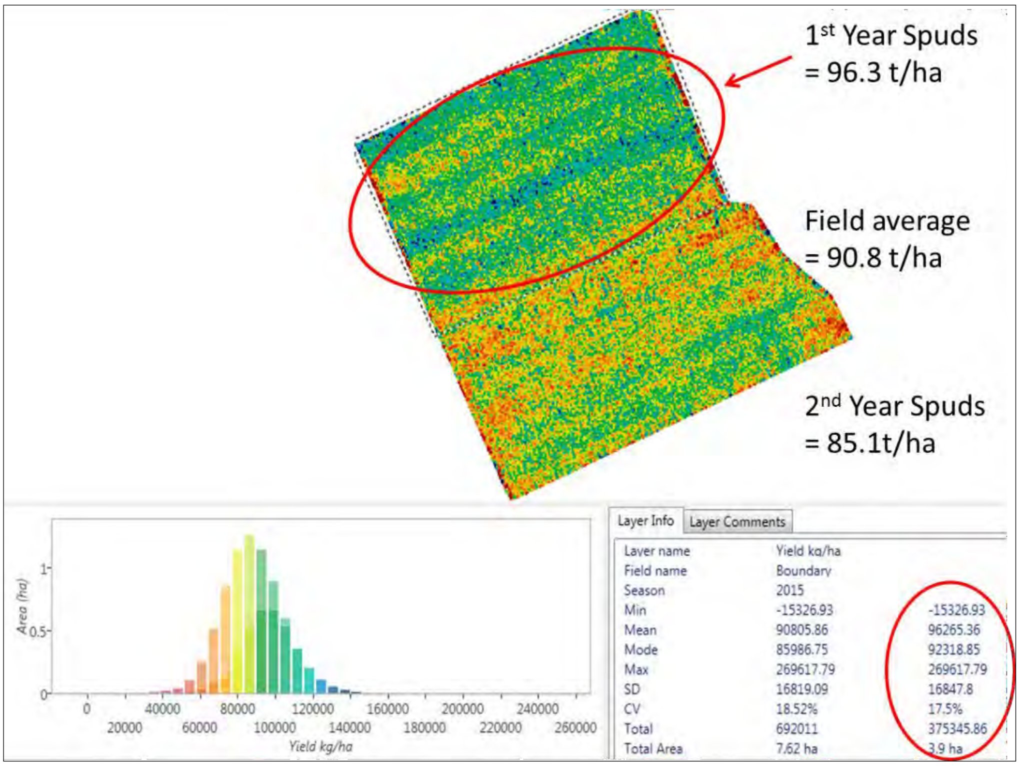


Figure 69: Yield data analysis showed that the northern section of Boundary block, that was freshly out of rotation from a cover crop had 13% higher yield than the southern section that had been successively cropped with sweetpotato.

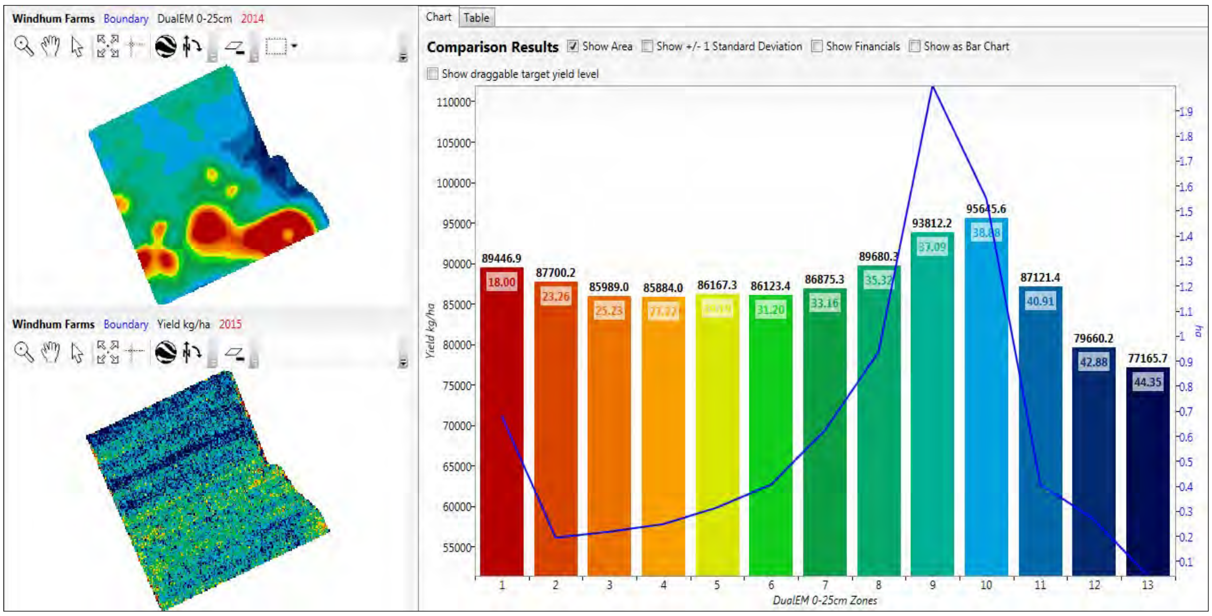


Figure 70: Correlation undertaken between Boundary block EM and yield. Analysis shows there are some yield effects with increasing EM, but further analysis and temporal yield data will be required to determine if there is a true correlation.

DAF acknowledges the contribution of Stephen Hegarty and Stephen Frahm of VNet. VNet Precision Farming is the technology division of Vanderfield Pty Ltd.

Analysis of variability layers

In the latter stages of the project effort was directed towards statistical analyses of the multiple spatial data layers to determine what, if any, relationships could be detected between mapping layers and also what additional information could be extracted from the mapping layers to assist in cost benefit analyses and/or to better understand the overall value of precision systems in vegetable production. One field that had exhibited good spatial variability and had the most complete data set in terms of mapping layers was selected for use as a case study for these analyses, Linton Pivot 2 (see case study Kengoon Farming - Example 3).

Yield data for Linton Pivot 2 was 'cleaned' by removing yield values in excess of 100 tonnes per hectare (**Figure 71 (A)**). Within the 8.9 hectare block there were 26,887 carrot yield measurements that ranged between 0 and 100 tonnes per hectare. Better contrast in yield across the field was more evident using quantiles of the distribution of yield measurements into four categories (**Figure 71 (B)**), 1-40 tonnes per hectare, 40-60 tonnes per hectare and 60-100 tonnes per hectare. From this it was possible to determine what percentages of the field area were performing at different levels (**Table 13**).

With 31% of the field performing below the average yield of 45 tonnes per hectare, management interventions to improve these underperforming areas could have significant impacts on the profitability of this field. Spatial yield values indicate that in the underperforming areas yield values tend to be in the mid 30's, while those in the 40-60t/ha category tend to be clustered around 50t/ha. With this data the grower would be able to run a coarse cost benefit on what these underperforming areas are costing in lost production and also an estimate on inputs that are not being utilised efficiently.

Ground-truthing of yield data for Linton Pivot 2 identified high yield measurements in the south-west and eastern edge of the field that was deemed to be affected by water logging following ground-truthing. Therefore they were removed from subsequent analyses by retaining only the data within the yellow delineated polygon in **Figure 72.** Available EM data for this area is represented by black dots.

For further comparison of the various mapping layers, data was rasterized (averaged over smaller areas) so that mapping data collected over different spatial vectors could be properly aligned for analysis. The relationship between the yield map and the EM soil mapping layer indicates that the EM data explains approximately 28% of the variability in carrot yield, **Figure 73 (left)**.

Comparison of the NDVI data and yield reveals an arc in the relationship between NDVI and yield, **Figure 73 (right)**. This indicates that there is a greater range in yield measurements as NDVI increases. This is not unexpected given current knowledge that NDVI measurements do tend to saturate as crop biomass gets larger making it harder to discern variability. Currently, work is continuing to fit a curve to this data which will give us an equation that could then be tested with future NDVI and yield mapping to assess the potential for NDVI or other spectral bands to be used to predict yield.

Table 13 Field area information for different yield categories

Yield category (t/ha)	Area (ha)	Percent of total area (%)
0-40	2.8	31 %
40-60	5.6	62 %
60-100	0.6	6 %

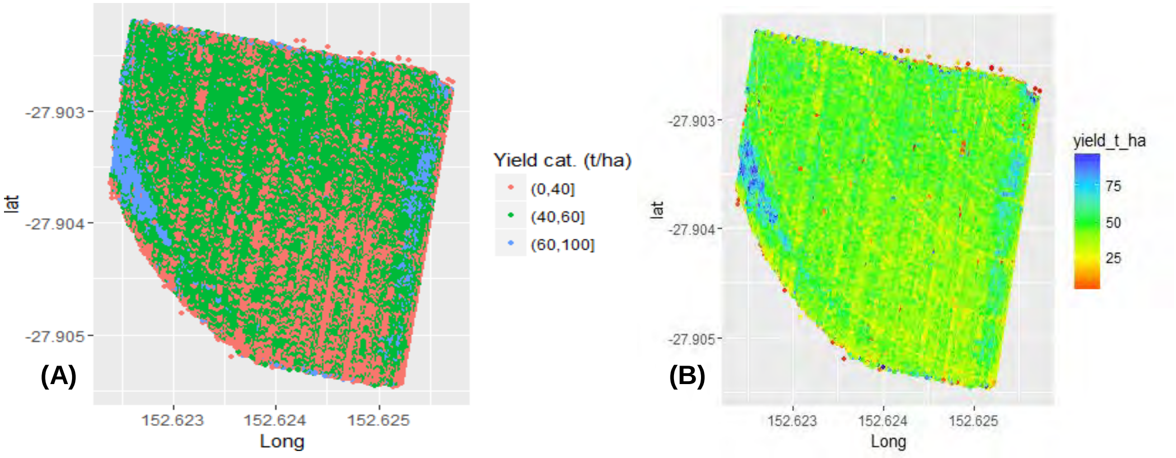


Figure 71: Cleaned yield data for Linton Pivot 2 (A) and categorised yield data (B).

Figure 72: Polygon used for analysis to eliminate known waterlogged areas of high yield. Black lines indicate EM data within this polygon.

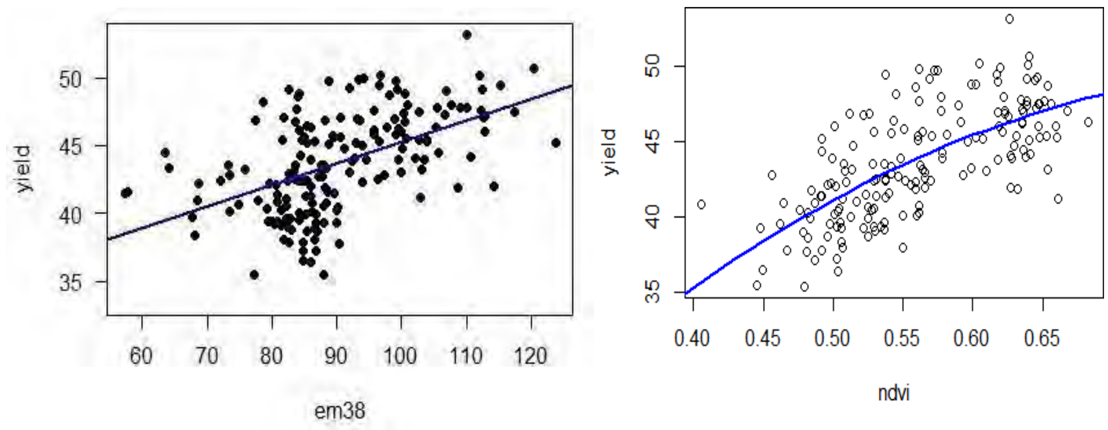


Figure 73: (A) Correlation between yield and EMI soil mapping data indicating a linear relationship between EMI and yield, **(B)** a non-linear relationship between yield and NDVI.

Extension and outreach

A range of products were developed to increase producer awareness and knowledge, and assist in producer decision making. These extension and outreach products included: video case studies, electronic factsheets, VR decision support tools, local and national industry media.

Extension events were held in each region to showcase demonstration site results and provide information for producer and agronomist decision making, including presentations by technical and service providers from within the PA industry. The workshops, field walks and training events conducted during the life of the project are listed in **Table 14**. The events were based on local producer's needs, identified through benchmarking and discussions with regional grower associations.

Table 14 Extension events held to increase awareness and adoption of VRT in Queensland vegetables

Event	Facilitator	Regions	Purpose	Attendees	Dates
Stakeholder Meeting	DAF	Queensland	Provide an overview of the PA/VR processes, Precision Agriculture discussed the process of turning data into useable mapping for assessing variability, the project: collaborators, budget and roles	2 Vegetable producers 3 Gower/NRM representatives 2 Industry personnel 4 Government personnel	26 May 2014
Yield monitoring and mapping field day	DAF and BFVG with Vanderfield and Windhum Farms	Bundaberg	Showcase VRT, yield monitoring in sweetpotato and outcomes	17 Vegetable producers 11 Land managers 17 Industry representatives	21 May 2015
SST Software training	SST Software Australia and DAF	Atherton	Provide training for Ben Poggioli and GTAg (agronomists) in farm data management software	1 producer 3 Agronomists	13 February 2015
Developing comparative VRT gross margins	DAF	Bundaberg	Work with Windhum Farms to develop a comparative analysis between traditional and VRT sweetpotato production systems	2 Producers	16 July 2015
Soil test interpretation workshop	Back Paddock Company	Bowen, Bundaberg, Lockyer Valley	Assist producers in understanding soil test results, developing their own amendment applications and benchmarking their soil against other local producers	25 Vegetable producers 16 Agronomists/Farm managers	15 November 2015 26 January 2016 1 March 2016
Innovations in Agriculture Bus Tour	Terrain, NQ Dry Tropics, Herbert Cane Productivity Services Ltd. and Reef Catchments	Atherton Tablelands to Mackay	Showcasing innovative farming practices and farmers – Ben Poggioli and DAF (Day 1) discussed zonal tillage, identifying variability and variable rate technology in vegetables on-farm and across Queensland	Vegetable, grains, sugar, tree-crop, livestock producers, NRM specialists, GIS and farm technology technicians.	12 April 2016 – 15 April 2016
VG15704- PA study tour of New Zealand (*funded by DAF and Horticulture Innovation Australia through grower levies*)	DAF	All regions including growers from Tas, Victoria	Develop a 'community of practice' of vegetable growers who are adopting PA systems	16 producers (5 from Qld project)	22nd May – 31st May 2016

Monitoring and Evaluation

Adoption of farm technologies is often viewed by producers as a pathway to increasing farm efficiency and productivity. Producers inherently understand and respect the natural resources they use and occupy and the drive to ensure efficient use of resources is as much about profitability as maintaining the resource condition. While project benchmarking typically reflects immediate changes in management practices, it can be limited in capturing the full gamut of producer perceptions and ongoing optimisation of equipment and practices. In some respect, adopting precision technologies like those undertaken in this project is so innovative that it is over and beyond current 'best management practice'. Therefore traditional practice adoption models are unlikely to reflect fully the nuances associated with adoption of advanced precision systems.

Predicted adoption levels

Using the CSIRO adoption tool (refer to methodology), the results indicates that it will take 18 years to reach 81% adoption of technology in the Qld vegetable industry, with 29.4% of the population adopting in 5 years and 67.6% adoption achievable in 10 years (**Table 15**).

The results are indicative only but do offer some insight into the likely timeframes required to achieve meaningful penetration of technology into the industry. Importantly, these predictions are based on the current situation and don't take into account the rapid evolution and streamlining that is occurring with technology and changes within the producer population through succession planning and perhaps agriculture more generally. It could be expected that the adoption time (years) could fall dramatically though peak adoption (e.g. saturation of the technology) would remain at or near the 80% level.

Table 15: Predicted adoption levels of advanced precision technologies in Qld vegetable production using ADOPT using current scenario.

Predicted peak level of adoption[1]	81%
Predicted years to peak adoption[2]	18
Predicted years to near-peak adoption[3]	12
Predicted adoption level in 5 years from start	29.4%
Predicted adoption level in 10 years from start	67.6%

1. The predictions of 'Peak Adoption Level' is a numeric output that is provided to assist with insight and understanding and like any forecasts should be used with caution.

2. The prediction of 'Time to Peak Adoption Level' is a numeric output that is provided to assist with insight and understanding and like any forecasts should be used with caution

3. 'Time to Near Peak Adoption' represents the time to 95% of the maximum predicted adoption level.

Effectiveness

The project has been effective in achieving the following key objectives: identifying spatial crop variation in vegetables and providing producers with skills and optimised tools and technologies to manage on-farm variability.

Key learnings associated with the implementation of PA technologies can be summarised as:

- The assessment of spatial variability and its management needs to be a targeted and focused process.
- Regional service and technology providers are limited, particularly in northern Queensland. However, the project has generated significant interest in these regions for existing service providers to extend their services or is an opportunity for the development of future services.
- There is a disconnect between producers and their ability to access real time data in large vegetable agribusinesses, however, producers are increasingly accessing developments in mobile applications/software to address this.
- Many collaborators have been impressed with the capability and convenience of mobile platforms and cloud storage systems and have rapidly adopted and expanded the use of these into other aspects of their farming system e.g. real-time irrigation monitoring tools.
- Intensive horticulture is unique in the volume of data generated through mapping and monitoring which can cause issues for services providers charged with post-processing.
- Not all spatial variability can be managed through variable rate applications, however, other management options and longer term strategies can be applied once strategic management zones have been identified.
- Not all individual data layers were able to identify variability, however, comparing multiple data layers proved valuable in identifying variability and potential underlying causes and can reduce the need intensity of groundtruthing activities.
- Savings in soil amendments and fertiliser are comparatively small components of the variable costs in vegetables (relative to other industries). Improved profitability from VR technologies arise through improved uniformity of yield and product quality characteristics.
- External service providers will be essential in adapting technologies on farm, troubleshooting and technical support for PA adoption into the future.

While the farmer to farmer extension model effectively encouraged producers to trial different aspects of the technologies encompassed by the project, some barriers have impacted on broader adoption, (or at the least stretched out the timeframe for it) throughout the project, these are:

- Technology optimisation and troubleshooting
- Volume of data generated for processing
- Time requirements associated with ground-truthing
- Lack of regional expertise and support to drive critical technological components and farming system approaches
- Difficult to measure impact: the fresh produce market is highly variable and the same fields are not utilised year after year, often without warning and due to market pressures. This results in fields not being revisited and therefore a reduction in producer confidence in the technology.

Adequate servicing and technology availability in North Queensland is still an issue however the project has generated significant interest in these regions for service personnel to extend their services. This is being driven by producer’s communication between them. During the course of the project, some reluctance was encountered from agronomy personnel to assist producers in engaging external service providers to do spatial mapping due to the amount of data the work generates.

Impact

The project identified and optimised a range of technologies that have significantly impacted on collaborators understanding and management of crop production in a spatial sense. Key changes to collaborator farming systems associated with the adoption of PA technologies include:

- Use of tractor mounted Greenseeker^{TM} crop sensing on farm (**4** units);
- Use of EM to map inherent soil variability
- Strategic sampling procedures
- Co-operators have invested in additional monitoring equipment to assist with groundtruthing activities e.g. pH meters.
- Yield monitoring capability (**5 units**) and ability to quantify the financial impact of poorer performing areas
- **2 x** spreading contractors now undertaking VR applications
- VR capability in Queensland vegetables: **1 x** VR irrigation, **6 x** VR capable spreaders
- VR applications now standard practice for some co-operators with prescription maps used for multiple products e.g. lime, fertiliser, compost, across multiple crops.
- VR management has proven savings in the cost of amendments:
    - In Atherton, 40% of a single lime application can be achieved, with two other 24 ha pivots showing potential for similar savings. Yield is yet to be compared to lime savings and will be available at final reporting
    - In a SEQ example, VR applied lime resulted in a 75% yield increase (in the poorer performing areas which equated to 28% of the field). This more than offset a 30% increase in the total amount of lime applied.
    - A VR fertiliser application in SEQ resulted in a 25% reduction in fertiliser for one block.
    - In the instance that there are no savings in the amount of product used, there has been a change in its distribution to ensure that it is being optimally placed to have the greatest impact.
- Many co-operators are already considering the next steps in technology adoption outside the scope of this project.

Benchmarking and collaboration in the project:

- Benchmarking has been successful and indicates that many farmers have advanced their management practices significantly as a result of the project;
- Many producers have extended their adoption of PA/VRT into other non-vegetable farming practices and into different regions.
- Communication outputs:
    - Producers are able to access the YouTube videos on permanently monitored channels which are easily accessible to producers https://www.youtube.com/user/HortSmart/feed
    - Internet searches via search engines such as Google for precision horticulture key words quickly generate suitable results and links to the project's information.
    - At the time of writing this report, the three videos had accumulated a total of 462 views, and social media has contributed to a total of 3,304 people reached
    - Landline news story is available on the ABC Landline website and, the story has been followed by 73 people, with 13 shares. http://www.abc.net.au/landline/content/2015/s4404766.htm

Appropriateness

Experience now highlights that having locally relevant data to demonstrate project collaborators' achievements is necessary to generate interest by the broader industry and in some cases the producer's advisory network. Initial discussions with some potential collaborators at the start of the project did not generate much interest, however follow up conversations with these same people recently, backed up with what the project has achieved so far, has resulted in completely different attitudes and interest in being involved during the remainder of the project.

The activities throughout this project have proven to be appropriate in not only working with producers to trial innovative management practices but in achieving adoption as their standard management practice. The ranges of crop sensing technologies employed have been successful in identifying crop variability and where they have not directly contributed to changes in management practices, they can be used to provide producers with another layer of information to compare crops, management practices and delineate management zones using multiple technologies. Yield monitoring, itself is the ultimate measurement of spatial variability as any variability directly influences a producers gross margin. Yield monitoring is being used as an assessment tool to determine the success of any in crop management practices to address variability.

Demonstration sites assisted in the adaptation of VR technology into vegetable systems and demonstrated the extent inputs, particularly nutrient, can be managed and optimised to reduce and/or increase efficiency. The sites provided an opportunity to quantify the benefits of variable rate applications and to develop robust gross margins based on real farm data.

Central Queensland University Practice Adoption and Project Impact Study

A deeper understanding of adoption barriers and feedback on the project design is critical for the development of future projects.

The results of a series of semi-structured interviews with 14 producers and consultants involved in the project from across the regions of Bowen Bundaberg, Atherton Tablelands, Lockyer Valley and Kalbar show:

1. The main reported outcome of the project was an increased awareness and improved knowledge of variability and precision technology
2. A perceived outcome and benefit of precision methods applied in the project was increased knowledge of soil tests, and capacity to identify variability and use technology
3. There were limited project outcomes perceived in terms of yield changes through reduced or improved variability (links to lack of time to truly assess yield impacts)
4. Perceived barriers to adoption of precision methods by producers included high cost, limited understanding/knowledge, time consumption and limited equipment.

The study also provided recommendations for adoption and any future project that seek to further develop precision systems

Recommendations from participants to provide adoption pathways for future projects include:

1. Need to assess yield data, to assess any pre and post on-field changes
2. Need to address questions regarding cost and timing for vegetable industry
3. Need to better understand technology and software compatibility
4. Implementation of processes that include clear steps for timing of data and technology, support for data collection and interpretation through more engagement with consultants, and pre/post assessment data in order to create whole-farming systems with integrated approaches.

Producers that were involved in the project readily reported that they have gained in increased knowledge and understanding of variability across their farm, the types of tools and processes that can be employed to identifying and potentially assist in reducing variability in vegetable crops. Producers also readily picked up the various computer applications and management technology, especially Google Earth and mobile devices as well as more understanding and ability to work with and program their own GPS units.

The adoption and impact study revealed that while producers were very interested in adopting PA and VRT, consultants that work with them had little knowledge of their PA and VRT goals despite the consultants rating their knowledge of PA and VRT significantly higher than producers. This indicates that consultants may need to be engaged from the very start of future projects to make sure outcomes are relevant and the support exists. These observations require important consideration for any future expectation of technology adaptation beyond the life of the project.

The yield monitors have been an essential part of the project and businesses that have adopted them to firstly identify yield variability and subsequently develop an understanding of the productivity of the business. Although there were few yield productivity effects reported in the short period of time of the project, this data is a valuable first step in the transition to a variable rate technology system and over the next few years if producers persist with the technology, they will be able to monitor and compare real changes in productivity, and by extension the effect on profitability, of their own farms as they make management changes.

Often, data collated throughout the short life of the project raised more questions than answers and this proves that having a dedicated project to assist producers in adoption of VRT is essential to maintaining their engagement with the technology and practices as well as promoting a long term perspective to adoption.

See Appendices for full report - *A study of grower and consultant perceptions of precision methods and project impact*

Economics of VRT: Savings and increasing farm profitability

Auernhammer (2001) states precision farming will gain a higher importance when it moves beyond the advantages of site-specific management into environmental benefits and the vast amounts of information that are generated by it are able to be analysed and evaluated effectively. Although current savings and benefits are modest, this step-change process will become much more important in future with the development of automated and robotic systems that can influence the cost of labour, currently the highest cost in horticultural production, accounting for around 27% of total costs depending on vegetable crop type.

Horticultural production in most cases is very intensive, using high amounts of inputs over small areas and short periods of time, concentrating the effects of fertilisers and chemicals (Wainwright *et al*, 2014). FAO (2014) report that by 2018, the world demand for nitrogenous fertilisers will reach to over 119 million tonnes with Good and Beatty (2011) stating that this figure is 18 million tonnes in excess of what is actually required. The fate of excess fertilisers applied to agricultural land is leaching, nitrification and denitrification, increasing nitrous oxide emissions and eutrophication of land and ocean waterways. The cost of excess nitrogen to the environment is estimated at 44% of the costs of excess nitrogen (Good and Beatty, 2011). Through PA and VRT, increasing production per hectare grown and improving soil health will reduce fertiliser leaching and nitrous emissions resulting in environmental and farm financial benefits.

Throughout this report, examples have been given showing the effects adopting VRT can have in terms identifying high vs. low yielding areas and in the application of fertiliser and amendments. Some of these will be discussed further for the farms that agreed to conduct gross margin analysis.

Gypsum – soil amendment

In the absence of post-treatment yield data, the project team used current and simulated values to predict the cost-benefit of PA and VRA for the Phantom Produce case study. Traditionally, the agronomic practice was to apply 1 t/ha of gypsum over 32 ha of cropland. As a result of this project work, this amount was deemed inadequate to remediate 53% of that land which is classified as moderately to severely saline-sodic. **Table 16** outlines the gypsum rates and costs associated with a traditional and VRA gypsum application and although the cost of a VRA gypsum application is more than double the traditional cost of spreading 1 t/ha, in terms of the total costs of growing an average yielding capsicum crop in the Bowen region, this equates to a $9/ha increase on gross margins or less than 0.02%.

Table 16: Cost comparison between traditional and VRT gypsum application at Phantom Produce, Bowen

Salinity Zone	Gypsum rate (t/ha)	Area affected (Ha)	Total gypsum (t)	Cost of application ($190/t)
Traditional	1	32	32	$6,080
Variable rate application based on EMI and soil sampling				
Low	0	16	0	
Medium	1.75	3.42	5.98	
High	3.25	9.76	31.72	
Severe	5	7.18	35.9	
Totals	2.3 (average)	32	73.6	$13,984

Compost – soil amendment

Traditional agronomic practice at Vee Jay's is to apply **5 t/ha of compost** to soils before laying mulch, drip tape and planting. The VRA practice in this case was to vary this rate from **5 t/ha up to 20 t/ha**, applying an average of **8.3 t/ha over 57 ha** of tomato and capsicum cropland. In terms of gross margins, this increase is just 0.007% of the total variable costs to grow a hectare of tomatoes and is not considered a significant cost increase

Lime – soil amendment

A cost comparison between the traditional and VRT lime rate at North Qual, Atherton shows a **saving of $1,848** was made (**Table 17**)**.** This takes into account the cost of extra soil sampling, on a 24.8 ha pivot irrigated field. This is a small saving, however the benefits gained from maintaining a desirable pH could be considerable in high risk soils like those red clay-loams of the Atherton Tablelands region where pathogens thrive in high pH soils. Potato scab, *Streptomyces sp*., is major pathogen affecting quality characteristics of fresh and processing potato in Australia and the Atherton Tablelands. This bacterium is generally present in most soils but on occasion, can produce a toxin that affects the cells of the periderm (outer "skin" of potato) causing scab-like pits on the surface of the potato (Lambert *et al*, 2005). An extensive literature review by the authors attribute creating a soil environment that minimises the severity of the pathogen, rather than using chemical control in an attempt to eliminate it. Soils with a pH of 5 suppress the growth of the pathogen and increasing the availability of some micronutrients such as manganese. Increasing calcium via lime application can also increase the tubers resilience to other pathogens, such as bacterial soft rots and verticillium wilts.

Table 17: Cost comparison of traditional and VRT lime amendment at North Qual, Atherton

pH Zone	pH (CaCl)	Area (ha)	Lime Required (t/ha)	Total Lime (t)	Cost of Lime Spreading $160/t
Normal	5.5 – 5.7	4.6	0	0.0	$0
Moderate	5.2 – 5.4	5.8	0.8	4.6	$736.00
Low	4.9 – 5.1	12.9	2	25.8	$4,128.00
Very Low	4.7 – 4.8	4.8	3	4.5	$720.00
VRT Lime Cost		*24.8*	*1.4 (average)*	*34.9*	*$5,584.00*
Cost of soil sampling (24 samples only)					*$2,487.20*
Traditional Lime Cost		*24.8*	*2.5*	*62*	*$9,920.00*
VRT saving (Approx.)					*$1,848.80*

Crop biomass monitoring

In the Vee Jay's case study, the inclusion of Greenseekers into their intensive cropping system may contribute to targeted chemical use and increases in efficacy of applied chemicals. Crop scouting makes up just 1% of pre-harvest variable costs; however it can play an important role in providing timely and targeted pest and disease information, and application of chemicals is the third largest variable pre-harvest cost at 13% (**Figure 74**)**.** Crop biomass monitoring technology regardless of platform (e.g. proximal or remote) has the real potential to direct crop monitoring operations to areas requiring immediate attention rather than the current practice of randomly sampling across crops.

Vee Jay's plan to develop their adoption of the Greenseeker technology further to deliver VRA chemical application, increasing the efficiency of their precision chemical application. Work by Stover at al. (2003) found that sensor-activated chemical application could save up to 18.6% in spray operations across 70% of farms surveyed. This method utilised technology to identify gaps in canopy cover in citrus groves and prevent chemical application to non-target areas. This technology could be particularly useful in Bowen, where skilled labour is difficult to obtain and operator confidence to adjust spray application appropriately is low.

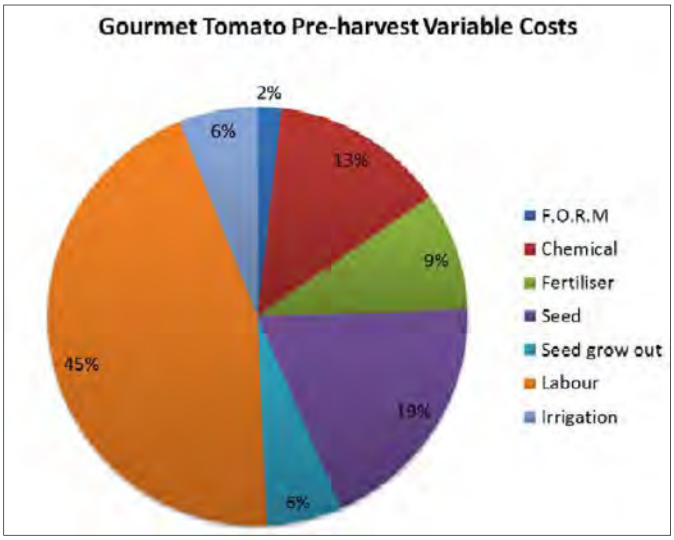


Figure 74: Pre-harvest variable cost distribution for trellised gourmet tomato grown in Bowen, Queensland (F.O.R.M: Fuel, Oil, Repairs and Maintenance)

Is there value in yield monitoring?

Although the activities outlined above have resulted in modest savings in soil amendments, the efficiencies gained will be best determined by the resulting yield and/or quality changes in the years to come. The yield monitors installed during this project will not contribute directly to yield improvements but they allow the producer to accurately quantify, geo-locate and investigate the causes of yield variability. Yield data (often termed the money layer) is very powerful in the precision farming space and allows the producer to assess the impact crop management actions and allows gross margin or *profit-loss* maps to be developed (**Figure 75**). These are potent farm management tools as profit and loss mapping will assist producers to develop and negotiate contracts, take advantage of market windows and impartially assess land based on its performance and the costs associated with maintaining or improving productivity.

In sweetpotato, yield monitoring indicated successive cropping of sweetpotato led to yield reductions of up to 16% compared to an adjacent field that had been planted with a sorghum cover crop. This producer deviated from their BMP to take advantage of market opportunities and successively planted this field. Gross margin (GM) analysis suggesting that this resulted in reduction in returns by up $255/ha, with an associated increase in soil pests.

In Atherton, the variation of yield data could be translated into GM variance for each of the different yield zones of a pivot irrigated potato crop. Of the 22.4 ha pivot, 79% of the crop produced a GM that was below the field average (**Table 18** and **Figure 76**). This means that although the total yield / income looks good on a whole field scale, in reality 21% of the yield is producing 60% of the income which translates to only 24% of the GM $/ha. The next steps here are to analyse this field to identify the causes for yield variability using the technologies described in this report in an attempt to lift productivity in the 79% of the crop that falls below the average GM. Once management practices can be identified and addressed, GM analysis can be reviewed to verify the benefits of the practice change.

The importance of yield monitoring and the lack of technology appropriate to vegetables is discussed in more detail later in the document.

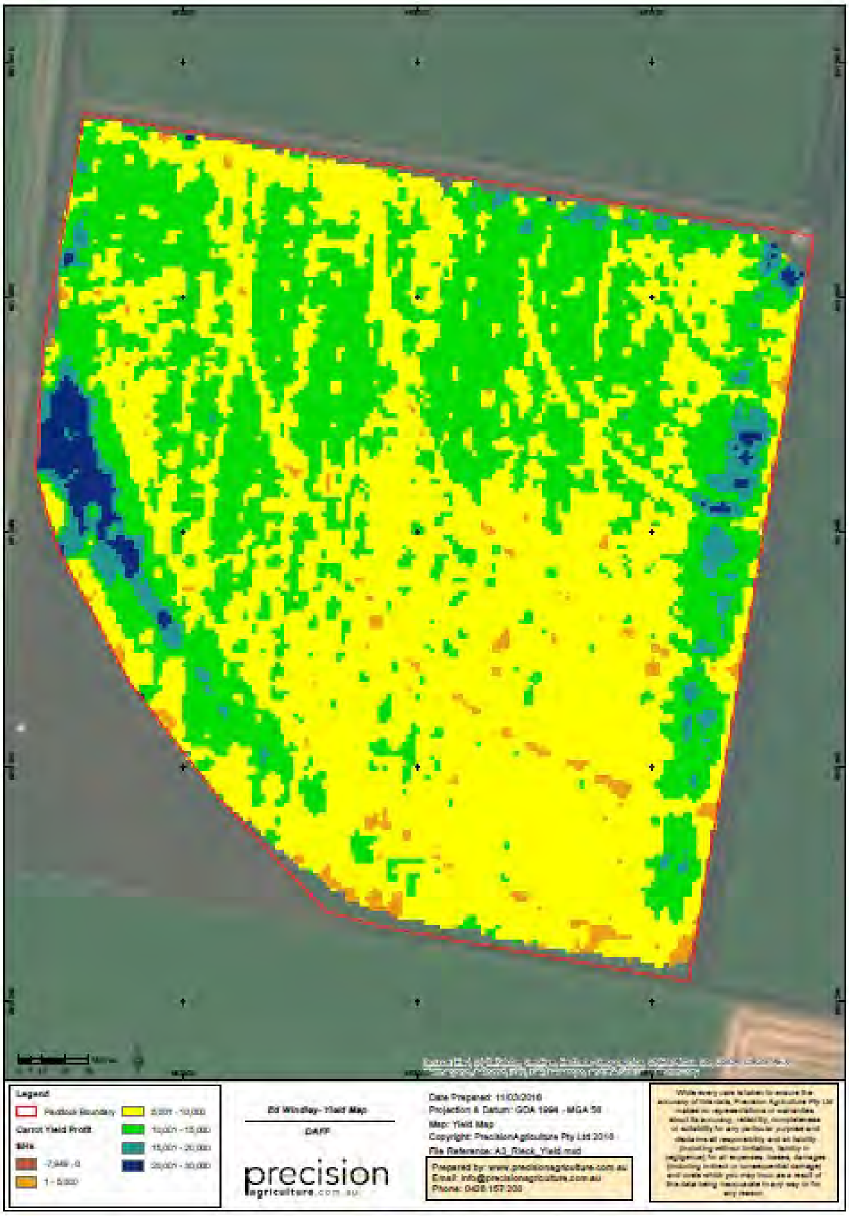


Figure 75: Carrot profit-loss map generated from the yield monitoring data. Blue represents high $/ha and brown/yellow low $/ha.

Table 18: Yield zone of Atherton potato and area of each zone in a 22.4 ha irrigated pivot.

Zone	Average (t/ha)	% Area	Area (Ha)
1	79.30	4.98%	1.12
2	51.30	15.99%	3.58
3	38.44	50.04%	11.21
4	25.58	27.09%	6.07
5	14.58	1.89%	0.42
Average/total	**38.59**	**100.00%**	**22.40**

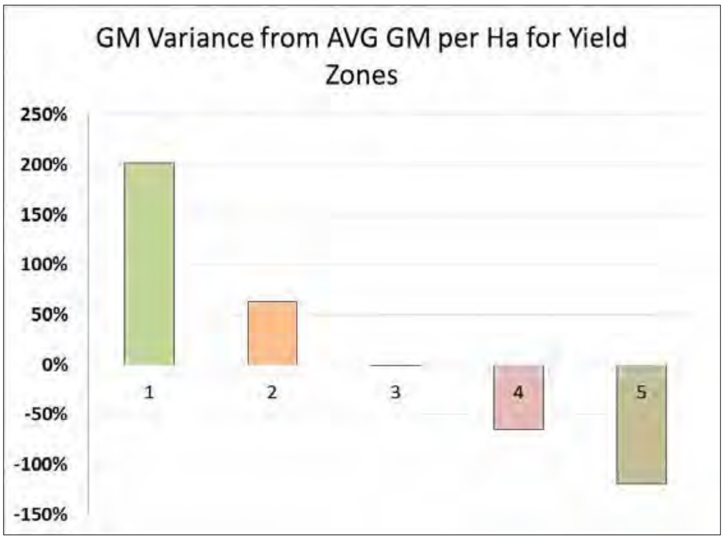


Figure 76: Gross margin variance based on yield zones of potato in Atherton.

Discussion

The significance of the findings for Australian resource based industries

Vegetable production like many intensive farming systems can be characterised as 'high-input' systems and therefore there is real potential for degrading the resource base and contributing to environmental degradation. Certainly, following more than fifty years of intensive (high rotation) and aggressive (high tillage) cropping it's not unreasonable to assume that there has been a decline on soil condition/quality in these farming systems. Though understanding where and how the resource conditions are being degraded and where crops are being affected can be better understood and managed using new tools and approaches.

The project has highlighted that precision approaches do have the ability to lessen the impact on natural resources while improving productivity outcomes, this is chiefly through:

- Improved understanding of soils and soil constraints for example soil types, soil textures, nutrient/water holding capacity and crop needs relevant to soils even in 'small' field sizes
- Generation of new spatially relevant data and visualisations of soils and crop growth
- Data aggregation and analysis of contrasting data sets (soil, weather, climate, crops, and producer practice) that allows a clearer picture of the farmscape to emerge and the influence of farm practices.

There is a perception held by producers, agronomists and researchers that horticultural blocks are often too small to exhibit significant spatial variability or that any variability would not warrant management interventions. Though, the axiom of '*you can't manage what you can't measure*' forms the basis of precision agriculture, with precision approaches allowing producers to quantify a range of farm variables and performance, in most cases for the first time. For example, within block spatial yield analysis or biomass which allows producers and their crop consultant to quantify and delineate poor performing areas. Therefore, the importance and impact of quantifying and visualising in-field variability in intensive systems or indeed any farming system should not be underestimated.

Significant findings:

- Within-block yield variability with associated economic consequences (yield or quality penalties) were present in the majority of vegetable systems involved in the project

- Soil mapping using EM38 / Dual EM has a strong affinity with most producers with other subsequent data layers overlaid on this base mapping

- Soil mapping and simple crop sensing approaches (remote or proximal) offers producers a good starting point into managing spatially (e.g. according to soil types/constraints) – these products along with interpretation are critical to progressing further into precision management

- Variability in crop performance can be accurately assessed and measured using a range of off-the-shelf technology (soil mapping, crop sensing, yield monitoring)

- Depending on the drivers and spatial scale of variability, treatment /management options do exist to improve the management of affected zones (soil moisture sensors, variable rate technologies, targeted agronomy practices)

- Once producers/consultants can view and quantify yield limiting areas, a broad range of strategies emerge to improve crop and resource management (soil, water) – addressing variability doesn't always require technology or hardware.

Crop sensing in horticulture

Of the crop sensing technologies implemented throughout the project, proximal crop sensing using commercially available tractor mounted NDVI sensors to identify crop variability (crop stress) has proven to be the most suitable for vegetable applications. However, high resolution (sub-metre accuracy) satellite and the rapidly emerging unmanned aerial systems (UAS) market will also be applicable to a range of producers, depending on farm size/type and aptitude for technology. These remote sensing platforms will be more applicable to situations where machinery spends little time in the field besides cultivation, planting and harvest. Recent amendments to the licencing and operation of UAS coupled with the improvements in technology and reductions in price, will no doubt allow producers to experiment more easily. Likewise, the increase in resolution and reduction in costs/timeframes to acquire satellite imagery accompanied by the increasing value of high quality imagery to producers will also be beneficial.

In many of the cases presented in this report, NDVI (and other spectral indices) can also be correlated to yield and therefore the technology could be used to infer or predict yield of crops from early sensing measurements. This opens a doorway into the potential for the horticultural producer to employ sensing platforms to undertake predictive studies on their crops and could assist them in targeting specific marketing timeframes or developing other markets or export pathways if they know they will have excess produce or renegotiating contracts at risk of under-supply.

As a vegetation index, NDVI is a robust measure for producers to employ, particularly as an 'entry' level data format. Though it does have its limitations, it is useful for crop scouting and identifying broad variability. NDVI sensors measure the apparent "greenness" of a crop using red and near-infrared light wavelengths and quantifies the readings into a scale from -1 to +1 (Hall et al. 2002). Despite its usefulness, NDVI is unable to explain the potential cause of crop variability and it is difficult to determine variability in a fully developed canopy (NDVI of 1, or near 1). Throughout this project, NDVI was tested as it is readily available, is a robust indices to use across a range of cropping situations and was suited the commercial/developmental nature of this project. However, as technology progresses other assessment tools, crop or disease specific indices and multi or hyperspectral sensors are likely to provide more targeted outcomes for the vegetable industry. Though, producers or agronomist capacity to actually exploit the technology will need to also be developed.

Variable rate approaches

Vegetable producers have increased their awareness of techniques to understand what is causing field variability and continue to develop effective options to manage it. VR applications allow for optimisation of soil amendments and nutrient applications based on crop needs at rates that are not detrimental to the better performing areas but that also maximise the poorer areas. In 'conventional' farming approaches there were three options:

- Under-applying where you needed to improve,
- Over-applying where you didn't need it and accepting the consequences of excess
- Applying a middle of the road rate that was not optimal.

With PA, VR spatial and temporal mapping and the ability to develop profit maps of cropland, there is now also a fourth option: taking unprofitable or land that is too costly to remediate effectively, out of the cropping rotation. In some cases, treating highly adverse soil conditions or disease infection will be cost-prohibitive, there have been three potential cases for this identified during this project. These were soils affected by *Fusarium* in Bowen tomatoes, high sodicity in Bowen and highly compacted sandy red clays in Atherton.

In Atherton, soil compaction could be ameliorated via VR cultivation in order to grow sweetpotato crops; however the producer chose to use another area of land because this challenges his farming model of minimal and zonal tillage. In this case the risk of planting a high cost horticultural crop in adverse soil conditions was a risk he was not willing to take. This land will now be spelled and planted with a cover crop in an effort to increase soil organic matter and in the hope that root development of the cover crop will assist in reducing this compaction.

In Bowen, markets and contract influences meant that a crop of tomatoes that were susceptible to *Fusarium* sp. were planted in an area that through this project was identified as potentially being highly inoculated with *Fusarium* sp. this meant that the crop suffered greatly and it most certainly affected yields. *Fusarium* sp. spores are highly resilient in soils and there are no cost-effective treatments for soil that are already inoculated. In this case, only highly resistant cultivars or crops should be planted in the region or, due to the risk of further infection of other fields via machinery and water movement, the land could be taken out of the cropping rotation. Both of these cases show the potential for maximising the efficiency of farm resources by reducing inputs into areas that may not cost-effective to ameliorate.

Across Queensland there have been a range of reported benefits from VR applications. These include, improved crop uniformity and yield, fertiliser savings and reduced fertiliser costs. Demonstrated savings in fertiliser and soil amendment product usage with VRA have been as high as 40% with subsequent financial savings. Even where overall fertiliser usage has remained the same or higher, co-operators are confident in their changed management practices and the targeted placement of fertiliser and soil amendments to where they are most needed. There have been visible improvements in crop uniformity as well as reported yield increases of up to 75% across previously poorer performing areas (28% of field). For many co-operators in this project, variable applications are now standard management within their farming system.

While there have been demonstrated productivity benefits from this targeted placement, it also has implications for the sustainability of the natural resource base. Tailored soil amendment and nutrient applications for more efficient and effective nutrient use also minimises the risk of off-site losses and could reduce mining of soil resources. In many cases, underlying causes of spatial variability have related to differential soil pH or electrical conductivity, which in addition to production impacts, could also potentially impact on ecosystem services.

Importantly, achieving full VR capability needn't be the goal, as simply adopting more strategic soil testing regimens and tailoring inputs to soils can deliver a suite of benefits without the complexity of employing technology.

Yield monitoring of high-value horticultural crops

Yield monitoring of vegetables and other high value crops is undoubtedly one area where investment in developing suitable technology would lead to an improvement in the uptake of precision crop management approaches. Currently, the mass (e.g. tonnes) based yield monitoring equipment is only suited to root crops such as potatoes, carrots and sweetpotatoes. However, unlike bulk commodities such as grains and sugarcane, most horticultural crops are sold on the market as a boxed/packaged units, therefore kilograms of product harvested from a given geo-referenced area of land (e.g. tonnes/hectare) is not the most useful unit for horticulture products and producers. Given that markets are specific about vegetable produce size and quality parameters, a percentage of what the harvester and yield monitor measures will never make it into a box to be purchased by a wholesaler or retailer. It is reported that up to 30% of total vegetable production is wasted during processing, distribution and consumption with the largest portion being attributed to waste at the farm gate (White, 2015). There is still much work to be done in the area of yield monitoring, and in-field and shed automation to adequately describe the 'marketable yield' or 'packout' before it leaves the farm gate.

Technology installation and optimisation

While much of the technology that has been installed and adapted into horticultural systems is commercially available equipment, implementation is far from straightforward for most producers and indeed equipment dealers. Technologies promoted as 'plug and play' often required significant technical support and optimisation to achieve functionality within vegetable systems.

Feedback from demonstration site collaborators has been that if not for the support provided by project staff and engaged agribusiness service providers, it is unlikely they would have persisted in this process of adaptation if it was something they had to undertake on their own. This is an important consideration for any future expectation of technology adaptation and practice adoption beyond the life of this project and in future similar projects. Supporting producers at the farm level with a broad range of expertise is critical to overcome the adoption barriers.

Yield monitors are critical to further adoption of precision farming systems in high value cropping. The retrofitting of monitors in this project required significant amounts of work to calibrate the equipment. This has been exacerbated by the nature of the crops that are being harvested as all are root crops that require digging at harvest which involves some component of soil also being weighed and recorded. Although very time consuming, in some cases this was able to be accurately measured and accounted for in post–processed yield maps. In other cases the setup of packing sheds did not easily facilitate this and other calibration methods had to be considered.

Variable rate functions embedded in existing tractor guidance systems required 'unlocking' to enable prescription mapping to proceed. A range of upgrades and/or additional equipment was required to ensure technology compatibilities and to enable use of technology across multiple tractor operating systems for use by multiple producers, where equipment sharing is occurring.

Finding suitable equipment and service providers proved difficult in some areas of regional Queensland and the project team suspects that this lack in support would also exist across regional Australia. This was a critical gap identified early in the project and clearly could have significant impacts on any meaningful adoption of PA technologies. Project staff addressed this by seeking to include (in some cases through formal agreement) agronomy and equipment providers to increase their capacity in undertaking more advanced precision approaches, and to work collaboratively with the project. Importantly the producers involved in the demonstration farms challenged their own consultants on skill development associated with variable rate technology. This was an exciting outcome as producers exposed the potential of the technology (via their consultants and equipment providers) challenged the status quo to drive the next wave of precision in horticulture beyond guidance systems.

Intensive horticulture is subject to very tight planting and harvest windows, this alone can make adoption of practices that initially increase the time taken to carry out field preparation and crop maintenance activities difficult to implement. Even where suitable service providers have existed, the intense nature of vegetable production and the short growing season windows have resulted in some producers eliminating the need for external service providers by developing their skill set so that they can create their own mapping products. External service providers are still an essential part of implementing and optimising precision technologies on farm, troubleshooting and technical support.

Data management

Precision in agriculture generates significant amounts of data compared to other industries. The vast amount of spatial data collected is a consequence of technology implementation. It was essential that collected data was able to be translated into knowledge, which necessitated that both producers and their management teams had the ability to record, access and employ data to make management decisions. The yield monitors generated a high volumes of data for processing and caused some delays in getting data back to co-operators. However, the yield mapping data, even in its raw state, proved valuable in identifying spatial (and in some cases temporal) variability in yield. Project staff and collaborators had to rapidly identify methods of handling the sheer volume of data and ensure stakeholder had access to up-to-date information. This involved necessary skills development for both project staff and collaborators alike.

Information access and mobile technology has so far had the largest impact of the innovative technologies, with data availability for consultants and producers accessing mobile platforms to view mapping, schedule sampling and record information. This has a major impact on the management of variable rate technology as timely data management and access is vital to initiating management schedules. The use of mobile platforms and storage of data in the 'cloud' is an effective and indeed necessary way of storing and accessing data. Mobile technology further enhanced the effectiveness of the data as participants could use their mobile device to ground-truth data and locate a particular feature from the map to a specific point on the Earth's surface, seen in **Figure 77** with the satellite map overlaid on Google Earth's mobile platform. Utilising these technologies as part of the project has improved producer and agribusiness confidence and skills, which can be directly applied to other aspects of their business.

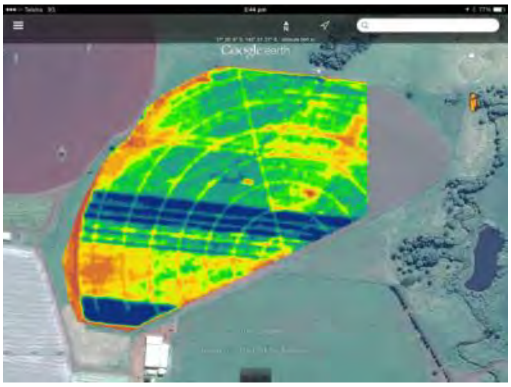


Figure 77: Use of mobile technology to display mapping data over Google Earth's mobile platform

While the project has succeeded in optimising data capture platforms, with the data making sense to producers at both spatial and temporal levels, employing the high quality data in new ways such as predictive capacity is an area for further work. Similarly, data management and manipulation approaches at the farm level will also require further investment, particularly if agriculture is to take advantage of opportunities presented by mobile and 'big data' networks and the wider digital revolution.

There are number of different methods that mapping data can be displayed. For ground-truthing using mobile devices, a Google Earth file (such as a *kmz or *kml file) is the most useful for targeted crop scouting. For data analysis, such as comparing data layers, extracting correlations from your data and performing prescription maps, a specialised Geographical Information Systems (GIS) file such as a *shp file, is required. A specialised GIS file will contain the actual data value and an x,y co-ordinate value (GPS co-ordinates) to pinpoint the data within the field. It is important to understand what data is expected from the service provider and what data is needed to make on-farm decisions. It is also important to understand map legends, maps are often set up with a logical colour code such as red = high or worse, and blue = low, or better, however sometimes these are reversed depending on the application and technician.

Precision technologies and its role in policy, industry groups and producers: addressing market failure

Interest and investment in PA and technology in farming systems is perhaps at an all-time high. Emerging areas such as Big Data, Internet of Things (IoT), unmanned aerial systems (UAS), robotics and automation are also likely to play an ever increasing role in food production and land management more generally. Despite the positive media and insightful investment from multi-national companies in agri-technology, deriving benefits at the individual farm gate level while possible will not happen quickly or easily across Queensland or indeed Australian agriculture.

Achieving meaningful adoption in time frames required to maintain or accelerate farm viability and profitability will require dedicated public and private investment. This investment should be into programs that aim to bridge the current gap between what's possible and what's currently occurring at the farm level. For instance, the adoption level of advanced precision technology pre-project was miniscule and where it was occurring can be solely attributed to public investment. This highlights that market failure conditions currently exist, where equipment and technical providers are not able to achieve any substantive penetration into the vegetable and arguably the entire horticulture industry.

Even though a range of agri- technologies and the interfaces/platforms employed are becoming easier to use and are beginning to offer greater comprehension of the farming system through data analysis; many producers and their advisors simply lack the resources (knowledge, time, financial resources) to employ most technologies without significant support. This is confirmed by the responses of producers and consultants adoption study carried out in this project. The issue is compounded by the lack of a suitable return–on-investment (ROI) in comparison to other areas requiring investment on-farm. It's well understood that precision approaches require significant time and resources upfront before any benefits can be realised. That said, generational change and the resulting proficiencies across a broad suite of technologies including the continued adopting of auto-steer are likely to improve adoption rates.

At the present time in rural and regional Queensland, producer support from advisors and dealers for precision technology remains an area for improvement; this is often a stumbling block when producers consider increasing their investment in technology. Appropriate policy and more importantly investment settings could address this through:

- Targeted investment that seeks to improve advisor and producer capacity and readiness
- Further development of local/regional case study crops or farms that allows technology providers and the farming community to assess technology capability and ROI
- The establishment of 'communities of practice' that leverages industry and equipment dealer interest along with the R&D community
- Improving wider industry outreach by using or leveraging industry funds (via R&D Corporations) to develop optimised precision technology on commercial farms
- Increasing the regional reach of enabling infrastructure such as adequate mobile data (such as 3G or 4G) networks, and coordinated reference stations (CoRS) that provide low cost-high accuracy spatial positioning
- Investing/embedding data analytics to make better use of spatial; and temporal data and subsequent ROI investment scenarios

The emerging areas of improved traceability, food safety, chemical application record keeping are all areas where precision technologies can assist both producers and other value chain participants, though realising any potential gains will require a more concerted extension effort and therefore investment into supporting producers and their advisors to exploit the opportunities presented by precision systems. In the medium to long term the major retailer's through their customers will demand greater transparency of farm practices, provenance and food handling (particularly of fresh food), as such even basic precision farming technologies will allow producers to demonstrate (possibly in real time) a range of farm and food safety practices.

Contributions to sustainable agriculture: increasing productivity while protecting the natural resource base

Adoption of precision tools and processes can contribute to sustainable agriculture while protecting the natural resource base. It gives producers tools to analyse their current management practices and processes to improve upon them. In several demonstration sites, reductions in both the cost of applying amendments and the amount of amendment required to address soil constraints, has been reduced, sometimes by up to 44%. This allows producers to focus inputs on areas that require more significant amelioration. Where savings have not been made, a yield, production or quality advantage is expected offsetting the cost of extra inputs including time to optimise precision equipment and processes.

The findings of this project demonstrate and quantify the effect management practices have on production. Best management practices for most crops suggest that successive plantings of the same, or similar, crops should be avoided to reduce the presence or severity of pests and diseases (Abawi et al. 2000). This is not always feasible in vegetable cropping and in some cases the market advantages of cropping successive parcels of land outweigh the disadvantages. Here, in sweetpotato, yield monitoring indicated successive cropping of sweetpotato led to yield reductions of up to 16%. This producer had previously adopted a standard farm management practice of crop rotation and spelling of vegetable production fields to reduce their reliance of nematicides to control root knot nematode (*Meloidogyne sp*.) and improve general soil condition and microbiology, and was astonished that only one year of successive cropping could cause such significant yield penalties. It was a costly lesson, with gross margin analysis suggesting that this resulted in reduction in returns by up $255/ha. Adopting VRT and yield monitoring has now given this farmer definitive proof that their previous best management practices are beneficial in intensive vegetable production.

Remote and/or proximal crop sensing technology has the potential to provide producers with the ability to spatially identify and temporally track disease presence and severity prior to the development of economic losses. Yield, quality and chemical application programs are strongly affected by diseases in tropical production systems with accelerated growing seasons. With field tomatoes being a major contributor to economies in the Queensland Dry Tropics Region (ca. $165M/pa), suppling up to 85% of the national fresh tomato crop from June to November, producers in the region agree that the timely identification of disease pressure is essential to the productivity and sustainability of their businesses as well as actively protecting natural resources. Trellised tomato crops are treated with pest and/or disease control chemicals up to every 7-10 days, this is a significant cost to producers and potentially to environmentally sensitive areas. Firstly, the implications for crop sensing approaches in trellis supported crops; and secondly the validation of inexpensive proximal sensors will help producers implement technologies to target areas where diseases are emerging before physical symptoms result in yield losses.

Vegetable producers and crop consultants have been through intense periods of learning and skill development as part of this project. Both have had to develop a range of different skills and practices. This has included the installation and operation of a range of new technologies. A not so obvious area of learning has been the use of 'cloud' based data storage and access and mobile devices for recording and mapping data and activities. This has proven to be a necessary step to facilitate access and sharing of the vast amounts of data generated in PA approaches.

The various tools utilised and data layers developed through the projects ground truthing activities have also facilitated a greater understanding for producers of their farming systems. In particular, this has been centred on inherent soil characteristics and constraints and how these impact on crop performance. It has also cemented spatially oriented soil testing as a critical component of soil and crop management. Involvement in this project required some of the most intensive soil sampling regimes many of these producers had ever experienced. This provided important detail around soil properties that most producers and their advisors were previously unaware of. While many of the tools and processes have been the same across

WHAT PRODUCER'S ARE THINKING

"Project has been fundamental in bringing new knowledge to have a go"

"Believe in technology enough – to start own project and looking at what can do"

The technology has got traction for the industry through the project – "would've been glacial pace" without a project of this complexity to get it started"

"Lap-top use and using google maps and GPS plots – using it for other things now, using the info- find out how to the apply the technology been good"

"Very relevant outcomes that are local – farmer knows farm but now also has analysis of the blocks through yield maps, soils maps and VR map to make application"

Source: CQU Adoption Study (2016).

multiple farming systems, the data revealed and how it has been used to modify management practices has varied with each producer and farming system.

Future Needs for Innovation Uptake

Undoubtedly the project has had a significant impact in accelerating the adoption of PA technologies in intensive horticulture. However, it has also been instrumental in identifying some limitations that should be considered by producers, equipment manufacturers and program investors. All of the technology implemented through this project is commercially available and much is marketed as ‘plug and play’ compatible with existing GPS guidance and tractor operating systems. However, this was not the case and most equipment required considerable post installation technical support to achieve functional capability. With some equipment providers/dealers also unable to get equipment to operate as intended. For the most part this relates to the dearth of advanced precision equipment actually operating and a serious lack of regionally based technical providers, who have the requisite experience in this area. This is an essential consideration for other industries who may be interested in PA adoption or for future policy development around PA.

Feedback from project collaborators has been that the support provided by DAF through the project has been critical for their continued perseverance and indeed adoption of PA technologies and strategies. It’s courageous to suggest that government RD&E agencies are the only entity that can increase adoption of technology across a large spatial footprint. That said, government does have a role to play in areas where acute market failure exists and where commercial realities indicate that no single commercial service provider can develop the multiple links and relationships needed to forge through the difficulties associated with technology adoption.

The use of mobile technology can assist in the timely identification of a range of crop production parameters; however the challenge is delivering applicable data for in-field decision making. Throughout the project, the process from information collection, post-processing and ground-truthing was typically too lengthy to address pest and disease issues in tropical vegetable production and the costs (including time delays) of processing that information may limit its adoption across the wider industry. However, this has led some producers towards processing their own data, which demonstrates that the precision approaches and the technology is beneficial.

Producers and agronomists have been impressed by the ability of a range of technologies to assist in improving their understanding of soil and or crop spatial variability and in developing more strategic sampling techniques. However they are also aware that variability not only occurs spatially, but also temporally and these trends may not be consistent over time. The data they have collected often leaves them asking more questions than it gives answers and although more data at a higher resolution may not solve this problem, more targeted information solutions could. While ‘off-the-shelf’ solutions were trialled across the project, they were useful in producing new information into where sampling or investigations into spatial variability should be carried out. Much of the sensing technology that can target specific crop traits such as water content or nutrient status, or pest identification is still in development and could provide more timely solutions in commercial applications. It’s important to note that the early adoption phase when using any new technologies or practices can be very onerous in terms of the time it takes to understand the results and outputs.

Data processing and the GIS professional service industry servicing horticulture is in its infancy and requires an understanding of horticulture’s unique systems to deliver suitable tools, processes and outcomes. That said, service industries will grow and mature as a result of producers adopting spatial technologies.

Summary of future needs to support innovation uptake:

- Targeted investment that supports producers and advisors to implement and fine-tune precision technology over time – to ensure that inevitable hurdles can be overcome

- Producers located in regional growing areas can lack adequate service and support for advanced precision technologies. While the supply and installation of hardware is often achievable, many producers expressed frustration that 'getting it working' requires a deeper knowledge and level of support

- Ensuring that enabling infrastructure such as mobile (3G/4G) and low-cost high accuracy positioning networks are available in rural and remote locations

- Investment into developing next–generation yield monitoring technology using vision systems/machine learning to measure size, shape and other quality attributes

- Improved crop sensors and associated algorithms that have better predictive capabilities

- Creation of formal and informal communities of practice (CoP) or similar networks that allows producers, agronomists, researchers, equipment providers to discuss and help each other implement precision farming systems

- Study tours that allow producers to see other industries/ countries efforts

- Data analytics - ensure that future projects have a broader mix of agricultural and data analytics expertise – to better maximise the effort and expense that goes into collecting high quality data

Communications

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May 2015, Fresh Pickings Newsletter, Bundaberg Fruit and Vegetable Producers Association, Bundaberg, Queensland

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DAF & Back Paddock Company, 15/11/2016, “Interpreting your own soil test workshop”, Bowen Research Station, Bowen, Queensland

DAF & Back Paddock Company, 26/1/2016, “Interpreting your own soil test workshop”, Bundaberg, Queensland

DAF & Back Paddock Company, 29/3/2016, “Interpreting your own soil test workshop”, Lockyer Valley, Queensland

DAF, John Deere & Precision Ag Solutions, “Basic training for VR applications using John Deere & Trimble equipment”, 2016, Kalbar, Queensland

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O’Halloran, J, 2016, “Smart Farming in Queensland – turning precision data into knowledge for vegetable systems”, LandWISE Conference 25th May 2016, New Zealand

Social Media Updates

Limpus, Sarah, 11/02/2016, @sarlimpus Via Twitter: “Watch #precisionag in #qldhort on Landline 7/2/16 in iView, start at 39min @precision_horti” (1 retweet, 1 favourite)

Layden, Ian., 25/11/2015, @precision_horti Via Twitter: "Getting some precision ag video case studies happening in north qld #presicionhorti #agriculture #YouTube #Hortsmart [photograph of filming discussion of yield monitoring and variable rate technology on-farm with Ben Poggioli for HortSMART You Tube series]", Mareeba (1 retweet)

Layden, Ian., 1/12/2014, @prescision_horti Via Twitter: "Yield monitoring sweetpotatoes going along ok got a few bits left in the puzzle @VanderfieldAU @AgPrecision" [Photograph of sweetpotato harvesting], Bundaberg (1 favourite)

Limpus, Sarah., 4/12/2015, @sarlimpus Via Twitter: "Solving the unique challenges for VRT in horticulture @davidevansgroup @QldAgriculture @fruitvegproducers #precisionagriculture" [photograph of custom spray boom to be fitted with Greenseeker technology], Bundaberg (2 favourite, 2 retweet)

Limpus, Sarah., 3/02/2015, @sarlimpus Via Twitter:"#PrecisionAg in #qldhorticulture feature in january2015 edition of #vegetablesaustralia @AUSVEG @precision_horti" [Photograph of Veg Australia article], Queensland (1 retweet, 1 favourite)

Limpus, Sarah., 13/02/2015, @sarlimpus Via Twitter: “#Sirrus training for #precisionag in #qldhorticulture with @SSTSoftware and Atherton’s GTAgServices #daffVRTproject [photograph of Grahame McKenzie of GTAg Services , Ben Poggioli of Tolga Farms and Mark Pawsey of SST Software at the training event]”, (1 retweet, 4 favourite)

Bundaberg Fruit and Vegetable Producers, Facebook, Bundaberg, www.facebook.com/BundabergFruitandVegetableProducers

Limpus, Sarah., 7/9/2015, @sarlimpus Via Twitter: “Hi Twitter, it’s been ages! Meanwhile in Atherton: 1st commercial VR lime in veg #precisionhort @precision_horti [photograph of VR lime application in 26ha pivot to be planted to potatoes” (1 retweet, 1 favourite)

Layden, Ian., 4/9/2015, @prescision_horti Via Twitter: "Stay tuned @Hort_Au @ausveg @SPAA_EO for some precision vegetable videos out next week. #precisionag #horticulture [photograph of professional filming for You Tube]", (1 retweet, 1 favourite)

Limpus, Sarah., 7/9/2015, @sarlimpus Via Twitter: "Our #vegVRT producers are getting excited about data management possibilities w @SSTSoftwareAUS @precision_horti #horticulture #SPAAsymposium2015" (2 favourite, 2 retweet)

Limpus, Sarah., 8/9/2015, @sarlimpus Via Twitter: "@precision_horti #precisionag tools in #qldveg a luxury w proven benefits, PA a big job for agronomy #pasymposium15"

Dimos, Nicole., 8/9/2015, @SPAA_EO via Twitter: "@precision_horti launches #vegie pa videos at #pasymposium15" (1 retweet, 1 favourite)

Layden, Ian., 8/9/2015, @prescision_horti Via Twitter: "#pasymposium15 @SPAA_EO thanks for the opportunity to present PA in Qld veg. See our PA videos at https://www.youtube.com/channel/UCrJSqXTKsjXEOBCcvfWjNFA " (2 retweet, 4favourite)

Layden, Ian., 22/9/2015, @prescision_horti Via Twitter: "Check out our yield monitoring in veg video! @KalfreshVeggies @Hort_Au @ AUSVEG @SPAA_EO @SoilWealth https://www.youtube.com/watch?v=zCA1vFk9Ri0 " (2 retweet)

Limpus, Sarah., 29/9/2015, @sarlimpus Via Twitter: "Watch Queensland vegetable producers discuss #yieldmonitoring #horticulture #precisionag, 1st seen at @SPAA_EO" https://www.youtube.com/watch?v=zCA1vFk9Ri0 (2 retweet, 3 favourite)

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