Hort Innovation

Final Report

Data Analytics and Application Technology to Guide on Farm Irrigation

Project leader:

Brett Pringle

Delivery partner:

The Yield

Project code:

VG15054

Project:

Data Analytics and Application Technology to Guide on Farm Irrigation – VG15054

Disclaimer:

Funding statement:

This project has been funded by Hort Innovation, using the vegetable research and development levy and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Publishing details:

ISBN 978 0 7341 4424 9

Published and distributed by: Hort Innovation

Level 8
1 Chifley Square
Sydney NSW 2000

Telephone: (02) 8295 2300

www.horticulture.com.au

Content

Summary

Background

The effectiveness of irrigation practices in Australian horticulture is currently limited by the availability of useful information to growers. Water applications are often based on observations i.e. gut feel or in limited instances (approximately 1% of growers in Australia) using data from soil probes. Growers have access to weather information from the Bureau of Meteorology (BOM) to help guide their irrigation decisions however the stations are often too far from the site to provide relevant information.

Evapotranspiration (ETo) is an established way to calculate water evaporation from the soil, and the transpiration from the plant, to support irrigation decision making. Whilst the BOM currently provides some ETo information it is only available from ~50% of weather stations, is a historic measure only, and is not overly easy to find and so not easily accessed.

The Yield is an organisation that has developed and implemented a new agriculture technology solution (Sensing+) that is being used by growers to make more informed crop management decisions. Sensing+ is an integrated end to end micro climate solution that uses data from sensors installed on farm to generate weather and crop-based predictions, displayed to growers via an app. A key part of the functionality included is the calculation and prediction related to water availability for the crop. The calculation is based on ETc principles (which is ETo paired with Kc, a crop coefficient). Both the current, and 7 day forecast for ETc are displayed in the Sensing+ app, providing growers with data-based insights into how much water a crop may need. The current approach used in The Yield's solution relies on static based modelling (using Food Authority Organisation and similar publicly available literature data for each crop type).

Objectives

Horticulture Innovation Australia in conjunction with The Yield have completed a two-year research project. The focus was on improving vegetable grower sustainability and resilience by creating models to support growers with the challenge of when and how much to irrigate. The project intent was to encourage efficiencies in irrigation management through development of these models and associated crop coefficients (Kc curves) for four crop types which consider ETo based on the plant growth stage. The ambition would then be to make the models available for incorporation into a The Yield's Sensing+ solution.

Scope

Two different approaches to calculating dynamic ETc were considered:

- Analytical modelling based on Bayesian estimation techniques; and
- NDVI modelling using data from low orbiting satellites.

Four different crop trials were completed (brassicas, carrots, lettuce and spinach). These were selected as they have the highest production value in Australian horticulture, and so the greatest reach for research outcomes.

Method

A project framework was developed. As this project was unique, subject matter experts were engaged to design the project framework. In summary this included:

- Completing a literature review to leverage any previously completed works on developing analytics/modelling the calculation of ETc and its use in the production environment;
- Developing the two different approaches for calculating dynamic ETc and comparing these to the existing modelling approach used in The Yield's solution (static modelling);
    - Approach 1 - Data analytics based on Bayesian estimation methods that dynamically infer ETc
    - Approach 2 - Dynamic ETc modelling using remote NDVI data from low orbiting satellites
- Completion of locally based field trials for the four crop types to capture in field data;
- Apply field trial data to the analytics that are being developed;
- Review outputs using the decision framework developed as part of the project design to compare the approaches;
- Engage with industry through a variety of communication channels to drive awareness of both the research being undertaken, as well as the ongoing advances being made in the micro climate sensing space.

Summary (Cont.)

Findings

In summary, after reviewing the approaches using the decision framework, neither drove significantly improved enough results when compared to static Kc curves currently being used. It became apparent that variation in how water moves through soil is a stronger driver of soil moisture variation than variable Kc curves. Note that:

- For Approach 1 (analytics based on Bayesian modelling techniques) only a single soil characteristic (drainage) was incorporated. However other soil factors (including texture/profile) are significant drivers of the availability of water available to the crop. For practical application these additional soil characteristics would have to be accounted for in the software.
- Vegetable production areas have large variation in soil types and profiles across a single crop or site. Whilst the drainage estimation techniques being modelled can be calibrated for a single soil type, there is currently no practical way to account for the variability of drainage and other aspects of water movement through soil across the farm.
- With the NDVI modelling, inputs are from low orbiting satellites. Cloud cover can dramatically impact data availability depending on geographical location. Whilst this is improving as the technology advances, the unreliability of the data at this point in time precludes it from use within the Sensing+ solution; and
- Both approaches are backwards looking. They only provide dynamic ETc (from Kc estimates) after a crop growth cycle is completed. Users would have to complete a full crop rotation before predictions of water availability can be activated (in The Yield's solution). As predictive functionality is core (as is AI or machine learning) this presents a major limitation.

Documentation on how the data analytics for approach 1 (using Bayesian techniques) were constructed and the approach used to complete this process have been completed. This intellectual property is available for use (and has been included in the Intellectual Property register) and could be leveraged by an alternate provider. All four crop types have been applied to the analytics and associated Kc curves created. This means that if a suitable technology provider wanted to leverage the significant work done on dynamic inference of ETc and Kc all supporting documentation required is available for them to do so.

(Note: incorporation of functionality into a software platform was not in scope, the Project was a proof of concept)

Keywords

1. Evapotranspiration
2. NDVI
3. Data analytics
4. In Field Trials
5. ETo
6. Dynamic Kc
7. Crop coefficients
8. Inference
9. Modelling
10. ETc

Introduction

Identifying new ways to optimise irrigation practices will be key to ensuring the ongoing viability of irrigated farming in Australia. Advances in microclimate sensing that combine data from on farm sensors with intelligent analytics is seen as a key way to provide growers with tools to support irrigation decisions. New innovations in this area have significant potential to help growers make better decisions on when and how much to irrigate by replacing the traditional 'gut-feel' approach with one centered around data-based evidence.

The Yield is an organisation at the forefront of the Ag Tech revolution and has been independently developing an integrated end to end micro climate solution. Included in The Yield's solution is information on historic and future availability of water to the crop using the principles of ETc. By capturing localised growing condition information from sensors installed on farm and running this through complex models, The Yield's solution calculates water available to the crop in the soil now and 7 days into the future. This information is made available to growers on a mobile phone application, meaning timely and relevant information is presented to support more informed irrigation decision making.

Of critical consideration when trying to understand what water is available (and so irrigation requirements) is the rate of evapotranspiration (Appendix 1). When ETo is combined with a crop coefficient (Kc) it becomes ETc, estimating water loss for a specific crop through crop transpiration and soil evaporation. The rate and level of ETc is driven by the crop type, its management, the growth stage and the weather conditions across the crop growth cycle. Any software-based solution that aims to use ETc as the proxy for calculating water availability needs to incorporate the factors that drive ETc into its analytic based processes.

A major component of The Yield's solutions has therefore been to build analytics into its software that calculates not only how much water is available to the crop now, but also what it is likely to be for the next seven days. These insights, coupled with seven-day weather predictions, provide growers with a powerful tool to support their irrigation decision making.

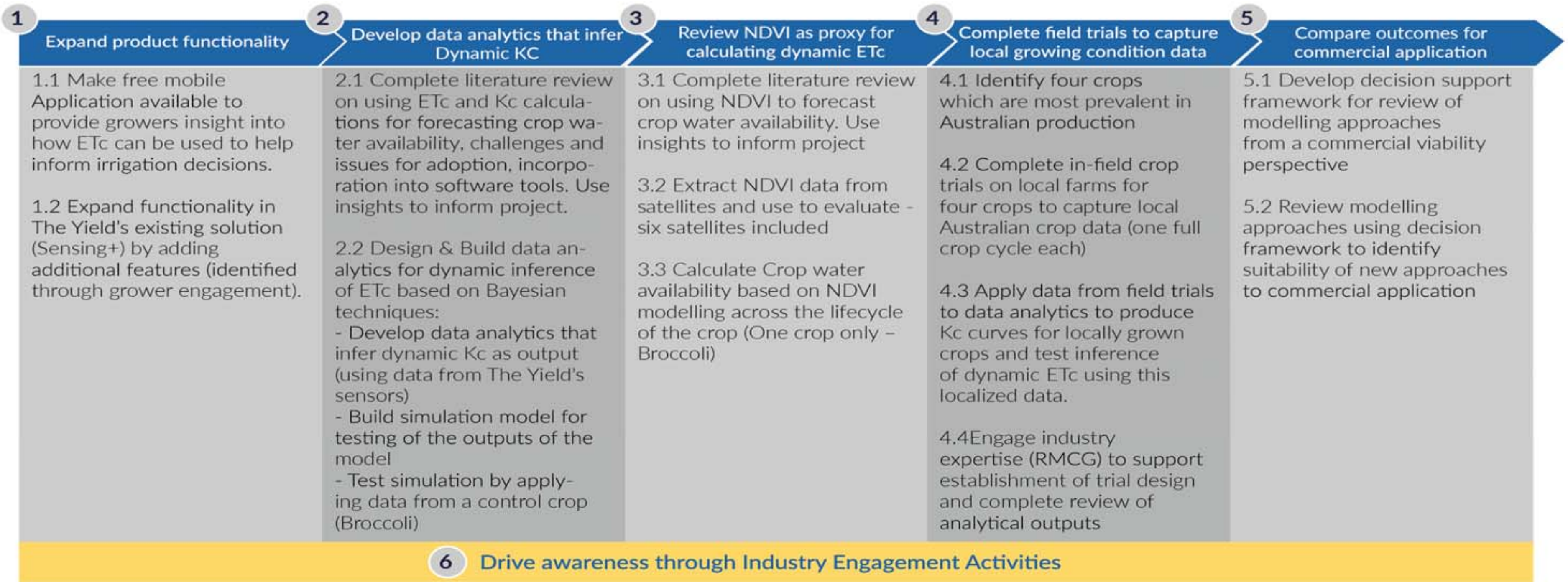
The Yield's current approach to completing these calculations relies on data from the micro climate sensors installed locally in the crop. The analytics use static tables (sourced from the Food Organisation Authority and similar literature values) which are built into the backend of the solution as part of the analytic process. This approach requires the grower to verify the growth stage of the crop manually in the app as it changes throughout the crop cycle which presents challenges from a scalability perspective.

Recognising the significant reach that this kind of tool has across Australian growers, The Yield, in conjunction with Hort Innovation, has undertaken a two-year research program to evaluate whether alternate modelling approaches that move away from static analytics could be developed, and so when implemented irrigated growers have a more powerful decision support tool. The research program also aimed to drive awareness of The Yield's existing solution, so that grower understanding of using data analytics to inform irrigation practices is increased, as well as the potential outcomes of developing the new approaches to modelling dynamic ETc. As well as a continuing drive to raise awareness more generally of the opportunity these new types of technologies offer for managing irrigation.

Methodology

Due to the unique nature of the project which included this new type of analytic approach, a methodology was developed using subject matter experts from across the Horticulture, Ag Tech, Quantitative Analytics and Data Science sectors. This included input from agronomists (Doris Blaesing from RMCG), quantitative modelling experts (Tristan Perez - Queensland University of Technology), Data Scientists and Plant Scientists (The Yield) and Ag Tech professionals (Tim and Peta Neale from Data Farming). The outputs of this process led to a program comprising six key areas, this included:

1. Using updates being made in The Yields solution (part of The Yields existing commercial strategy) to improve grower awareness across the Horticulture sector of advances being made in micro-climate sensing technologies and how ETc calculations can be used as the basis for improving irrigation decisions.
2. Developing data analytics that dynamically infer ETc (based on Kc curves) using Bayesian modelling techniques. Two different methods of completing this would be developed (Supporting Report 4).
3. Completing field trials in local growing conditions to capture baseline crop information and apply this to the data analytics to produce crop Coefficients (Kc) for the four crops (Spinach, Lettuce, Carrots and Broccoli) included in the study (Appendix 3).
4. Reviewing the use of NDVI as an alternate approach to Bayesian based technique for inferring dynamic ETc, using field data (Broccoli crop only) as a comparison point.
5. Reviewing outputs from the different approaches and determining whether new approaches being considered provide a better solution.



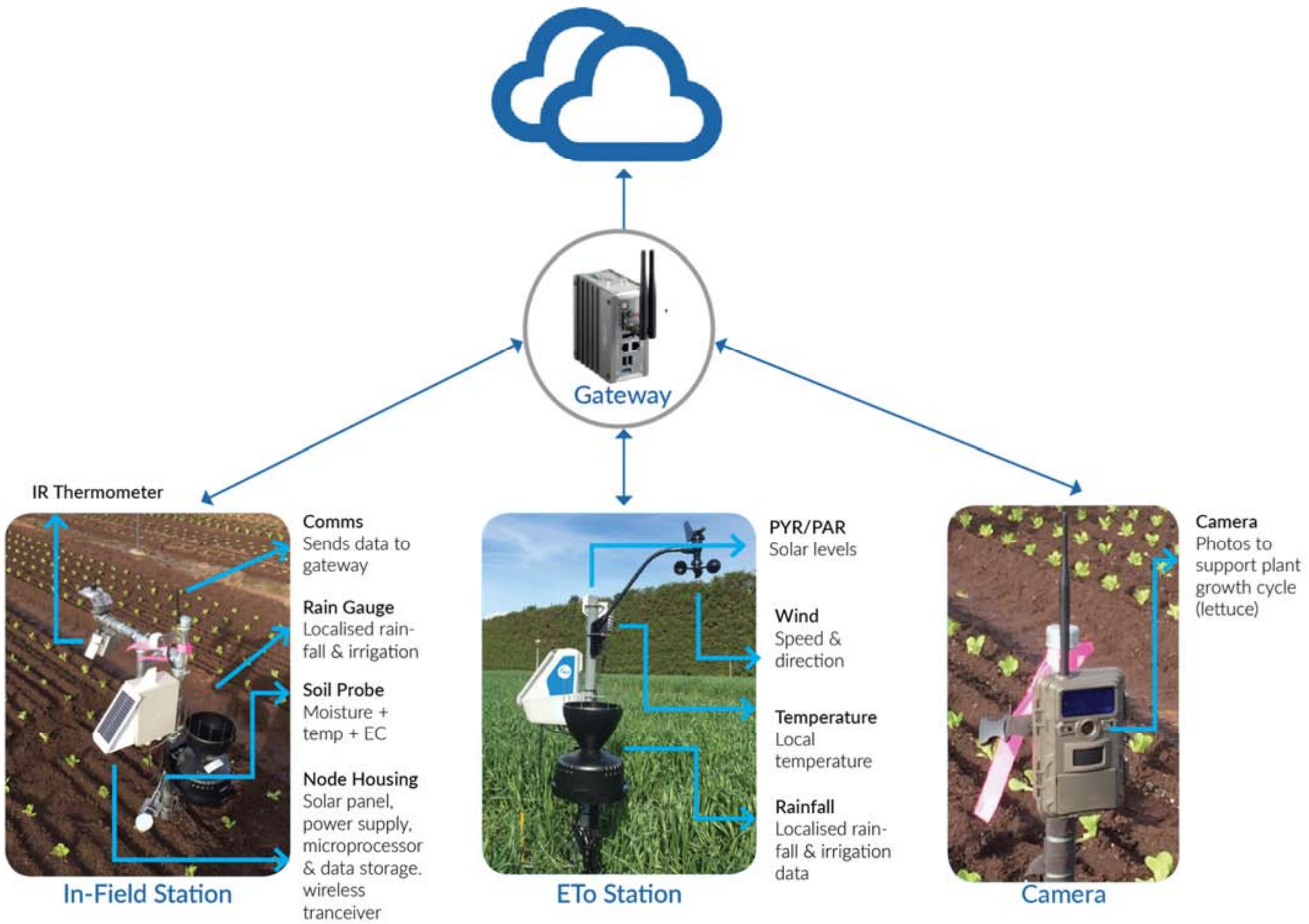
Industry engagement activities by way of webinars, presentations, fact sheets and attendance at seminars and conferences were completed to promote the research program across growers and industry groups.

Methodology (Cont.)

Complete In Field Trials to Capture Local Growing Condition Data

Field Trials – Design

A major component of the research program was to run on-farm field trials for each of the crops included in the study(Broccoli, Carrots, Spinach and Lettuce). This meant data could be captured for crops being grown in local Australian growing conditions, and once applied to the analytics Kc curves produced. All trials were run using the same installation configuration shown below.



Note:
The field trial sensor configuration was built to align with the requirements of the analytics so the new approach to inferring dynamic Kc would be able to be implemented in practical application.

The ETo station depicted to the left was used so that the parameters of ETc (Temp, Humidity, Wind and Solar) were captured

The In Field station was used to capture water into the system (Rainfall and Irrigation) and Soil Moisture was then captured as a reference point.

The Camera was used to provide guidance on what the growth stage of the crop was and when the growth stage changed as a reference point

Methodology (Cont.)

Field Trials – Timing

The field trials were run in two phases to align with the growth cycle of the different types of crops, additional trials were run for Lettuce and Spinach to capture an extra data set for use and comparison in the analytics. Over the two-year program the field trials ran from July 2017 to May 2018. Shown below is the field trial timeline for each crop rotation.

		2017								2018										
Crop Type	Start Date	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Trial Finishes	Location
Lettuce – Trial 1	Mid May																		Mid Nov	Southern Fields, South (TAS)
Lettuce – Trial 2	Late Nov																		Early May	Southern Fields, South (TAS)
Spinach – Trial 1	Mid Aug																		Mid Nov	Houston's Farms, Cambridge (TAS)
Spinach - Trial 2	Early Nov																		Mid May	Houston's Farms, Cambridge (TAS)
Carrots	Late Oct																		Early July	Greenhill Brothers, Moriarty (TAS)
Broccoli	Late Nov																		Late July	Lake River Farms, Cressy (TAS)

Key

- Equipment Installed
- Crop Planted
- Harvest
- Data Extraction & Conversion
- Analytics – Modelling of Kc analyzed and completed

Methodology (Cont.)

Field Trials – Details

Lettuce

Two Lettuce field trials were completed at the Southern Fields property in Tasmania. Southern Fields was and existing participant of previous Yield trials which was beneficial in leveraging already established relationships and grower understanding of The Yields solution. The first Lettuce trial started in mid May 2017 (when equipment was installed) and ran until late November 2017 (Data conversion and analysis completed). This Included the crop rotation which ran for ~17 weeks from the 14th June to the 5th October. After completion of the first trial sensing equipment was then reinstalled in a second crop rotation in a different block on the same farm. This gave an opportunity to capture second data set for use in the analytics. Equipment was installed at the second site in October 2017 with data conversion and analysis being completed in March 2018.

Spinach

As with the Lettuce trials, two crop rotations were completed for Spinach. Both were undertaken at Houston Brothers farm in Cambridge Tasmania this was also an organization The Yield had an established relationship with. Two different sites at the Houston's operation were selected as they had varying growing conditions. The first Spinach trial started in early August 2017 (when equipment was installed) and ran to November of the same year (Data conversion and analysis completed). This Included the crop rotation which ran ~8 weeks from the 12th of September to the 14th of October. Post completion of the first trial sensing equipment was reinstalled in a second crop in a different block on the farm. This gave an opportunity to capture a second data set for use in the analytics. Equipment was installed in November 2017, with data conversion an analysis completed by April 2018 for this trial.

Carrots

The Carrot trial was conducted at Greenhill Brothers farms in Moriarty, Tasmania. The trial started in Mid Oct 2017 (when equipment was installed) and ran to July 2018 (Data conversion and analysis completed). This included the crop rotation which went for 5 months from December 2017 until April of 2018 when the crop reached maturity. Data extraction was completed to the crop being harvested as this crop remains in the ground and is dormant over the winter, harvest is completed to align with demand for the crop

Broccoli

The Broccoli trial was conducted at Lake River Farms in Cressy, Tasmania. The trial started in late January 2018 (when equipment was installed) and ran to July 2018 (Data conversion and analysis completed). This included the crop growth cycle which ran for 4 months with planting being completed on the 13th February and harvest in late April, data extraction and analysis was completed post-harvest in July of 2018.

Data Capture

Sensors installed in all of the crop trials above are programmed to take data readings every 15m, over the course the trial period they recorded approximately 8.2 million data points. These data points were then converted for application to the developed data analytics which were built using Metlab. The conversion process was completed by the Data Science team at The Yield with outputs then provided to the QUT research team to apply to the data to analytics. For the trials (Carrots) a camera was also installed as a way to verify the growth stage of the crop.

In regard to the NDVi component of the trial, IrriSat data (developed by CSIRO) was used. This is a freely available source of information and so served as the most logical point of reference to estimate Kc from NDVI readings (As appose to the other bands). An image of the site is captured every 8 days (as the satellite images become available) however in the Broccoli trial due to consecutive days of cloud cover, a data gap of 24 days was experienced. This is one of the limitations with using NDVi from low orbiting satellites to estimate Kc on an ongoing basis and gain accurate results.

Methodology (Cont.)

Field Trials – Additional Details

The predominant focus of the field trials was to capture growing condition data sets for conversion and use in the Bayesian based analytics (8.2 million data points). An automatic camera was also installed in the trials to capture photos across the crop cycle to see if this could be used as a reference point to understand when growth stage changes. Whilst this was not built into the Bayesian based analytic models as a data input (Not possible in practical application) it provided some additional context of how the crop was growing and to reviewing Kc outputs.

Installation of Equipment – Lettuce Trial

Provided below are examples of the setup of The Yield's sensing equipment.

Example of the in field node which is used to capture rainfall and irrigation data, readings of soil moisture in one of the lettuce field trials.

In field node with automatic camera taking photos across the growth stages.

Installation of the Gateway which is used to communicate the data being captured by the sensors installed to the backend of The Yield solution. Data is uploaded every 15m. Once the trial is complete the Data Science team can complete the extraction process for conversion in the analytics.

Southern Fields trial

Camera was installed at the head of the row and took photos down the crop to identify growth stage changes, examples shown below of crop changing in the second lettuce trial

Outputs

Expand Product Functionality

Develop Free Mobile Application

To drive awareness of advances being made in micro climate technology a mobile app that shows ETo rates today and 3 days into the future was built (Appendix 2). The solution uses publicly available weather data from the closest BOM weather station to give growers a high-level insight into water loss through transpiration. As the data is sourced from local BOM weather stations (as opposed to using in crop sensing technologies) it provides guidance only on crop water changes. As at the 30th September 2018 the free Application had been downloaded over 5,000 times in Australia (The industry or role type of the user is not tracked as part of the download process, only total downloads are available).

Expanding the Functionality of The Yield's solution by adding additional features

Functionality was added to The Yield's software to provide growers with additional value and help drive adoption of the product. This included adding task allocation functionality to the Mobile Application, additional notifications functionality where growers can customize growing condition notifications, and an activities section to track irrigation and spray activities in the system. This was part of The Yield's existing commercial strategy to increase adoption of the product. (Appendix 3)

Develop Data Analytics That Infer Dynamic Kc based on Bayesian Estimation Techniques

Literature Review

In the first instance a review of available literature was completed to help inform the program on:

- The rationale, model structures, and models for crop evapotranspiration coefficients (Supplementary Report 1)
- Factors affecting the adoption of irrigation tools in commercial horticulture production environments. This was completed to provide situational awareness of using irrigations tools and how users may respond to using new irrigation tools (Supplementary Report 2)
- The landscape of precision agriculture and how this is changing to understand the opportunity associated with irrigation tool functionality (Supplementary Report 2)

Development and testing of data analytics for the inference of dynamic ETc

A major component of the program was the development of data analytics that can be used to infer ETc using dynamic Kc coefficients. Analytics were developed by the Queensland University of Technology (QUT) by researching the approach (Supplementary report 3,4 & 5). Outputs from this includes intellectual property in the form of a series of detailed reports which articulate the techniques undertaken to build the analytics and the associated algorithms that are included.

Production of KC curves using the developed analytics

Outputs from the algorithms in the form of Kc curves from the crops being modelled (Supplementary report 6,7,8 & 9).

Complete Field Trials in Local Growing Conditions and Apply Data to Develop Analytics

Field trials were run for all four crop types in the program. Each trial captured approximately 1.3m data records that were then converted for incorporation into the developed analytics and for use in the NDVI study. Outputs in the form of growing condition data is in-confidence and was supplied to QUT to apply to the analytical modelling (Appendix 4).

Engage Subject Matter Experts (RMCG) from industry to review outputs from the analytics

External industry representatives (RMCG) were engaged to support the approach to overall research program, support the design and setup of the field trials which included placement of sensing equipment at the sites. Also, once data had been converted and applied to the analytics RMCG was included in the review of the outputs and resulting findings.

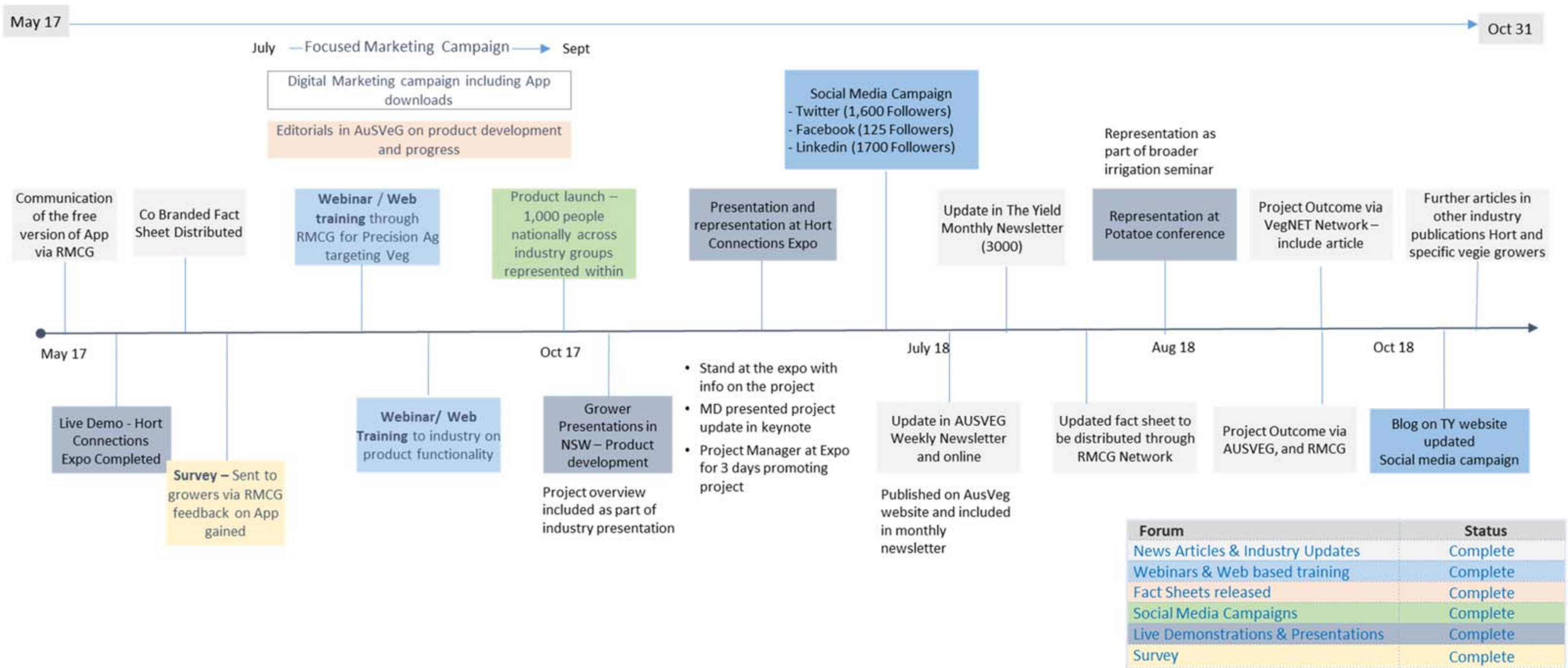
Compare Suitability of the Approaches for use in Commercial Software Application

A decision framework was established as part of the program framework to objectively compare the approaches to calculating and forecasting ETc. The review centered around reviewing the approaches and their applicability for inclusion in a commercially available software solution.

Outputs (Cont.)

Driving awareness though Industry Engagement Activities

An important focus area of the project was to complete regular Industry Engagement activities to inform representatives across the Horticulture sector of the opportunity new micro climate solutions present to growers of irrigated vegetable crops. This included a focus on creating awareness of the research being completed and that industry and Hort Innovation have joined forces to work on the development of new decision support tools for irrigated growers. The industry engagement activities shown below were completed across the course of the project.



Forum	Status
News Articles & Industry Updates	Complete
Webinars & Web based training	Complete
Fact Sheets released	Complete
Social Media Campaigns	Complete
Live Demonstrations & Presentations	Complete
Survey	Complete

Outputs (Cont.)

An example of news articles and media releases that were included in the industry engagement is shown below.

We're working to optimise water use for vegetable growers.

Hort Innovation Australia, The Yield and the Queensland University of Technology have joined forces.

Our current research project is investigating how vegetable growers can use sensing and digital technologies to improve irrigation decision-making.

What is the goal of the project?

Hort Innovation Australia is funding a research project which evaluates different crop coefficient modelling approaches for four key crops: cauliflower, spinach, carrots and lettuce.

The aim is to identify new ways to optimise irrigation, improving the success and sustainability of irrigated farming in Australia.

The project has leveraged the research capabilities of the Queensland University of Technology (QUT) and the commercial expertise of The Yield, an Australian agtech company providing a leading microclimate sensing solution.

What could this research change for growers?

One of the most important calculations that helps growers manage irrigation is the evapotranspiration of a crop (ETc), which measures water that evaporates from both the plants and the land.

Currently, growers rely on their own calculations made from at times unreliable weather data. The rate and level of evapotranspiration depends on the type of crop, its management, growth stage and the weather. For example, water evaporates off a field of spinach much differently than it does a field of cauliflower.

However, new digital technologies make it possible to incorporate dynamic models that automatically adjust for growth stages and biomass production to gain an accurate view of ETc, now and several days in advance.

Where is the project at now?

For the past two years, Hort Innovation, The Yield and QUT have been developing enhanced predictive models that calculate crop water requirements using ETo predictions and dynamically adjusting the crop coefficient (Kc) to specific crops, growth stages and locations.

With analytical models for the four crops now developed and field trials conducted throughout the current growing season, the research project has reached ground truth stage. Researchers at QUT are verifying models by applying local field trial data, with the final report expected in October 2018.

Horticulture Innovation Australia | THE YIELD | QUT Queensland University of Technology

Want to know more?

Contact us at
The Yield
info@theyield.com

Keep an eye out for the full report coming in October 2018!

Monitoring and Evaluation Plan

The Project Monitoring and Evaluation plan was developed during the initiation phase of the project and was primarily focused on monitoring and evaluating how the project contributed to overall goal of optimizing irrigation decision processes in Vegetable businesses, at summary level this included:

- People: Reduce uncertainty, risk and stress, achieve better staff performance;
- Crops: Reduce consequences of crop stress due to lack of or excess water, improved nutrient uptake, resilience and yield potential;
- Business: Quantitative and or qualitative information on savings (e.g. time, resources, inputs) or productivity gains (marketable yield, water use efficiency).

Evaluation level	Comment
People: Reduce uncertainty, risk and stress, save time, get better staff performance	The “Free App” that was developed was used as a way to educate growers of Horticulture crops on how evapotranspiration can be used to guide irrigation decision making. Included in the functionality of this product is forecast ETo rates up to 3 days out. During the launch of the product and promotion of the project there was high levels of uptake as grower awareness increased on both The Yields broader product offering (Sensing+) and the free App Whilst a new approach is not being incorporated into The Yields solution and so won’t serve as the catalyst for driving adoption of this type of solution, the Industry Engagement process was effective in continuing to drive grower understanding of the advances being made in using data-based tools to inform irrigation decisions. Currently there have been 5,000 downloads of the Free Application tool, with regular ongoing use. (Currently we are unable to track the type of user i.e. Growers vs Other as this is included in system analytics)
Crops: Reduce consequences of stress due to lack of or excess water, improved nutrient uptake, resilience and yield potential	
Advanced users can provide qualitative or quantitative information on e.g.: savings, productivity gains, positive environmental impacts, positive outcomes for staff that can be attributed to the APP use	
High level and rapid adoption of new technology (App)	
Decision making process is easier / quicker, Improved decision-making processes support good resource use and management (e.g. savings in time, water, pumping costs; reduced stress).	Survey’s and conversations with growers identified that the App (commercially and with trial participants) is being used by growers (across sectors) to make more informed decisions on their irrigating requirements. Having information from the localized growing conditions is aiding growers by helping them make more effective, data-based decisions. As use of the App spans additional growing seasons understanding of the benefits will improve. As the new approach has not been incorporated into the solution quantifying cost benefits based on improved decision making cannot be completed.
Collated and refined data sets that will enable more informed decision-making frameworks for both industry and individual growers.	
Improved water use efficiencies through the use of water monitoring app tool	The monitoring of water use (Energy Saving tool) was removed from the scope of the project
Improved understanding of user needs support	Interviews and ongoing conversations with Growers participating in the trials were used to capture feedback on how this type of technological could be applied at the operational level to improve irrigation management. Identifying user needs in the operational environment helped facilitate understanding of how the solution could be better structured such that it is more user friendly in practical application

Outcomes & Recommendations

Over the course of the two-year research program data was captured from the Sensing+ equipment installed in local field trials. A major driver for completing these field trials was so data from an Australian based production environment could be captured and applied to the analytics. Up until completion of the trials, testing of the analytics had been from simulated data that was based on literature values of crop water usage**.** Reference evapotranspiration rates (ETo) and soil moisture readings were captured and applied to the analytics to produce Kc curves which form the basis of the approach to infer dynamic ETc in both the Bayesian and NDVI approaches.

What was identified through this process was the that while dynamic modelling of ETc has potential to infer how much water a crop is using in a controlled environment where conditions are static, in the commercial environment the variation and influence of soil characteristics was much more dramatic than originally anticipated. This then diminishes the usability of the solution in practical application. In some instances when considering Kc (and so ETc) as the factor driving water availability it was identified that Kc was not the main driver of water availability. For example, accurately knowing water in (rain + irrigation) and soil characteristics such as drainage explain substantially more variation in soil moisture than Kc. Furthermore, the Kc curves derived from the Bayesian analytics were similar to literature values; it is not clear from the real-world trials that dynamic Kc curves will consistently outperform literature values or if there are circumstances under which the analytics substantially underperform relative to static literature values. The decision framework outlines, for each approach under consideration, how applicable it is in terms of providing a practical solution to the grower.

Decision Criteria	Static Kc (Using FAO Guidelines)	Dynamic Kc curves (QUT)	Kc using NDVI	Commentary
• Supports predictive functionality (core requirement of Sensing+)	High	Low	Low	• Static Kc predictions are available at the first crop cycle. QUT curves require a crop cycle to be completed. NDVI values are available during the first crop cycle, but only reflect point measurements in near real time, not predictions.
• Accommodates variability of soil characteristics on water balance	Med	Low	Low	• Soil characteristics are increasingly apparent as a core driver of crop water use. All of the approaches, if implemented, would allow for a single soil profile only to be factored into the model
• Accommodates variability of crop success i.e. uniformity and coverage	Med	Med	High	• Because NDVI accommodates the whole crop, it has potential to better identify foliage coverage and the average water need; e.g., when crop success is variable from season to season.
• Ease of implementation i.e. complexity and maintenance	High	Low	Med	• In the QUT method, multiple crops cycles would have to be run to create Kc coefficients with high certainty. NDVI processes would have to be built and incorporated.
• Scalable - Supports large clients with multiple sites and crops	Med	High	High	• QUT and NDVI remove the need for growth stage verification. However, for QUT, multiple crop cycles have to be completed to achieve this.
• Robust against data stream drop-outs	High	High	Low	• Because NDVI relies on low orbiting satellites taking images of crops based on GPS locations adverse weather conditions can significantly impact data feeds. This could distort water balance calculations.

Key

HIGH - Closely Aligned	Med - Somewhat Aligned	LOW – Limited aligned

Outcomes & Recommendations (cont.)

The algorithms that were developed for the Bayesian modelling approach (Approach 1) are documented and included as part of the Intellectual Property transfer. If an alternate solution provider wanted to us the analytics that have been developed or if further research was to be undertaken the foundation for the modelling approach has been constructed. If further research was to be undertaken it should consider the following factors:

1. It requires soil moisture probe data. Not all Sensing+ users have soil moisture probes, and users with probes do not have them in every block. That means that The Yield would have to have separate Kc models for blocks with and without probes, which adds expense and complexity.
2. The field trials demonstrated that Kc curves from the analytics solution aligned with literature values. That is evidence that the analytics produce accurate results, but also suggests that they do not provide a substantial improvement over the current static Kc curves used in Sensing+.
3. It is unknown at what point the analytics fail when considering the output of Kc, for example by inputting low quality soil moisture data. The result is that using the solution in Sensing+ would introduce an unknown risk.
4. Kc is not as substantial a driver of soil moisture variation as originally thought. Soil characteristics, such as drainage, substantially affect soil moisture. That was recognized and incorporated into the analytics, but there are likely additional soil characteristics, associate with soil types and profiles, that explain additional variation. That variation is likely greater than the variation explained by dynamic Kc curves. Therefore, more gains in modelling soil moisture accurately could be made by accounting for additional soil characteristics than in implementing the analytics solution. That is a future direction of The Yield’s R&D program.
5. Review by industry experts (RMCG) was an important part of the project. As they were involved in the project inception i.e. trial design and setup, provided input into the ongoing industry engagement process and completed a review of the outputs of the Bayesian modelling approach it is recommended that if the research were to be continued it would be prudent to continue engaging with RMCG representatives to support the process.
6. It was identified through the industry engagement process that there is a wide range in terms of understanding of both using ETc as a method for understanding crop water requirements and the value of using sensing technology to guide on farm irrigation decisions. Whilst growers are enthusiastic about the potential opportunity data-based tools can provide, there is still skepticism on how effectively they can be applied in practical application. As advances in this area continue and awareness of the value they can provide increases, grower adoption of these types of solutions will continue to gain traction

References & Refereed scientific publications

There are no references or scientific publications included in the report.

Intellectual property, commercialisation and confidentiality

An exploitation plan was agreed in regard to project Intellectual Property. This on focused on development of advanced analytical approaches for calculating availability of water to the crop and building the associated models such that they could be incorporated into The Yield's technology solution. Building off this was creation of an associated Commercialisation Plan however this was not executed. As the research progressed it became apparent that applicability of the advanced analytical techniques being developed were not suited to The Yield's software solution.

An IP Register is included (Appendix 5) which summarizes the documents created as part of this process. These documents include details of how the analytics being researched have been constructed. The documents are provided as supplementary to this report.

Appendices

Appendix 1

Evapotranspiration Explained

Achieving the right water balance for crops is a critical factor in optimizing water usage and harvest quality. Around Australia in 2014-15, it is estimated that agricultural businesses used 9 million megaliters of water to irrigate 2.1 million hectares of crops[1]. One of the most effective ways of estimating when and how much to irrigate is to measure evapotranspiration. Evapotranspiration describes the processes of water loss from the land surface to the atmosphere. It measures how much water returns to the air from the ground, through evaporation, and from vegetation, through transpiration. Both processes can be measured to give an understanding of your water deficit or surplus.

By understanding ETo, growers can schedule irrigation with greater accuracy and optimize water performance.

Defining ETo

A baseline measure of evapotranspiration, called ETo, has been set by the UN's Food and Agriculture Organization (FAO). This is essentially a standard calculation based on a sward of grass under the following conditions:

"The evapotranspiration rate from a uniform surface of dense, actively growing grass crop with a uniform height of 0.12 m, an albedo of 0.23, not short of soil water, and representing an expanse of at least 100m of the same or similar grass crop"

The Penman-Monteith equation is recognised as the best method for calculating ETo, which is expressed in millimeters of water loss per unit time (typically per day or per hour).

How ETo and Kc become ETc

While plenty of growers still rely the 'water drum and tape measure' test to evaluate water loss, more are seeking to better understand ETo, and the impact it has on their crops.

Determining ETo in a growers' local area will often confirm what they are seeing in the paddock. But it's important to have hard evidence to inform planning and decision-making.

"The problem is that ETo as a science is quite complex, and most of the places you can go for information don't present data in a meaningful way. For example, the Bureau of Meteorology provides ETo values for around 50 percent of its weather stations around the country. To work out what it means for them, growers have to manually input data values into a spreadsheet, which has to be kept updated every week. Not only is this time consuming, but it's also based on their nearest ETo-enabled weather station, which might be miles away."

Another challenge is that – while useful – ETo is calculated based on a presumed set of optimal conditions, which include an unshaded, grass-covered surface with plenty of water. "The reality is, each crop loses and takes up water differently, so the biggest question for farmers is what about my paddock, for my crop, and my irrigation system?"

The unique rate of ETo for a crop during different growth stages is called a crop coefficient (Kc). This coefficient is multiplied by standard ETo to determine an ETc value.

Factors that influence ETo

Several climate conditions need to be measured to calculate ETo under the Penman-Monteith equation. These include total solar radiation over a given period (a day or an hour), air temperature, relative humidity and atmospheric pressure (for vapor pressure deficit), and wind velocity.

The difference between the atmosphere and the water vapor pressure on an evaporating surface is what drives evaporation. The surrounding air gradually becomes more saturated as evaporation proceeds; however, the process slows down - and can come to a stop - if wet air is not transferred to the atmosphere. The rate at which saturated air is replaced with drier air depends greatly on wind speed. Where the evaporating surface is soil, the degree of shading of the crop canopy and the amount of water available also affect evaporation.

Transpiration involves the vaporization of water contained in plant tissues and the vapor removal to the atmosphere. The rate of transpiration greatly depends on energy supply, vapor pressure gradient and wind, which is why solar radiation, air temperature, air humidity and wind parameters are required to determine it.

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1 Australian Bureau of Statistics: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4618.0

Appendix 2

Develop a free mobile Application to give growers an insight into how ETc can be used to help inform irrigation decisions. (Project Framework ID 1.1)

Overview

The Yield developed a Free Grower's App that shows public weather data from a grower's perspective. It provides insights into the growing conditions that impact the crop, from water balance and rainfall to humidity and wind behaviours.

What does it provide growers?

The intent - Quickly see at a glance:

- TODAY's evapotranspiration (daily water loss), rainfall and water balance on one screen
- TODAY'S temperature, wind speed and direction, and relative humidity
- PAST 7 DAYS' evapotranspiration, rainfall and water balance
- NEXT 7 DAYS' evapotranspiration, rainfall and water balance

What is the Grower experience like?

Easy to use functionality provides growers timely information on their Android or IOS device. Calculations are based on data provided from the nearest BOM weather station

Note: *This was included as part of The Yield's commercial strategy of continuous improvement but was used as an opportunity to drive awareness of the project and future opportunity the research presents.*

First screen in the app showing the water deficit since midnight, ETo and todays rainfall

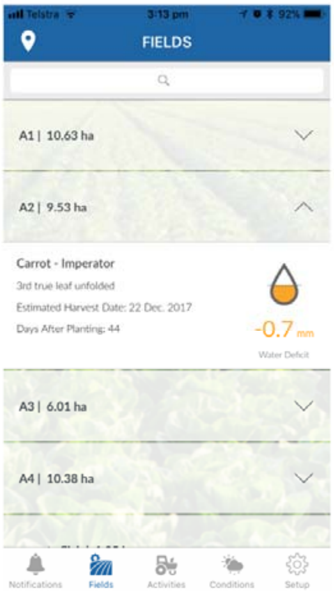
Second screen showing the forecast water deficit, rainfall and rainfall for the next 7 days

Third screen showing the Wind temperature, rainfall and humidity right now. There is also a 7-day forecast

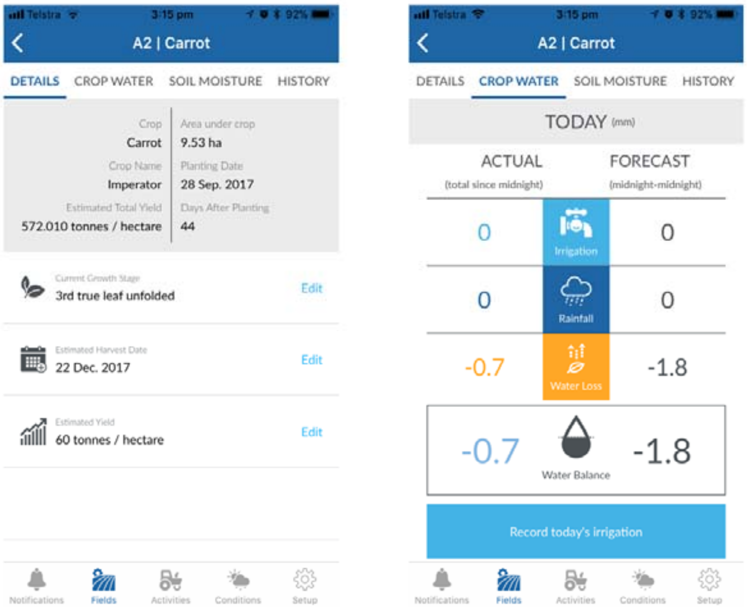
Appendix 3

Expand functionality in The Yield's existing solution (Sensing+) by adding additional features (identified through grower engagement) to expedite the uptake of the solution. (Project Framework ID 1.2)

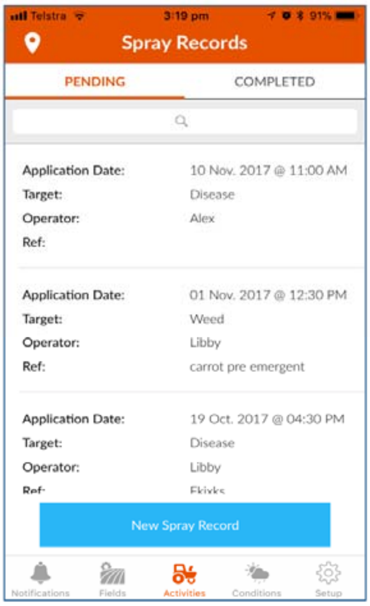
Note: This was included as part of The Yield's commercial strategy of continuous improvement but was used as an opportunity to drive awareness of the project and future opportunity the research presents.



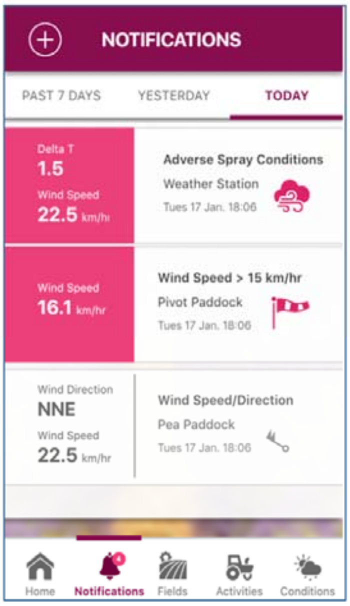
Example – Multifield / Farm view, this example shows Carrot field as part of farm view



Example – Multifield / Farm view, these examples show specific info associated with Carrots as part of Multifield/ Farm functionality



Example of a Task Allocation, this example shows pending spray records



Example of a Customizable Alert, this example shows a wind speed trigger event+

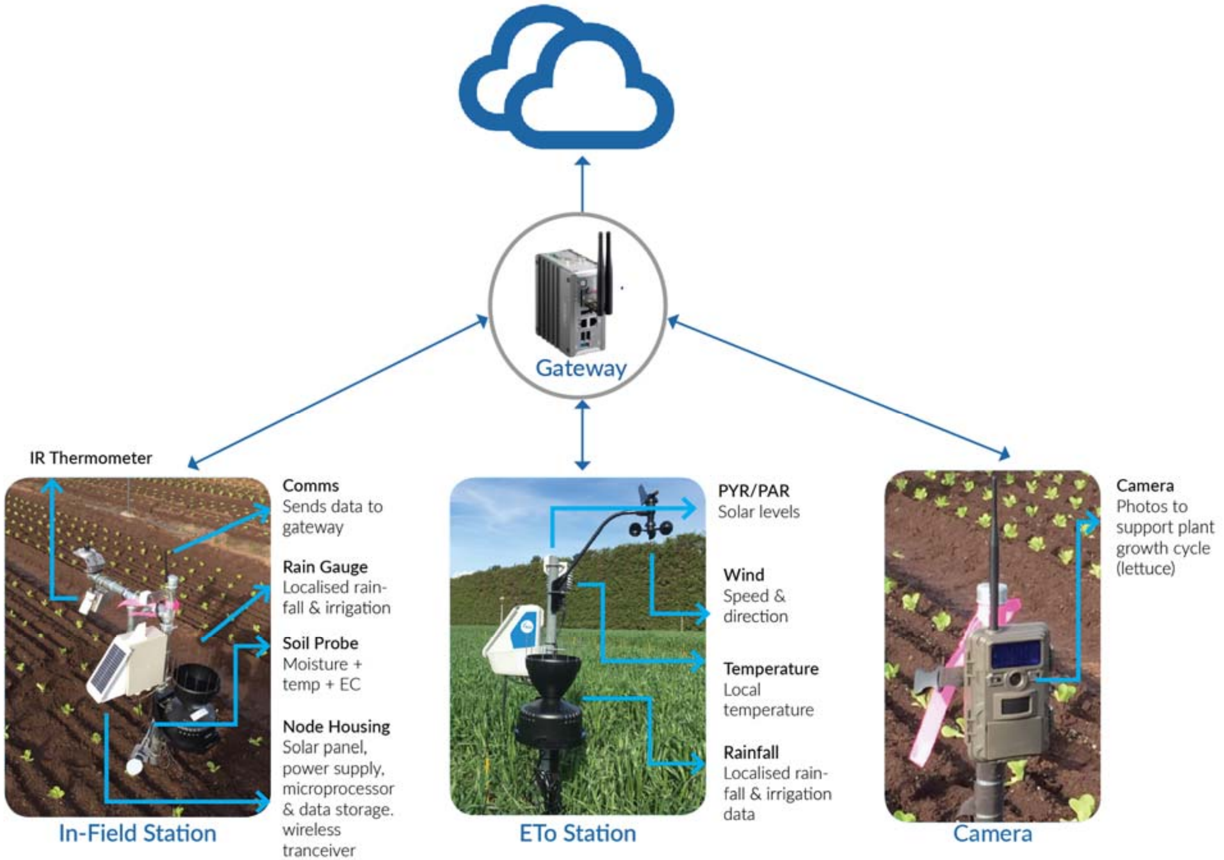
Example of a Customizable Alert, push notification to phone from Sensing +

Appendix 4

Identify four crops which are most prevalent in Australian production and complete in field trials on local farms for the four crops under consideration to capture local Australian crop data (Project Framework ID 4.1)

Field Trial Design

An on-farm field trial was run for each of the crops (Broccoli, Carrots, Spinach and Lettuce). This allowed for data to be captured for crops based on local growing conditions in Australia, and so once applied to the analytics Kc curves produced. All trials were run using the same sensor configuration as shown in diagram 3.



Note:
The field trial sensor configuration was built to align with the requirements of the analytics so the new approach to inferring dynamic Kc would be able to be implemented in practical application.

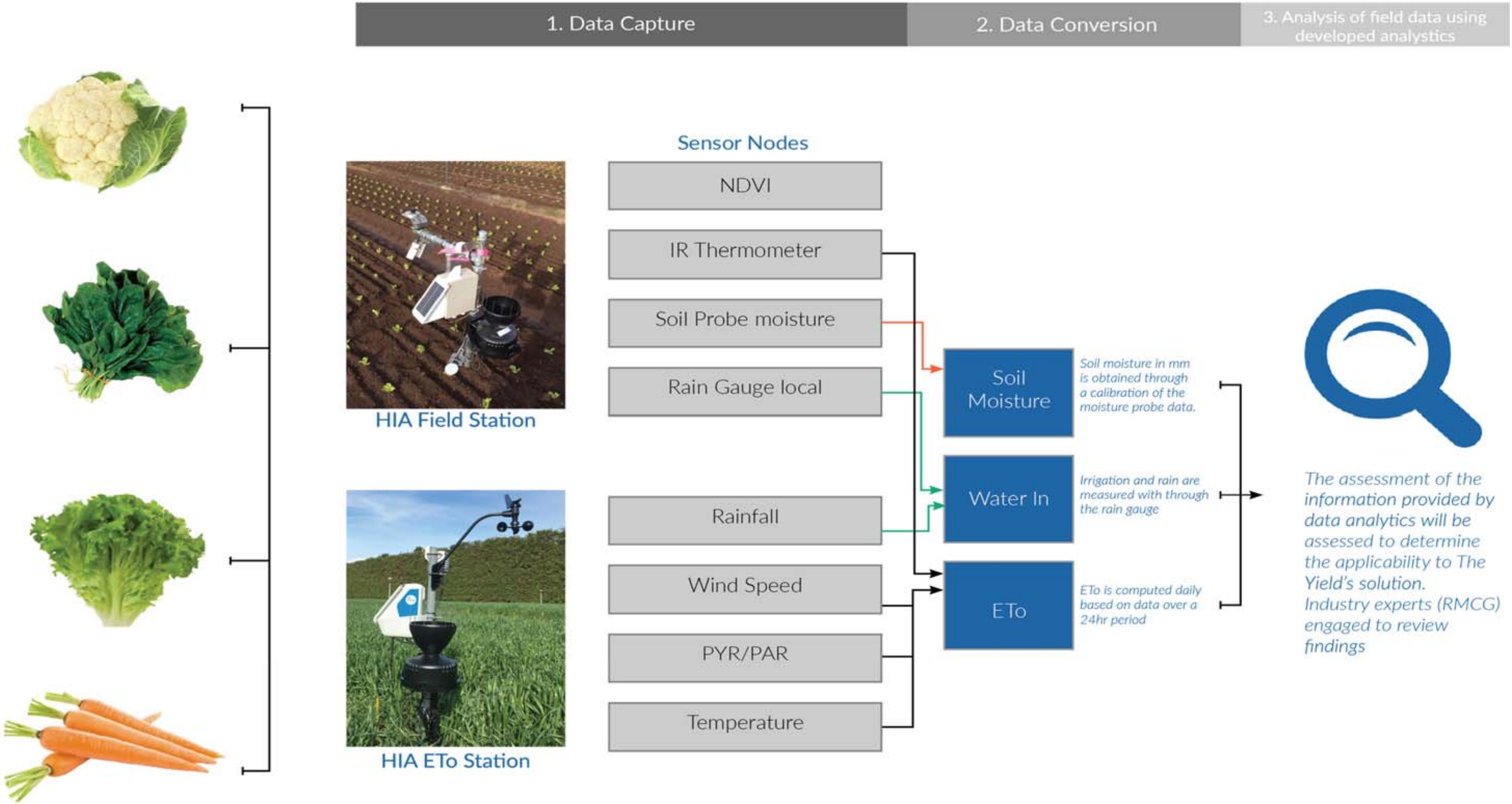
The ETo station depicted to the left was used so that the parameters of ETc (Temp, Humidity, Wind and Solar) were captured

The In Field station was used to capture water into the system (Rainfall and Irrigation) and Soil Moisture was then captured as a reference point.

The Camera was used to provide guidance on what the growth stage of the crop was and when the growth stage changed as a reference point

Appendix 4 (Cont.)

Apply data from field trials to data analytics to produce Kc curves for these locally grown crops and test inference of dynamic ETc using this localized data (Project Framework ID 4.2)



Appendix 5

Intellectual Property Register

PROJECT INTELLECTUAL PROPERTY REGISTER							
No	Date (i.e. date on which details were initially listed and/or modified)	IP Category (e.g. plant variety, gene, formulation, software, thesis, report, data etc)	Specific Description of IP	Nature of IP (e.g. copyright, patent, trade mark, design) and the form in which the IP subsists (ego device, process, formulation, document)	Registration/ application details (if registered) (ego registration number, date of registration and expiry)	Intended purpose and value of the IP that is provided	Contains BGIP and/or TPIP (yes/no) and, if yes, description of the BGIP and TPIP
1	NOVEMBER 2016	REPORT	FINITE-DIMENSIONAL PARAMETRIC MODELS OF CROP EVAPOTRANSPIRATION COEEFICIENT	DOCUMENT	N/A	TECHNICAL REPORT DESCRIBES THE RATIONALE, MODEL STRUCTURES, AND PARTICULAR MODELS FOR CROP EVAPOTRANSPIRATION COEEFICIENT BASED ON FAO1-LIKE DATA	NO
DETAILS OF RESTRICTIONS ON USE OF COMMERCIALISATION OF PROJECT IP (IE RESTRICTIONS ON BGIP AND TPIP SUBSISTING IN PROJECT IP):							
2	FEBRUARY 2017	REPORT	LITERATURE REVIEW ON FACTORS AFFECTING ADOPTION OF IRRIGATION TOOLS	DOCUMENT	N/A	TO UNDERSTAND FACTORS AFFECTING THE ADOPTION OF IRRIGATION TOOLS AT THE OPERATIONAL LEVEL TO INFORM PROJECT APPROACH	YES PRIOR RESEARCH ON THE FACTORS EFFECTING UPTAKE OF IRRIGATION TOOLS
DETAILS OF RESTRICTIONS ON USE OF COMMERCIALISATION OF PROJECT IP:							
3	FEBRUARY 2017	REPORT	METHODOLOGY FOR THE DEVELOPMENT AND ASSESSMENT OF IRRIGATION DATA ANALYTIC	DOCUMENT	N/A	PROVIDES A BACKGROUND PROCESS TO DEVELOP THE DATA ANALYTICS FOR IRRIGATION DECISION MAKING. IT STATES THE	NO

						ASSUMPTIONS USED TO DEVELOP THE ANALYTICS NAMELY, WHAT INFORMATION IS REQUIRED AND FOR WHAT PURPOSE TO PRODUCE THE KC OUTPUTS	
DETAILS OF RESTRICTIONS ON USE OF COMMERCIALISATION OF PROJECT IP:							
4	AUGUST 2017	RECORDING	Overview and Outline of the Irrigation Data Analytics	DOCUMENT	N/A	PROVIDE AN UPDATE AS TO THE STRUCTURE OF THE ANALYTIC MODELS	NO
DETAILS OF RESTRICTIONS ON USE OF COMMERCIALISATION OF PROJECT IP:							
5.	NOVEMBER 2017	REPORT	DATA ANALYTICS FOR INFERENCE OF CROP WATER INTAKE	DOCUMENT	N/A	TECHNICAL REPORT DETAILS THE STRUCTURE OF TWO DATA ANALYTICS FOR THE DYNAMIC INFERENCE OF ETC AND THE KC CURVES OF CROPS BASED ON SOIL-MOISTURE MEASUREMENTS. A LINEAR MODEL BASED ON ETC AND SOIL MOISTURE AS STATES IS CONSIDERED	NO
DETAILS OF RESTRICTIONS ON USE OF COMMERCIALISATION OF PROJECT IP:							
6.	DECEMBER 2017	REPORT	ANALYSIS OF CROP-WATER-USE DATA ANALYTICS FROM TRIAL DATA - LETTUCE AND SPINACH	DOCUMENT	N/A	THIS REPORT DOCUMENTS THE USE OF DATA ANALYTICS FOR CROP-WATER INTAKE WITH DATA FROM TRIALS OF LETTUCE AND SPINACH CROPS FOR THE FIRST CROP TRIALS AND SHOWS THE KC CURVES PRODUCED	NO
7	DECEMBER 17	REPORT	PROCEDURES TO VALIDATE DATA ANALYTICS	DOCUMENT	N/A	TECHNICAL NOTE DISCUSSES DEFERENT GENERAL PROCEDURES FOR VALIDATING DATA ANALYTICS. THE	NO

						CONTEXT WITHIN WHICH THIS NOTE IS WRITTEN RELATES TO THE DATA ANALYTICS FOR INFERENCE OF CROP EVAPOTRANSPIRATION	
8	APRIIL 2018	REPORT	SUMMARY OF THE OUTPUTS AND APPROACH TO THE DATA ANALYTICS	DOCUMENT	N/A	REPORT DETAILING THE OUTPUTS FROM THE QUT ANALYTICS. THIS INCLUDES OVERVIEW OF DEVELOPMENT OF MATHEMATICAL MODELS FOR CALCULATING CROP-WATER INTAKE AND PRELIMINARY OUTPUTS .	NO
9.	JULY 2018	REPORT	OUTPUTS OF THE ANALYTICS USING CARROT TRIAL DATA	DOCUMENT	N/A	THIS REPORT PRESENTS THE APPLICATION OF CROP-WATER-USE DATA ANALYTICS TO DATA FROM A NEW TRIAL OF CARROT. THE DATA ANALYTICS USED IS AN ALGORITHM DEVELOPED BY QUT	NO
10	AUGUST 2018	REPORT	OUTPUTS OF THE ANALYTICS USING BROCCOLI TRIAL DATA	DOCUMENT	N/A	THIS REPORT PRESENTS THE APPLICATION OF CROP-WATER-USE DATA ANALYTICS TO DATA FROM A NEW TRIAL OF BROCCOLI. THE DATA ANALYTICS USED IS AN ALGORITHM DEVELOPED BY QUT	NO