Enhancing the profitability and value of Class 1 New Zealand onions: Development of technologies for mapping onions at the field scale

Bloomer D, Pishief J, Searle B, Folkers C

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Report for Onions New Zealand: Prepared under MPI SFF Project No. 408098, 2015-2018

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Executive summary

Enhancing the profitability and value of Class 1 New Zealand onions: Development of technologies for mapping onions at the field scale

Bloomer D[1] Pishief J[1], Searle B[2], Folkers C[1]. [1]LandWISE Inc., [2]Plant & Food Research

July 2018

This is a final report for “Enhancing the profitability and value of New Zealand onions”, a 3-year Sustainable Farming Fund project to understand the causes of variability in onion crops and provide industry with tools to monitor, map and quantify variability in yields and crop development. A methodology was developed to map developing crops and collect ground truth data to distinguish areas with different growth. A Management Action Zone (MAZ) concept to aid decision making was developed and tested.

A separate Plant & Food Research Report covers onion bulb variability, implications for expected variation within crops and the contribution various factors make to that variation. Soil compaction, waterlogging and inadequate irrigation were shown to be the key management factors causing greater CV% (more variability) in crops. Additionally, this measure of variability and the major causes are the same, whether measuring variability between individual bulbs or total yield at field scale.

Notably, most of this variability is already expressed by the three-leaf stage. Many key management decisions are taken by the onset of bulbing, so mapping crops in the field can be focused on the three-leaf to seven-leaf period.

In work completed in 2015-16 we demonstrated a close relationship between the percent of green pixels in a camera image and laboratory measurements of leaf mass and leaf area index. Plant & Food Research showed these factors to be strongly related to potential yield. This gave confidence that processed camera imagery can be used to identify areas with likely different yields and to predict the likely yields early in crop development.

We have used a process of field scale GPS referenced image capture and analysis to produce maps of canopy cover. Ground truth sampling within identified zones provides data of population and canopy size contributions to crop differences. We have also sought to relate these maps to plot data collected with stationary image capture and ultimately to the actual crop yield in each plot.

We used the MAZ concept to develop a web-based calculator and used it to guide management practice in a field with good results, thus indicating the potential value for growers.

For further information please contact:
Dan Bloomer
LandWISE Incorporated
21 Ruahapia Rd, RD 10
Hastings 4180
NEW ZEALAND

Tel: +64 21 356 801
Email: dan@landwise.org.nz

1 Background

The aim of the Onions New Zealand Inc. Sustainable Farming Fund project "Enhancing the profitability and value of New Zealand onions" (Project No. 408098) was to understand the causes of variability in onion crops and provide industry with tools to monitor, map and quantify variability in yields and crop development.

This report summarises work over three years in collaboration with Plant and Food Research to identify and measure variability in onions fields. A separate Plant & Food report[1] describes the expected variability between plants and the significance of contributing factors. LandWISE Inc. focused on the development of approaches to map and quantify yield variability at field scale, and the development and use of a web-based tool to understand drivers of variability in a field.

The two work streams were closely linked to draw together data obtained from field mapping and proximal plot sampling with understanding the plant variability and crop modelling. The two streams converge in the technological development of *SmartFarm*, a web-tool to hold and process farmer and agronomist captured data with crop modelling to identify Management Action Zones.

The overall aim is for a decision support process to aid management including better fertiliser prescription, early yield prediction to support packing and marketing preparations and identification of paddock areas that would benefit from remediation such as drainage or improved irrigation.

2 Technologies to Map Onion Crops at Field Scale

Before this project we had shown that a series of GPS-tagged processed images could be used to identify and map areas with different degrees of canopy cover. The image processing and GPS location tagging is encapsulated in a third-party smartphone app, *"CoverMap*" developed and owned by ASL Software Ltd.

Through this project, we mapped onion crops and identified areas of canopy with different amounts of ground cover. We quantified the canopy differences and related them to Canopy Fresh Mass and Canopy Leaf Area Index. We compared the processed optical image approach of *CoverMap* with three other technologies; a tractor-mounted *GreenSeeker* NDVI map, a high-resolution *WorldView2* satellite NDVI image and a UAV mounted *MicaSense* camera providing NDVI and several other indices.

All the resultant maps showed essentially similar results once the onion canopy was well developed. Prior to bulbing, the NDVI maps are confounded by background soil variability. The direct assessment of canopy size or ground cover using image analysis avoids this issue and can detect differences when plants are very small, certainly by 3-leaf stage. Given the crop variability is largely determined by 3-leaf stage, and most crop decisions made by 7-leaf or bulbing, we focused on the processed optical image approach of *CoverMap.*

Images collected at three leaf stage can show different levels of canopy cover. However, at this stage canopy cover percentage is relatively low (typically 1 - 2%) so error can be relatively large. Camera calibration is essential.

While the system is imperfect, indications are that mapping the whole field with a tool such as ASL *CoverMap* is a better way to identify Management Action Zone boundaries that preselecting areas based on scant paddock knowledge.

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[1] Enhancing the profitability and value of Class 1 New Zealand onions—final report. July 2018. PFR SPTS No.16713

2.1 Ground (tractor) based mapping

The *CoverMap* tool (supplied by ASL Software) and a Trimble *GreenSeeker* NDVI sensor (supplied by AgriOptics Ltd) were used to map the crop in its very early stages. Both sensors were connected to high accuracy GPS to get measurements located with sub-metre accuracy, importantly within a single onion bed. All equipment was mounted on a small farm tractor (Figure 1).

Figure 1 Canopy Sensors and GPS mounted on front of tractor

The first maps produced show measurements are accurately located is observable. Initially the GPS was off-centre, so alternate passes show closer together and further apart (Figure 2).

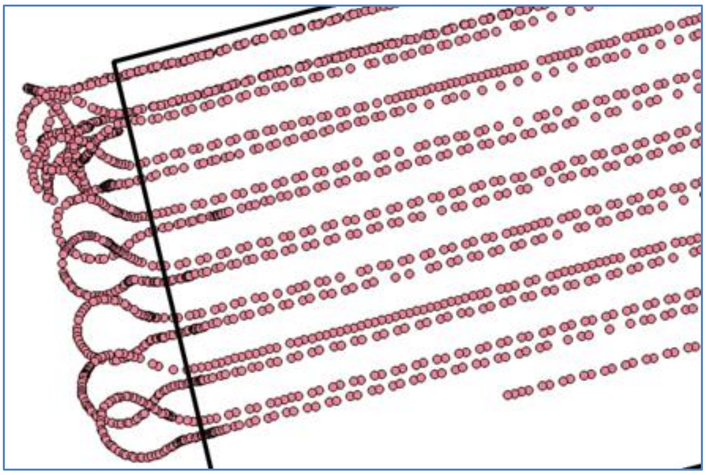

Figure 2 Map showing GPS location for each sensor reading is correctly recorded along the bed but offset due to tractor configuration.

2.1.1 CoverMap: GPS tagged processed images

The iPhone crop canopy assessment tool, *CoverMap* made by ASL Agricultural software was the primary technology used. The basis for the tool is processing camera images of the crop to identify and count the number of green pixels. This can be done in several ways and *CoverMap* has undergone some revisions since 2014. The percentage of green pixels defines the percentage ground cover of the crop sample. The result is logged against a GPS position enabling maps to be prepared.

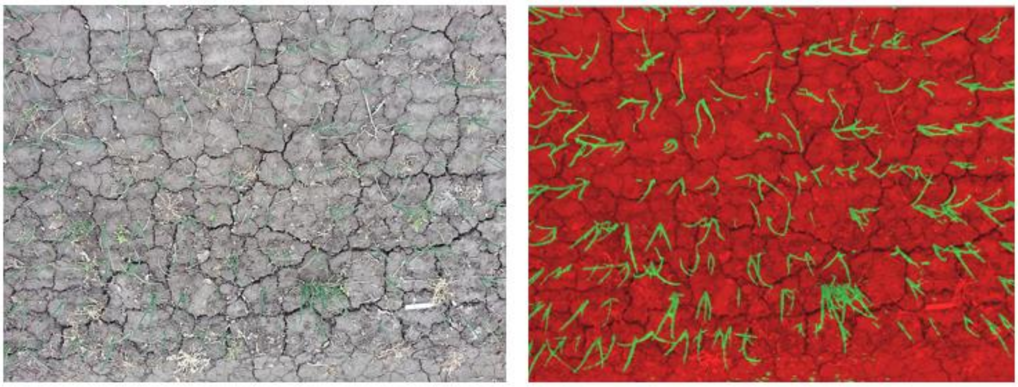

Figure 3 A smartphone camera picture (left) and the subsequent processed image identifying green pixels (right) enables percentage ground cover to be determined

Our trials show this method can capture information as early as two-leaf stage both by hand and automatically from a tractor mounted smartphone. Generally, we recommend first mapping at three-leaf stage because crop variation is evident by this stage. That means plants will be within a range and smaller, slower emerging plants can be a leaf behind those developing at potential rates.

CoverMap is an optical system subject to influence of light, so calibration is essential.

2.1.2 GreenSeeker: GPS tagged reflectance measurements

GreenSeeker is an active sensor; it has its own light source to help minimise the effect of changing light such as sun elevation or intermittent cloud cover. The *GreenSeeker* system emits brief bursts of red and infrared light, and then measures the amount of each type of light that is reflected back at the sensor. A calculated ratio provides a normalised difference vegetative index NDVI.

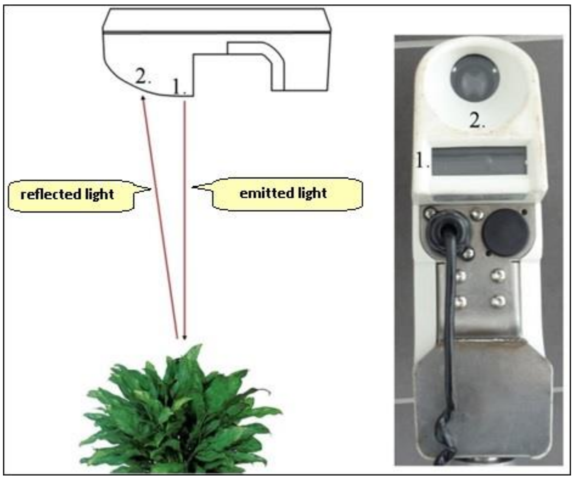

Figure 4 Graphic showing the GreenSeeker Light Source (1), sensor (2) and the operation of data capture[2]

Our trials found the system took a number of readings along a bed and averaged them before logging the result at a given point. This gave a lower than anticipated set of data for later mapping.

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[2] https://www.tankonyvtar.hu/hu/tartalom/tamop412A/2011-0085_precision_farming/ch12s04.html

2.1.3 GreenSeeker versus CoverMap

The difference between early season maps created at the same time from *GreenSeeker* and *CoverMap* data is shown in Figure 5 and Figure 6. The influence on NDVI result of soil background is seen in **Error! Reference source not found.** with the area having a higher level of cover crop residue o bscuring onion canopy differences.

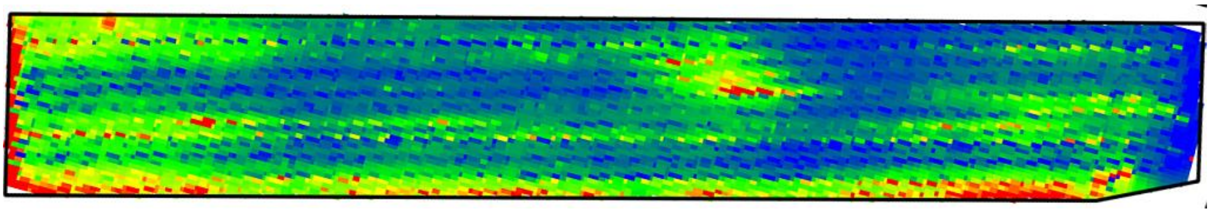


Figure 5 ASL CoverMap map created from Smartphone App data shows variation and some zoning. The effect of char from historic bonfires can be seen right of centre top. Red at left and bottom edges relate to grass on boundaries.

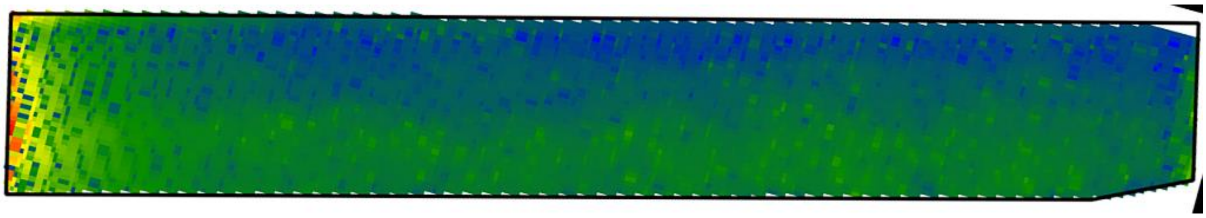


Figure 6 GreenSeeker map created at early three leaf stage still shows soil influence. Higher readings are greener, lower are blue. High readings in lower greener half include oat cover crop residues. The bluer top half had been in mustard cover crop and little residue remained.

We believe the difference is largely due to the nature of the sensing as illustrated in the simulated image Figure 7; the *CoverMap* image processing identifies the green leaf tissue and quantifies the percentage of green pixels. The *GreenSeeker* sensor averages reflectance measurements, represented by red circles, that may or may not include leaf. Soil does have an NDVI response though very low. Early in the crop, there is not enough leaf to outweigh soil reflectance differences.

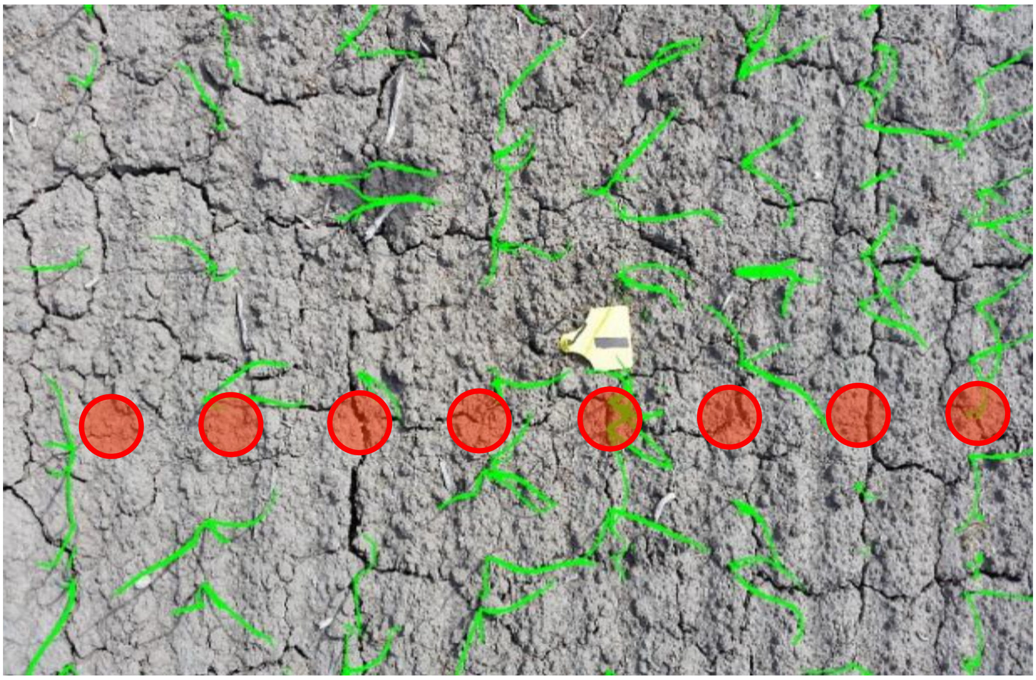


Figure 7 Simulated example of a section of onion bed as measured by CoverMap image analysis (green onion leaves) and GreenSeeker active sensor (red circles)

2.2 Aerial (UAS and satellite) based mapping

2.2.1 Aerial Mapping with UAS mounted MicaSense

UAS (UAV) sensing data supplied by AltusUAS Ltd were collected using a *MicaSense* "*Red Edge*" multi-spectral camera. Many overlapping images were photo-stitched and alternative crop indices determined.

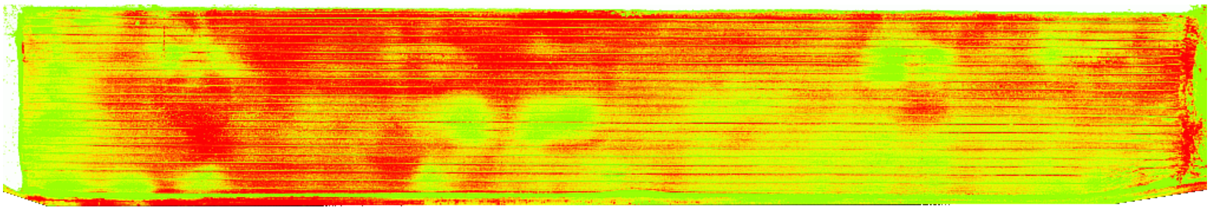


Figure 8 NDVI map of onion field made from MicaSense at early two leaf stage shows soil differences rather than canopy variation

MicaSense records five spectral bands. Using GIS, we can combine different combinations of bands to create different images (Figure 9).

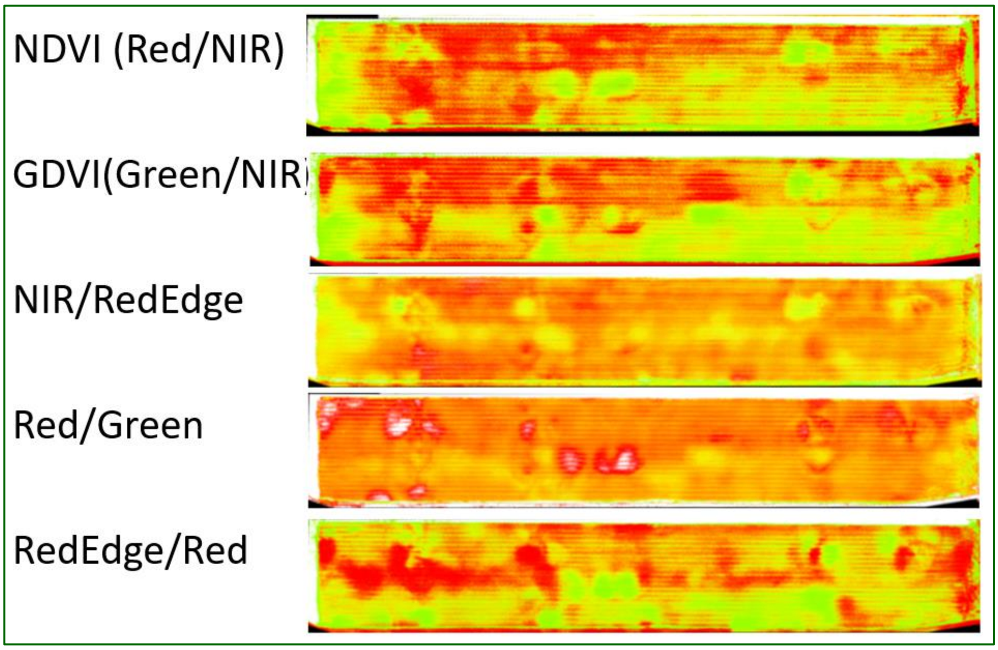
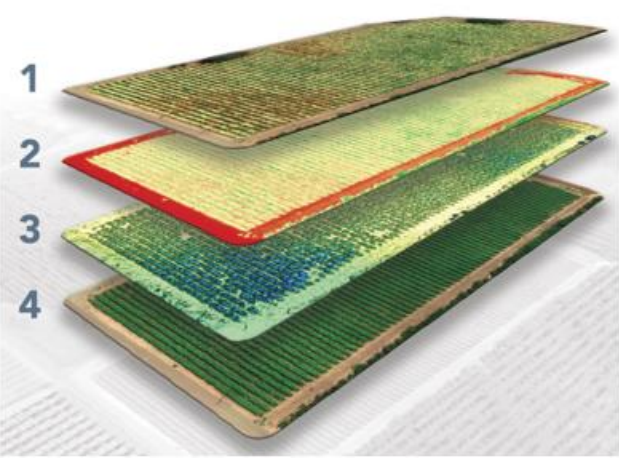


Figure 9 Onion canopy maps generated by calculating indices from different combinations of reflectance bands show canopy differences in different ways.

We were not as part of this project able to fully interpret and compare the maps created using different indices. What is evident is that the two indices show some broadly similar patterns, but there are areas that are significantly different.

The red edge band covers a waveband where plant reflection changes very rapidly. The red-edge index is commonly described as a chlorophyll assessment. It is reported to be sensitive to crop stress, but we did not have data to assess is this was the case. This is an area that may warrant further research. An example graphic of different maps types produced from a UAS with *MicaSense* is shown in Figure 10.



1 ***Chlorophyll Map:*** Red edge spectral band in conjunction with other bands provides a measure of plant vigour and plant health.

2 ***NDVI Layer:*** Compares the reflectance of the red band with that of the near-infrared band.

3 ***Digital Surface Model:*** A enables assessment of surface properties and water flow.

4 ***RGB Image:*** Includes red, green, and blue bands for RGB colour images familiar in standard photography.

Image and legend adapted from MicaSense https://www.micasense.com/rededge-m/

Figure 10 Example image layers produced from MicaSence (TM) camera and support technology. Image © MicaSense via https://www.micasense.com/rededge-m/

2.2.2 Satellite NDVI

In the 2015-16 season, we accessed *WorldView2* satellite imagery. Satellite data has been used for decades to provide NDVI data. In recent years the resolution and availability has been increasing and the cost decreasing. Ordered satellite imaging had a minimum area of 10,000 ha, obviously far greater than the research paddock. Therefore, we met with growers to identify other paddocks of interest in the district to get information from as many as possible.

With onion blocks spread across the Heretaunga Plains only a portion could be included, and we chose the Eastern side of Hastings. These blocks typically have silt or silt loam soils from greywacke alluvium. Blocks to the West are generally on volcanic ash or light pumice soils.

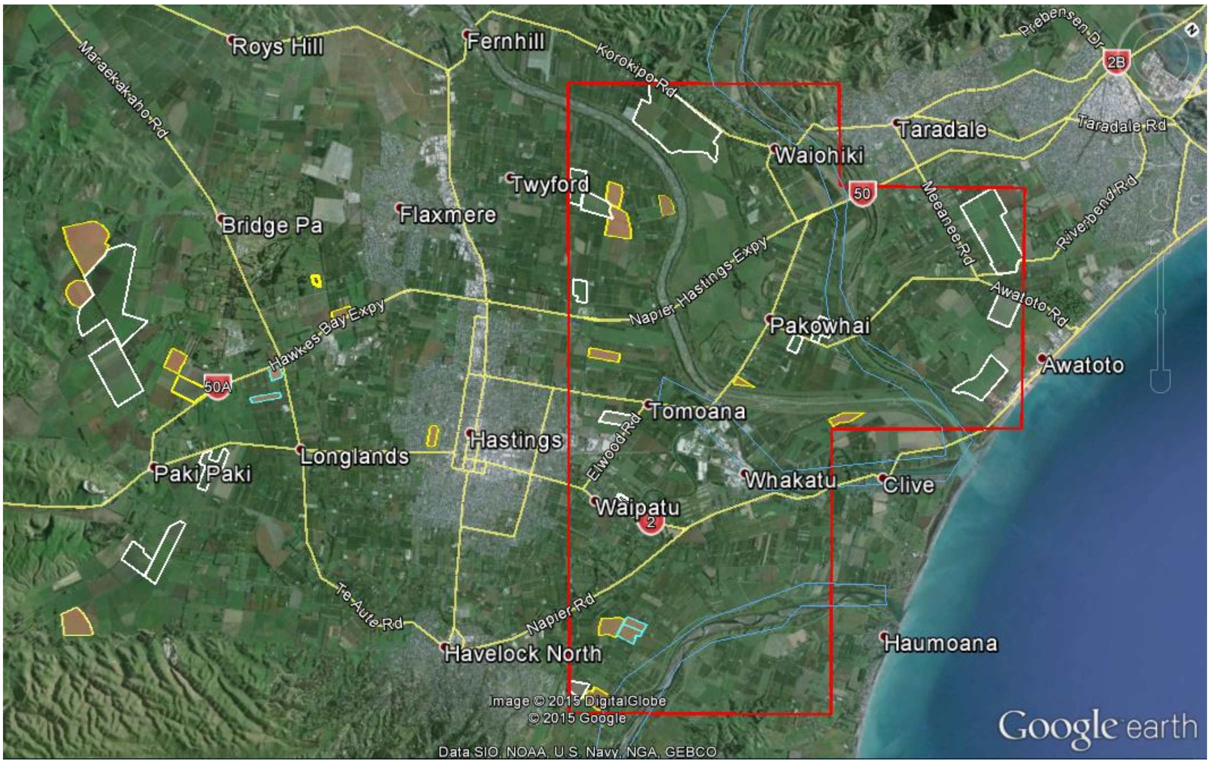


Figure 11 Map of Heretaunga Plains showing a sample of onion paddocks marked as yellow, white and pale green polygons. The satellite imagery obtained is encompassed by the large red polygon. The MicroFarm is under the Waipatu label.

Cloud cover and satellite tracking patterns both influence final capture date(s) and it is possible that multi-date images may be provided. We ordered data for the polygon area shown in Figure 11 with the satellite tasking set near 20 November.

Fresh capture Ortho-Ready Standard Level 2A WorldView-2 imagery with 50cm resolution for panchromatic data and 2m resolution for 4-band multispectral (BGRN) data was acquired on 22 November 2015. This was processed by Australian provider, Geoimage (www.geoimage.com.au).

Imagery provided was contrast-enhanced GeoTIFF format images of the pan-sharpened data:

- Natural colour (NC) – visible red, visible green, and visible blue in RGB
- False colour (FC) – NIR, visible red, and visible green in RGB
- Enhanced natural colour (EnhNC) – visible red, visible green + NIR, and visible blue in RGB

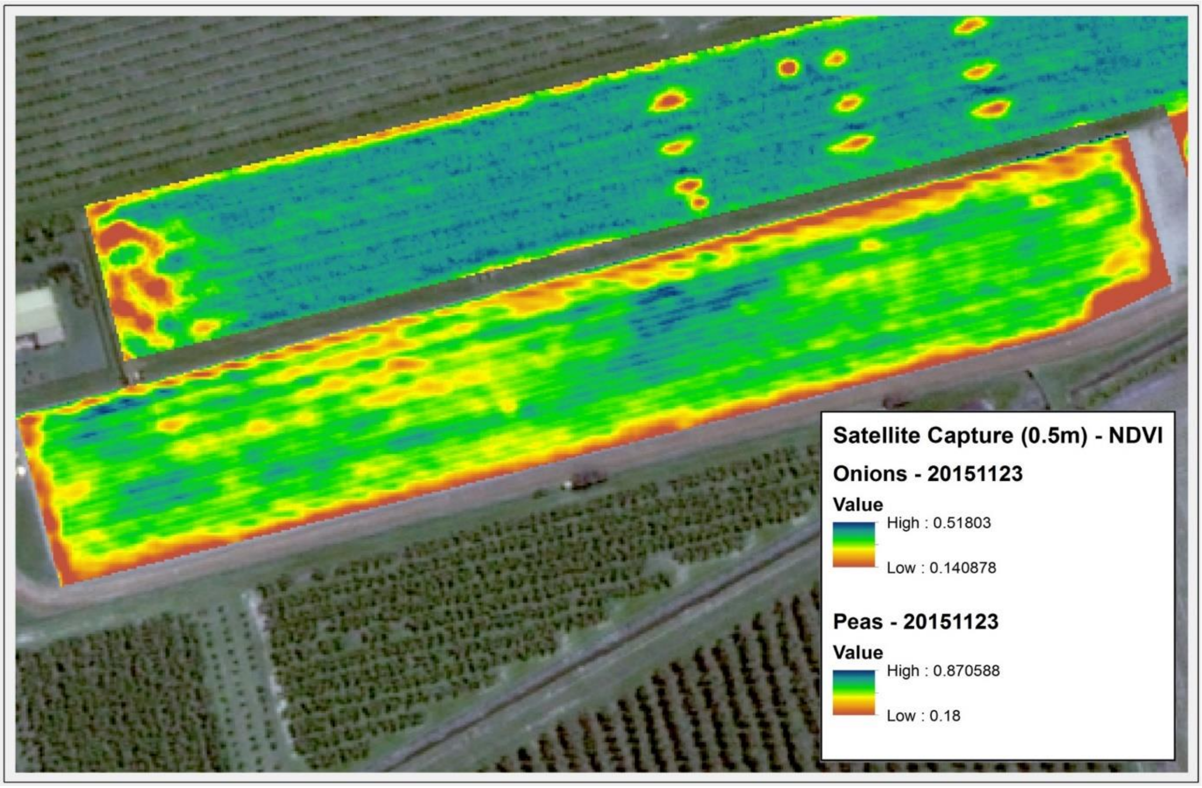


Figure 12 Satellite sourced NDVI map of the MicroFarm created from red and near infrared spectral bands. The onion crop is the lower paddock and the red around the edge is bare soil. Peas are growing in the upper paddock (red areas are bare soil)

The 0.5m resolution provided three pixels across an onion bed; relatively detailed information. This allows beds to be detected as seen in Figure 12 where the pattern of beds and wheel tracks is evident. Note this image is later in the crop and that earlier imagery is likely to be confounded by background soil reflectance, as it is with *GreenSeeker* and UAV *MicaSense* systems.

2.3 Comparing the Technologies

When the four systems are compared, the same general picture shows through but with higher or lower resolution as seen in Figure 13.

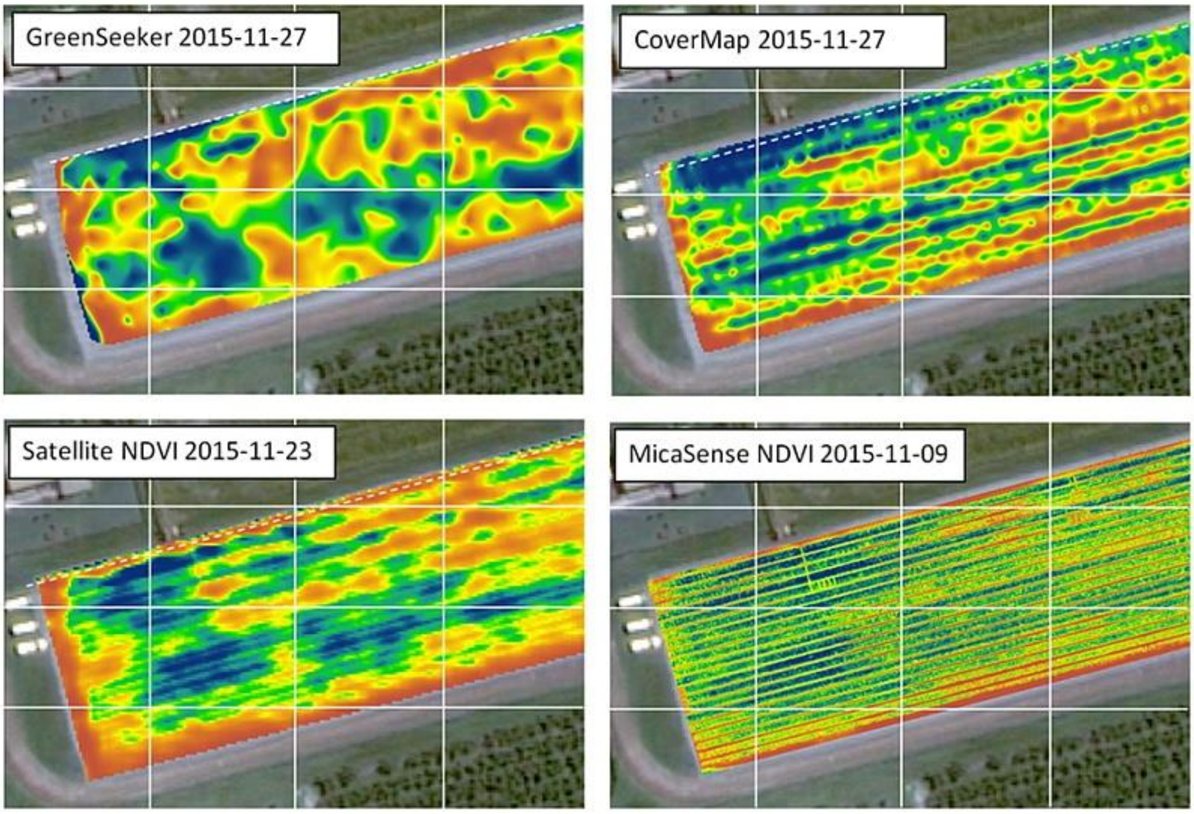


Figure 13 Comparison of canopy variation as mapped using GreenSeeker NDVI, WorldView2 satellite NDVI, MicaSense UAS NDVI and CoverMap Smartphone Ground Cover Percentage

Figure 13 shows a grid imposed over each of the derived maps to help visually compare the resultant variations. In general, they are the same, but the detail shown varies, representing the resolution with which data were captured and the processing methods used to generate maps. This is highlighted in Cell “column 2 row 2”. The *MicaSense* image identifies a set of four research plots from which the onion plant material had been removed, and a foot trail to them from the side of the paddock.

An earlier UAS image (Figure 14) shows this cell in detail. The UAS *MicaSense* imagery had a pixel size of approximately 5 to 7 cm and is not able to be seen in other coarser images.

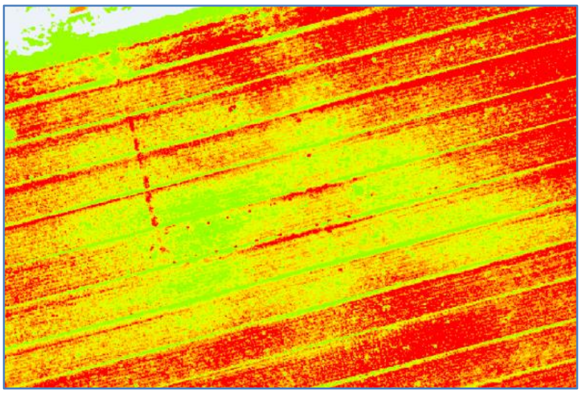


Figure 14 Selection from AltusUAS MicaSense map shows beds, wheel tracks, footprints and plastic eartags used to mark corners of individual sub-plots being sampled.

Individual beds and wheel tracks are readily seen as bands left to right in Figure 14. The red trail from upper to lower are footprints and the small dots along the edge of the centre bed are plastic eartags.

The difference in data point density of the tractor mounted systems (*GreenSeeker* and *CoverMap*) is clearly shown in Figure 15 and Figure 16. In these presentations, each mapped point is shown and colourised to show relative canopy cover with brown being none to low and dark blue the highest cover.

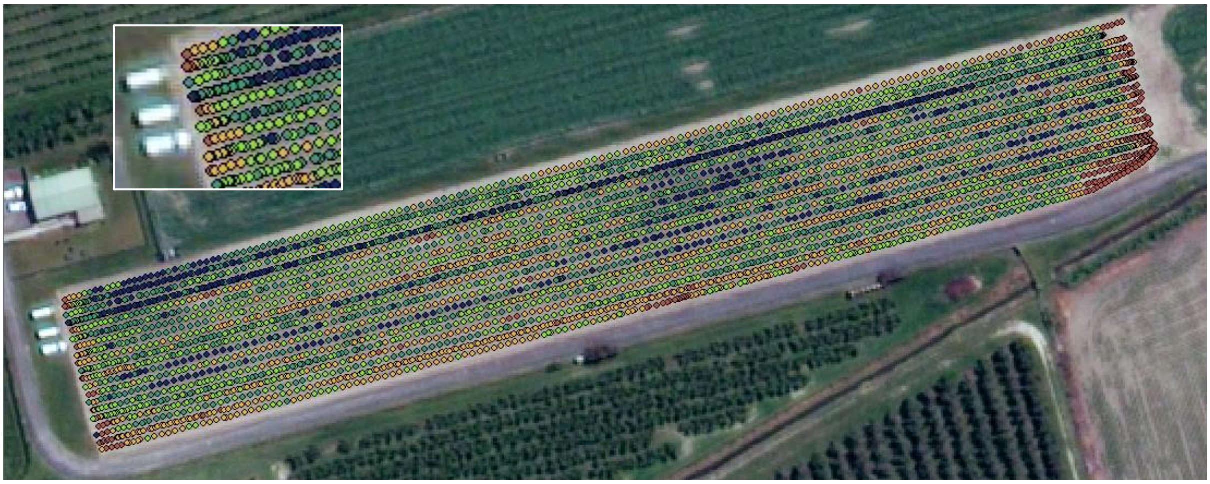


Figure 15 Data points captured using the smartphone application CoverMap with each dot representing a logged point and the colour relating to its relative canopy size.

The insert frame in Figure 15 shows each data point at approximately the scale of the captured photo used in the *CoverMap* system. There is virtually full coverage of the beds and no coverage of the between bed wheel track areas.

Figure 16 Data points captured using the GreenSeeker NDVI Sensor with each dot representing a logged point and the colour relating to its relative canopy size

The insert frame in Figure 16 shows each data point for the *GreenSeeker*. There are far fewer points along the beds; while the sensor makes many readings, it appears to average them over a period and log a single computed value at intervals. As with the *CoverMap* system, the sensor was mounted to avoid coverage of the between-bed wheel track areas.

2.3.1 Advantages and Limitations

Each system offers value, and each has limitations. Note that the images compared in this report are for a well-developed crop. At three to five leaf stage, when growers make critical decisions particularly about fertiliser, onions are hard to see. Using NDVI systems, much variation is hidden by background noise including soil reflectance. Processed optical images that identify the green pixels can differentiate and are useful for decision support.

2.3.1.1 Satellite NDVI

Satellite imagery shows crop variability once a reasonable amount of canopy is present. By this time many decisions have already been made. High resolution satellite images are expensive and minimum areas are too large for most New Zealand uses. The high resolution is needed to get a bed by bed comparison, although 10m images could be useful to inform decisions such as variable rate fertiliser spreading at, for example, 20m bouts.

Capture with current technology is dependent on suitable weather conditions and there was only one day within a 5-week period where Hawke's Bay had completely clear skies at the time the satellite passed. New satellite offerings are changing available resolution, ability to penetrate cloud and the minimum purchase area. Free or very cheap data are becoming available at useful resolution. However, these are still not useful for early in crop development so use for in-season decision making is limited.

2.3.1.2 UAS MicaSense

The UAS system is somewhat weather dependent and high-quality equipment comes at some cost.

Commercial use demands CAA certification, and the imagery collected requires considerable but manageable processing. The detail captured is very high, but probably unnecessarily so - we cannot manage crops at 5cm resolution. The *MicaSense* system has an extra band (red-edge) captured so offers several extra indices which may offer additional crop insights.

The range of UAV options and NDVI cameras is rapidly increasing and costs decreasing. On-line image processing is available, so this technology may soon show value. It may inform in-season irrigation management, disease identification or nutrient issues.

2.3.1.3 GreenSeeker

The *GreenSeeker* is a well-known technology and provides NDVI capture from near ground. It can be set to capture only the crop, not the inter-rows and as it is an active sensor, lighting changes are less likely to affect results. It captured the least density of data points of the systems trialled. Particularly when the plants are small, the system appears to miss the plants and measure the soil. In later season, it may provide useful information about crop nutrient (nitrogen) status.

2.3.1.4 CoverMap

CoverMap is a proprietary application that uses recognised algorithms for image analysis and logs results against a GPS position. It processes images fast and virtually full paddock coverage can be obtained at sensible tractor speeds. It is a passive system relying on ambient light although a light source could be used especially at night. This means calibration is necessary and changing conditions can impact results.

Comparable free apps are available but only do single images. We found they give comparable results and used them for individual plot measurements as described below. This allows a workflow where a professional service does field surveys and map generation, and farmers or agronomists can do zone-based monitoring.

3 Canopy Maps as Tools for Management

We believed that, if the anticipated relationships between canopy cover and yield hold true, they could be used to inform in-season management such as prescribing fertiliser applications. They also assist with tactical questions such as whether investment in paddock drainage is cost effective. Examples are illustrated through number of case studies are presented below.

3.1 Canopy Maps to identify Zones

We surveyed paddocks using *CoverMap* and generated canopy maps by interpolating the data. GIS systems allow data to be presented in many ways. Examples are presented below as Figure 17 and Figure 18.

Figure 17 presents data as a graduated scale with each individual pixel (data point) coloured according to the percentage ground cover.

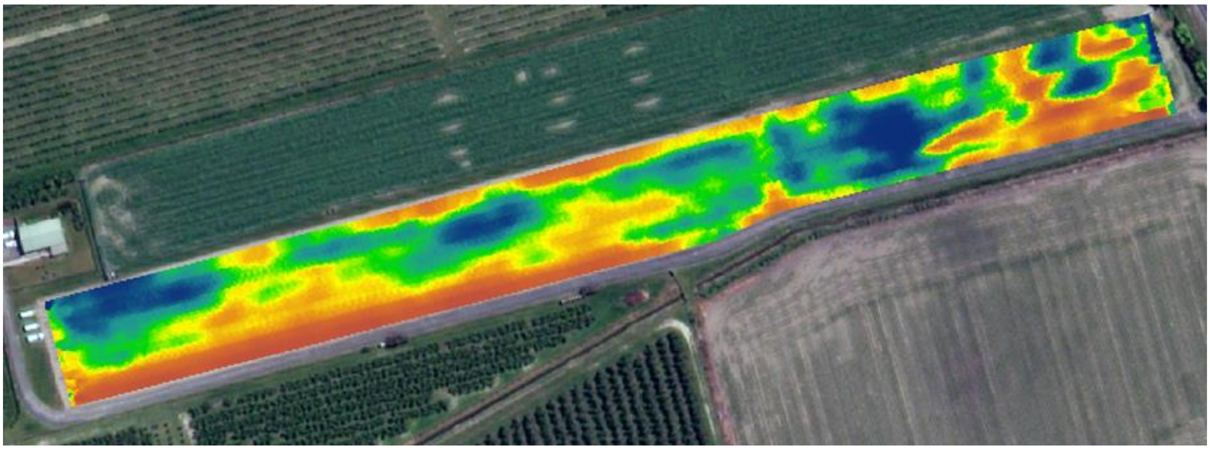


Figure 17 Onion canopy percent canopy cover assessed by CoverMap (Brown low, blue high)

In Figure 18, the canopy cover map is split into five bands using natural breaks. This provides an effective five Management Action Zones based on actual canopy size rather than areas of assumed paddock performance.

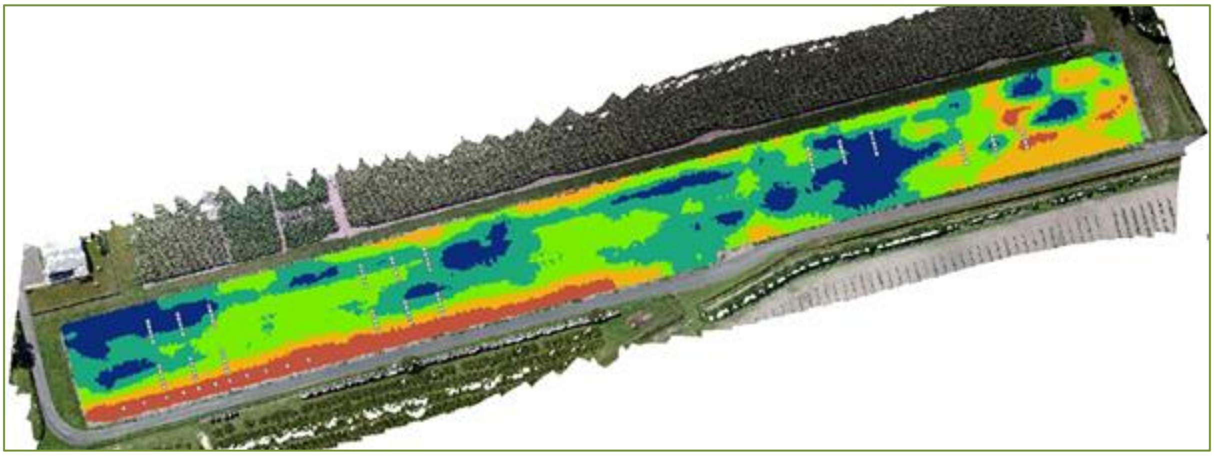


Figure 18. Positions of 90 Management Zone plots and 11 additional Irrigation Stress Zone plots overlaid on ASL CoverMap canopy map made at bulbing

The values shown for any particular pixel in our canopy cover maps (and hence yield maps) are not actual measurements made at that point. Unlike a photograph such as a UAV or satellite image, the CoverMap maps are interpolations (mathematical estimates) using the relatively sparse data points collected and displayed as pixels of a size chosen as part of the process (Figure 19 and Figure 20).

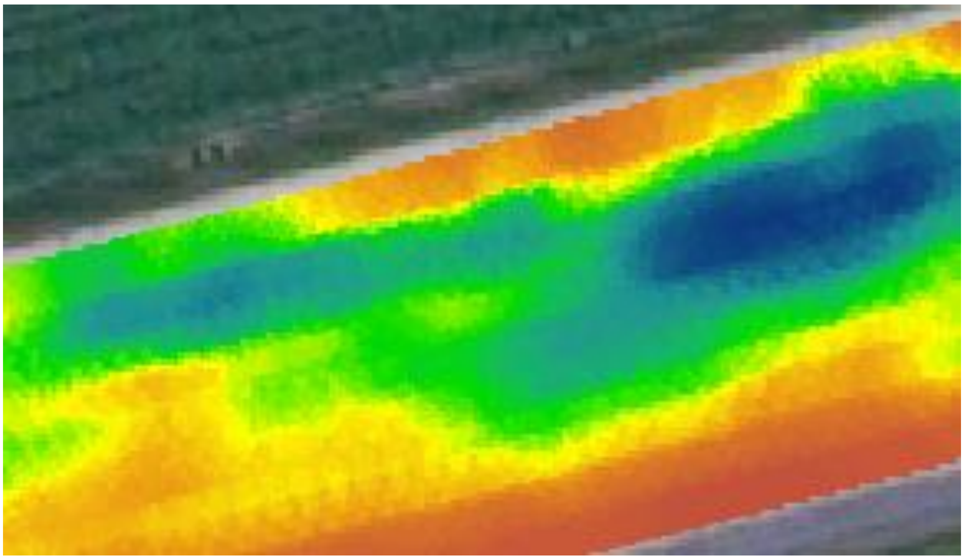


Figure 19. A section of the MicroFarm canopy cover map generated in GIS from interpolations of data collected at points in the field

Figure 20 shows one of the MicroFarm Management Action Zones and its research plots. The 15 rectangles locate each of the 15 measurement plots in the zone and the dots show where ASL *CoverMap* readings were logged.

Each line of dots from left to right represents the centre of an onion bed. The rows in Figure 20 are not equally spaced because our GPS was slightly offset on the offset tractor. The points in each row are the nearest GPS location to where the image was taken for processing with their separation reflecting different processing times and different tractor speeds.

It can be seen in Figure 20 that there were no ASL *CoverMap* readings at all in some plots, one in others and in one case two points.

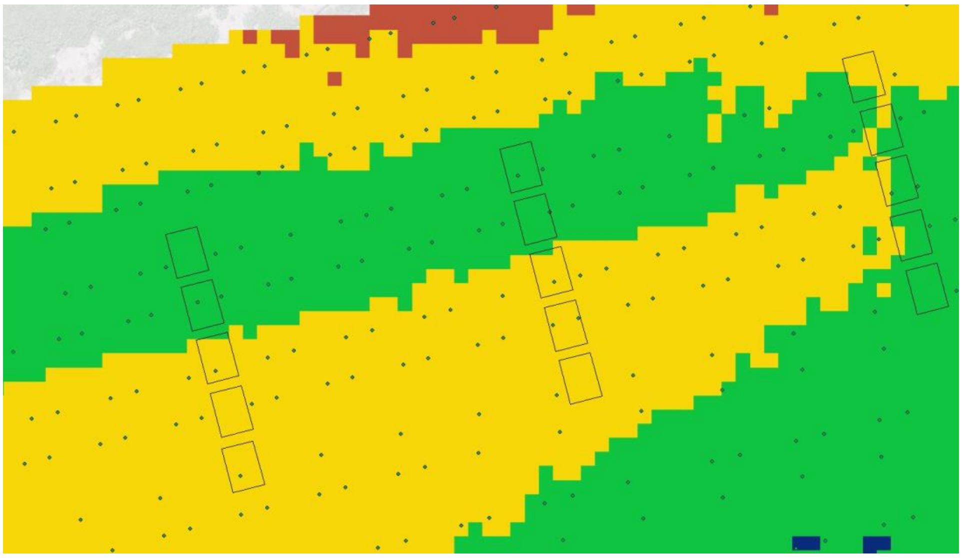


Figure 20. A section of the cover map, split into five cover bands, showing one Management Zone, the location of its 15 sampling plots and the points in the field where ASL *CoverMap* readings were made

3.2 Canopy Maps for Yield Mapping

In 2015/16 we showed that harvest samples showed good relationships with biomass within identified (satellite NDVI) zones. We used the relationships to generate yield maps that agreed reasonably with total known paddock yield.

In 2016/17 we repeated this process using the canopy cover as assessed by *CoverMap* in mid-December. Using the geo-located MicroFarm sample plots we compared actual yields (mass and bulb number) with the canopy maps and generated a postulated actual yield map (Figure 21).

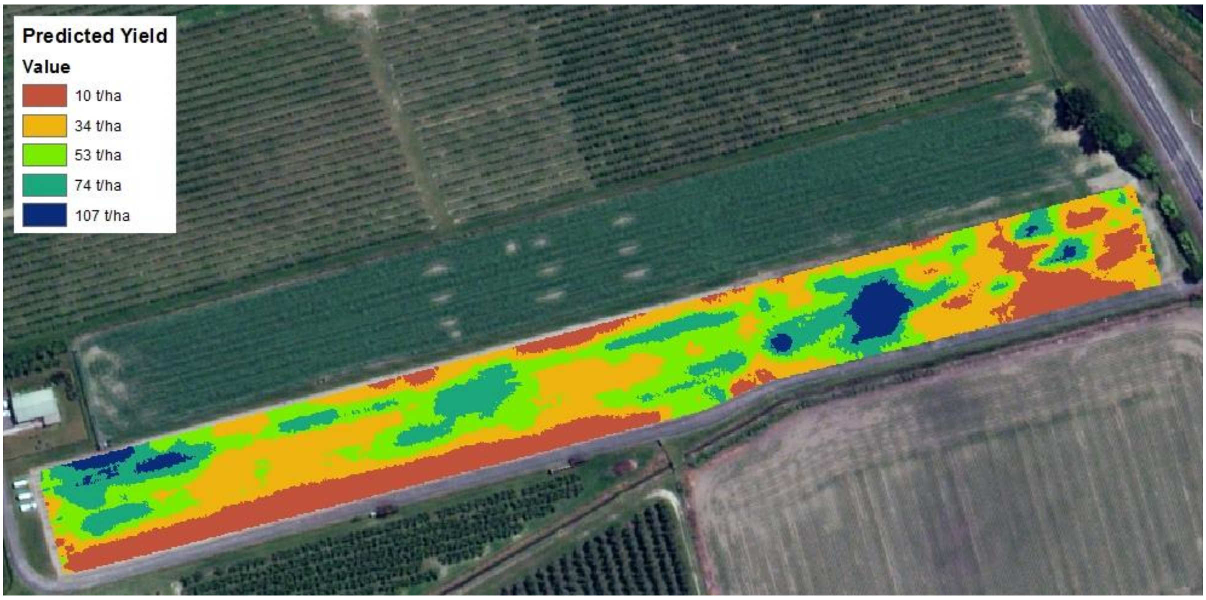


Figure 21 Potential Yield Map generated from canopy cover map created from CoverMap data and relationships between canopy cover and yield used in the On-line Tool at www.smartfarm.nz

Comparisons of the plot weights and canopy covers calculated from the maps showed a reasonable but not very tight relationship (Figure 22).

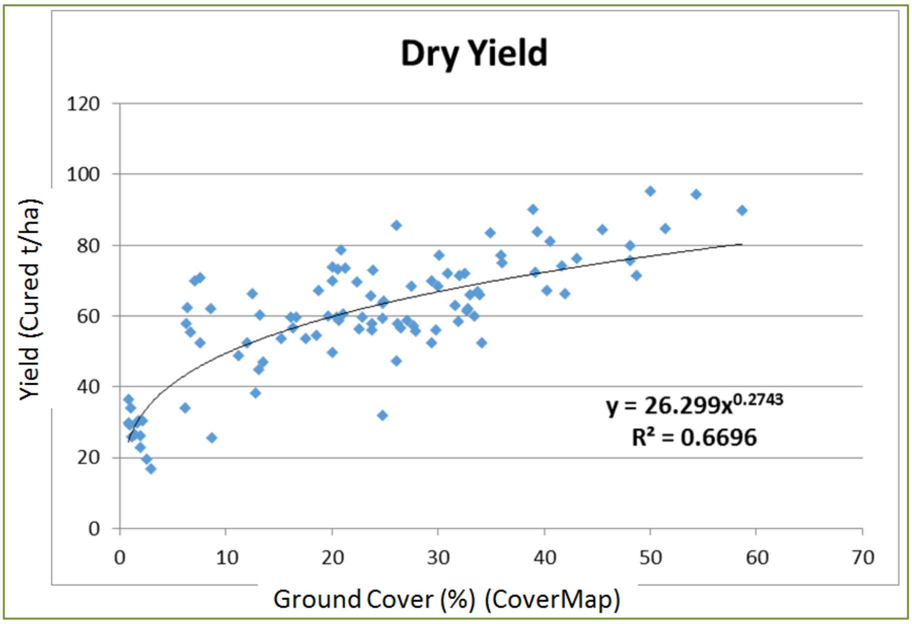


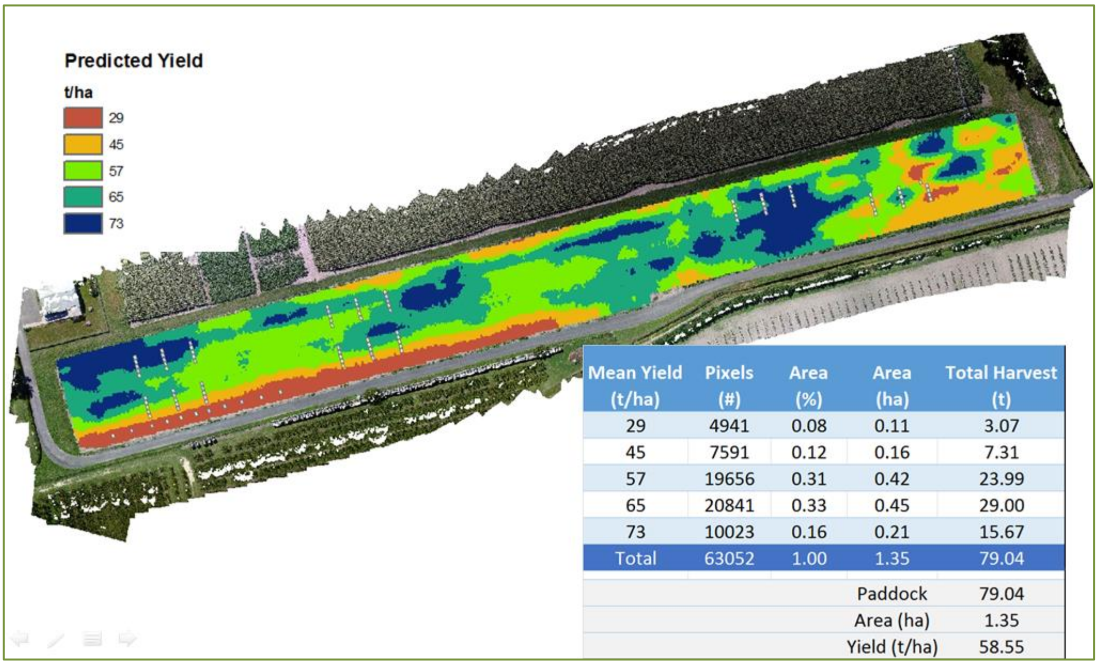
Figure 22. Mean pixel Canopy cover % value versus cure adjusted fresh weights of sample plots at the MicroFarm

Figure 22 includes no direct consideration of plant population. It relates final yield to canopy cover alone, yet still shows a reasonable correlation. Note: The algorithms used in the SmartFarm Onion calculator do include population as it is deemed an important factor.

Further “noise” (variability) is introduced because of the difficulty in extracting actual plot canopy measurements from the prepared canopy cover maps.

Extracting the exact canopy cover percentage for each plot is not possible, because there are not necessarily any plot specific measurements taken by the ASL *CoverMap* tool As described in Section 3.1 and shown in Figure 20. Whereas our detailed plot images are collected manually, with the camera carefully held over each plot in turn, the ASL *CoverMap* system takes and processes imagery at roughly even time increments as the camera is driven across the field. By chance some readings may overlap plots.

To create the final yield map, the trend line formula derived for the Canopy cover % value versus cure adjusted fresh weights data (Figure 19) was applied to all map pixels. This generated a spatial yield assessment map, a total tonnes produced value and a tonnes per hectare value (Figure 23).



Mean Yield (t/ha)	Pixels (#)	Area (%)	Area (ha)	Total Harvest (t)
29	4941	0.08	0.11	3.07
45	7591	0.12	0.16	7.31
57	19656	0.31	0.42	23.99
65	20841	0.33	0.45	29.00
73	10023	0.16	0.21	15.67
Total	63052	1.00	1.35	79.04
			Paddock	79.04
			Area (ha)	1.35
			Yield (t/ha)	58.55

Figure 23. MicroFarm onion yield derived from actual plot hand harvest weights and canopy cover % values determined from an ASL *CoverMap* survey undertaken at bulbing

Figure 23 shows the average yield determined in each of five yield bands. The dark brown zone had an average of 29 t/ha, and the dark blue band had an average of 73 t/ha. The full range is of course much greater, from effectively 0 t/ha to over 100 t/ha.

The total predicted yield for the whole paddock was 79 tonnes. The packhouse received 100.3 bins of which four were weighed on receipt. They ranged from 765kg to 805 kg each suggesting a total yield of about 78.5 tonnes.

In 2017/18 we repeated the process and again found the total paddock yield calculated from maps and plots samples was very close to tonnes trucked from the paddock. The alignment of computer modelled yield and trucked yield does give some confidence and suggests the relationship formula “unders and overs” balance each other.

3.3 Canopy maps for Profit Assessment

The yield map prepared from canopy and harvest data can be further processed to compare profitability across a paddock. If all inputs are the same, the profit is driven by yield.

While our system does not account for quality differences in different areas, it does show general trends as seen in Figure 24. Divided into five bands, the profit ranges from $2,896 to $12,116. The blank area at the top of Figure 24 are where crop was lost due to flooding. This would have negative profit. A similar analysis at the MicroFarm is described below in Section 3.7.

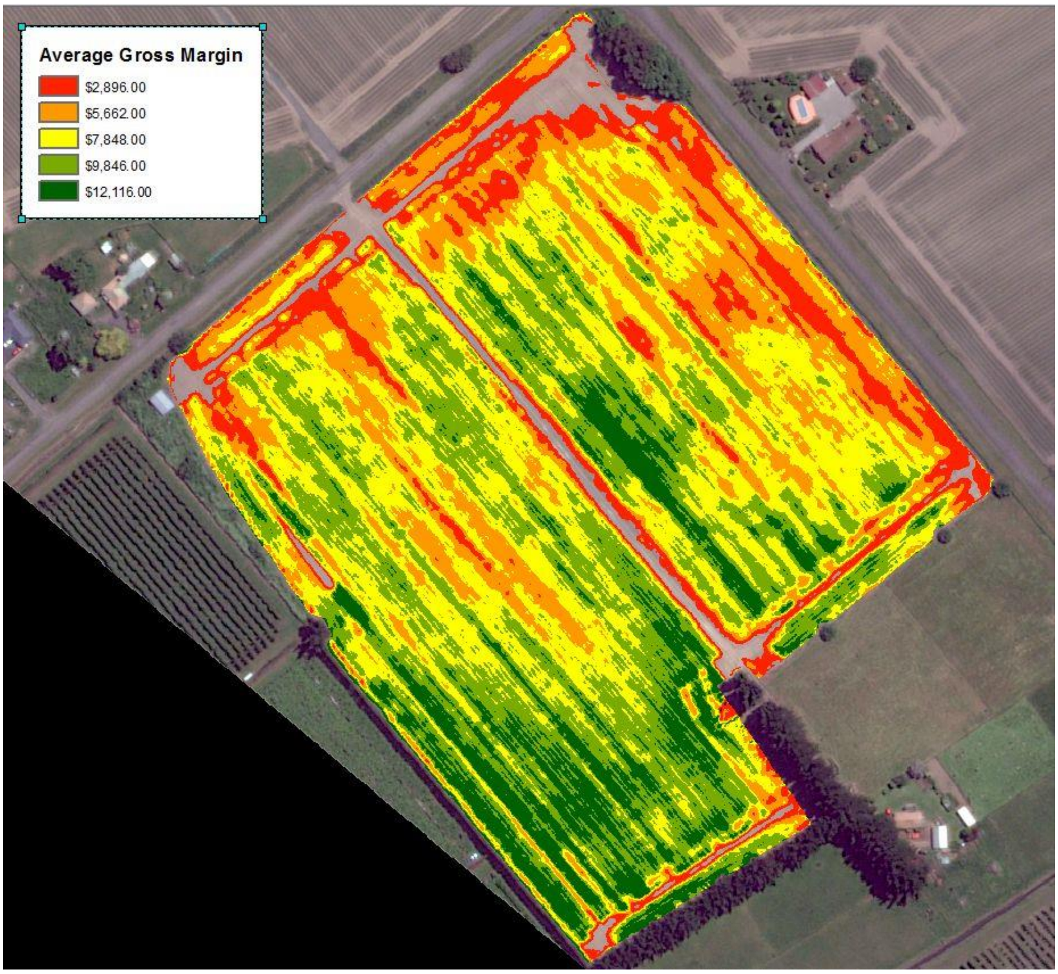


Figure 24 A profit map derived from satellite image NDVI, correlated harvest data and financial information.

3.4 Canopy maps for Decision Making

We remain confident the relationship between a processed image and developing crop size (leaf area index or fresh mass) is sound.

A purpose of the Management Action Zone approach is to enable growers to improve strategic and tactical decision making by providing better information.

We suggest prior knowledge (forecasting) yield should aid tactical decisions such as input application rates (fertiliser) or sales planning according to assessments of likely keeping quality. Spatial knowledge of actual yields may aid strategic decisions such as whether to invest in irrigation upgrades or field drainage.

Drainage limitations are indicated in the case shown in Figure 24. If levelling brought poor performing areas to the upper quartile, it would pay for itself in one season.

3.5 Canopy Maps for Variable Rate Application

We do not yet have good models to drive variable rate fertiliser application in onion crops, so its relevance and utility is unknown. There is some belief that excess nitrogen does reduce storage potential, so applying less to areas with smaller canopy and lower potential yield could have benefit. This is yet to be demonstrated.

There is a limited amount of equipment currently available in the sector that can apply inputs on a truly variable rate basis. Some consideration was given to blocking maps based on machinery working or swath widths.

Using the MicroFarm map as a case study, the resultant maps with 10 m cells and 20 m cells are shown below (Figure 25 and Figure 26).

In Figure 25 the detailed data are shown averaged within 10 m cells and in Figure 26 averaged within 20 m cells. These cells sizes represent potential application bands for equipment spreading a product such as fertiliser on 10 m and 20 m swathes respectively. Clearly, the resultant application patterns are quite different depending on the scale of management unit assumed.

A further complication would be to determine the correct prescription rate – does a farmer use the mean, the minimum, the maximum for each cell, or some level in between?

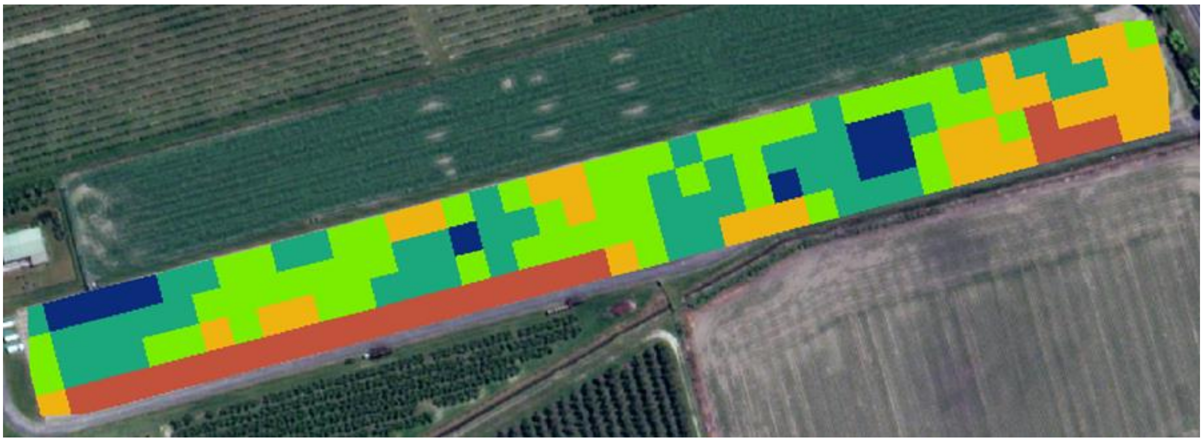


Figure 25 Management zone map created on 10 m cells basis from onion canopy assessed by CoverMap

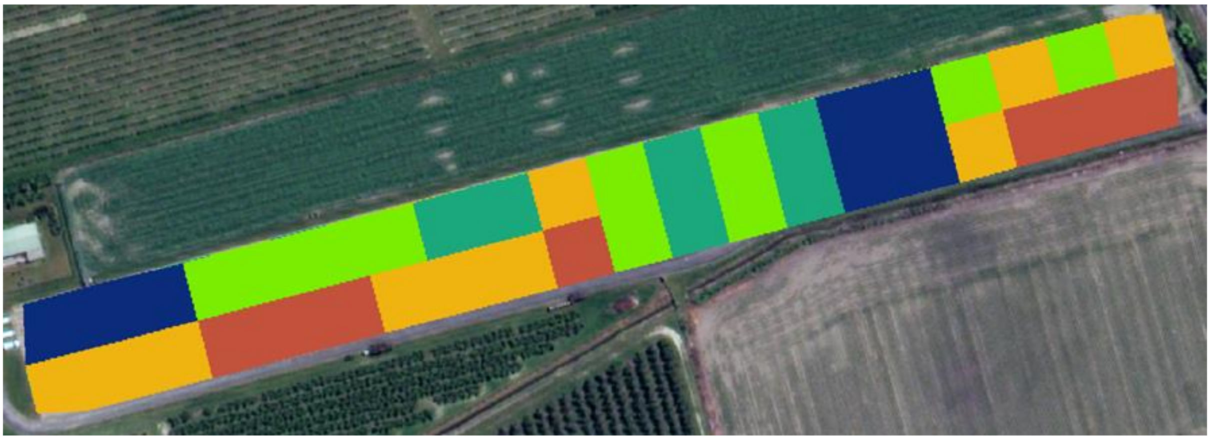


Figure 26 Management zone map created on 20 m cells basis from onion canopy assessed by CoverMap

3.6 Canopy Maps to assess Irrigation Performance

As seen in the UAV photo of the developing crop (Figure 27), three beds have greatly reduced canopy cover. This was caused by a lack of soil moisture, the result of the irrigator not reaching those beds effectively. Even though the irrigator was extended, canopy development remained slower than the rest of the paddock.

Figure 27. A UAV photo of the developing crop shows three beds with greatly reduced canopy cover

The impact of the water stress is shown in Figure 28, which shows the predicted yields at bulbing.

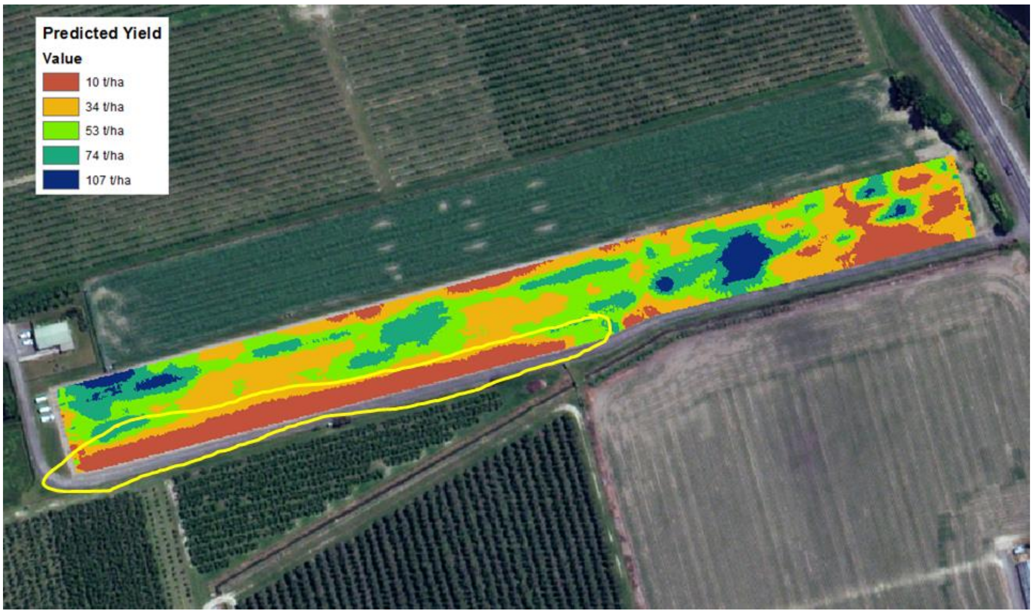


Figure 28. Predicted yield across the crop with the area inadequately irrigated outlined in yellow

At the end of the season simple irrigation soil moisture budgets were prepared for the full and limited irrigation areas. The fully irrigated area (Figure 29) which was monitored weekly by HydroServices neutron probe scheduling service, remained between field capacity and stress point.

A separate budget developed for the area inadequately irrigated at the start of the season shows that it continued to go into water stress throughout January as the initial soil moisture deficit was not made up (Figure 30).

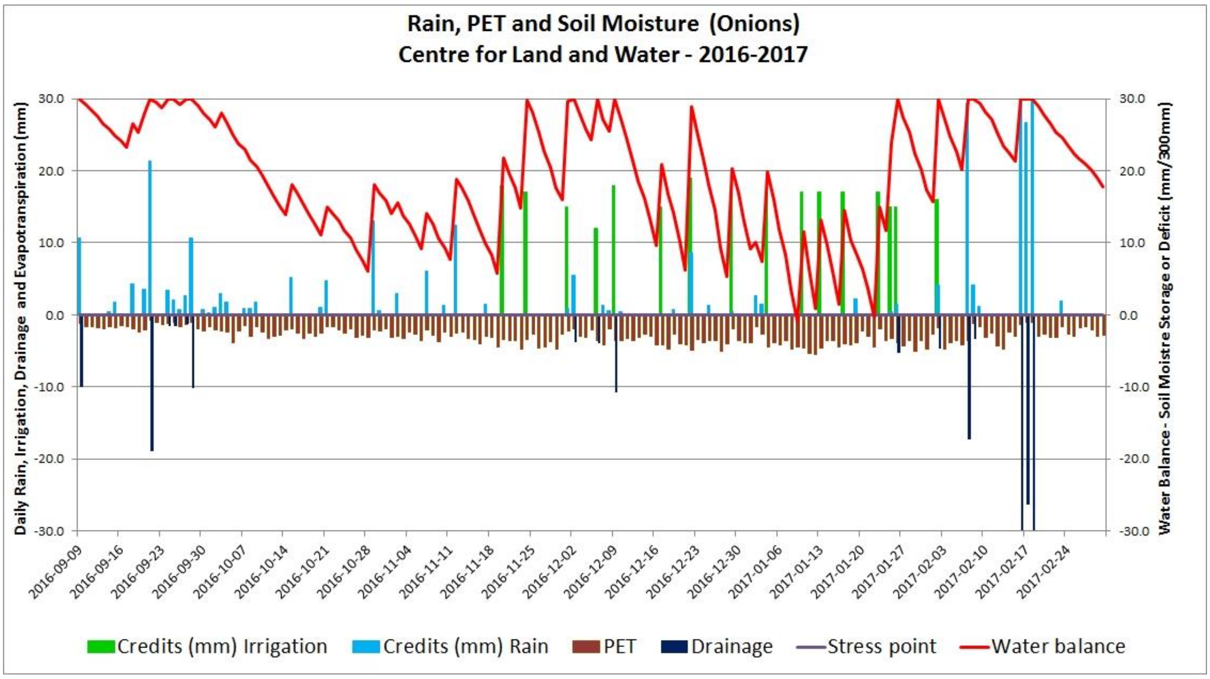


Figure 29. A simple water budget for the main area of the onion crop irrigated correctly through the season shows soil moisture levels were generally maintained between field capacity and stress point.

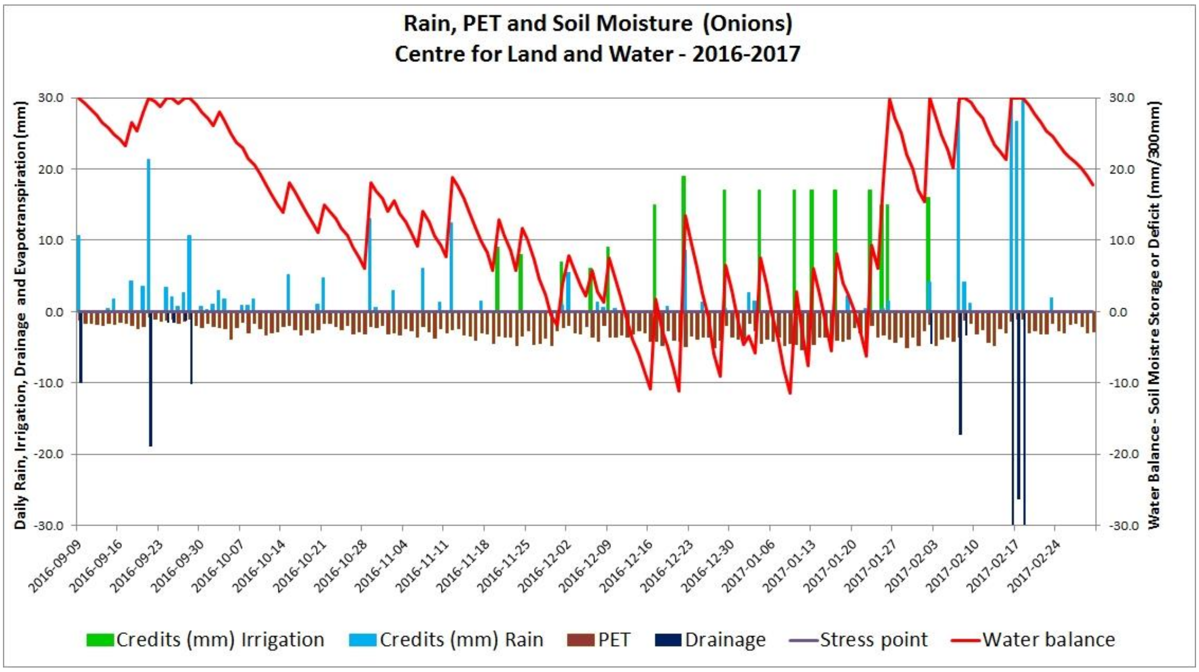


Figure 30. A simple water budget for the area inadequately irrigated at the start of the season shows the crop remained stressed even after the irrigator was extended and full watering applied

We do not have sufficient data to accurately determine a formula for the impact of irrigation stress.

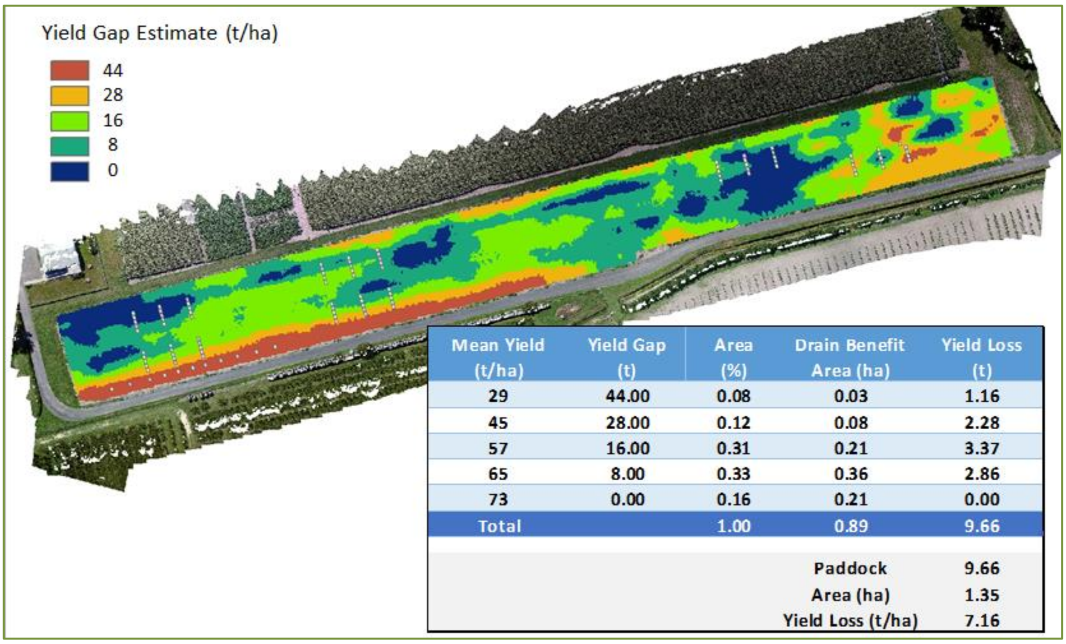
The Potential Soil Moisture Deficit approach may be suitable, and a very rough calculation suggests that yield losses could be as high as 0.4%/mm PSMD. That could mean 2% yield loss if irrigation is one day late in mid-season and 6% if irrigation is two days late. This is significantly higher than other crops, and the value should be treated as generally indicative only.

3.7 Canopy Maps to assess Impact of Drainage

We have been aware of onion crop variability at the MicroFarm since our first year growing. There is a mounting quantity of evidence that site drainage is playing a significant role in this.

Figure 31. Poor site drainage is suspected of playing a significant role in MicroFarm onion crop variability

To assess the possible impact of drainage, we used a Yield Gap approach, comparing the achieved yields in different areas to the mean yield in the best areas. The assumption is that yield in the best areas is not limited by drainage, so is a measure of yield potential. This is shown in Figure 32.



Mean Yield (t/ha)	Yield Gap (t)	Area (%)	Drain Benefit Area (ha)	Yield Loss (t)
29	44.00	0.08	0.03	1.16
45	28.00	0.12	0.08	2.28
57	16.00	0.31	0.21	3.37
65	8.00	0.33	0.36	2.86
73	0.00	0.16	0.21	0.00
Total		1.00	0.89	9.66
			Paddock	9.66
			Area (ha)	1.35
			Yield Loss (t/ha)	7.16

Figure 32. Onion yields at the MicroFarm expressed as t/ha Yield Gap relating the mean yield in each yield band to the mean yield in the highest producing band

The dark brown area in Figure 32 yielded 29 t/ha compared to 73 t/ha in the best area. This gives a potential yield loss or yield gap of 44 t/ha.

When the loss in each yield band is multiplied by the area each band covers, the total tonnes lost is determined. We had reason to believe some of the yield gap was due to factors other than drainage (irrigation for example) so we factored that into our calculations.

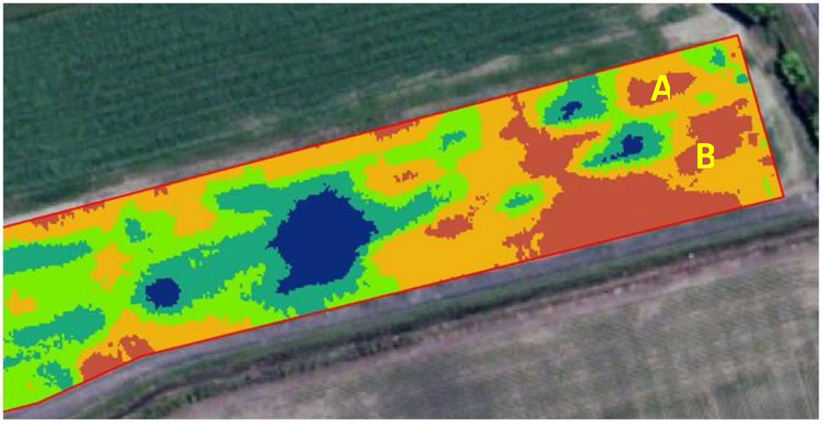
We thus determined that drainage losses were about 9.7 tonnes, or about 12% of yield overall. This allows us to estimate the dollar cost and determine whether money spent improving drainage will be well spent. A simple budget shows that assuming a high earth moving cost (small area, significant topsoil removal and replacement) and an onion price of $450/t, the yield increase would more than cover its costs in the first season.

- Costs
  OptiSurface Cut&Fill design ~ 300m^3/ha
  Earthmoving ~ $3 – 9/m^3
  Cost ~ $2,000/ha
- Returns
  Increased Yield ~ 7 t/ha
  Value ~ $450/t
  Return ~ $3,150/ha
- Benefit
  $1,150/ha

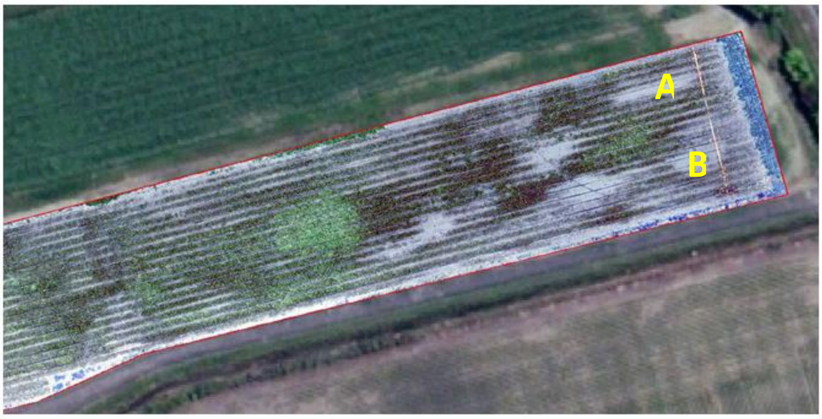
3.8 Canopy Maps to assess quality and storage potential

A comparison of UAV imagery and the interpolated canopy cover maps suggests the areas that grew best reached top down first. Areas that were stressed by excess wetness or by inadequate irrigation reached top down later, and in some cases did not reach top down before lifting.

Figure 33 shows the eastern end of the MicroFarm. The top map is created from the ASL *CoverMap* survey made at bulbing. The bottom image shows the crop as seem in UAV imagery from a flight shown just prior to lifting. Figure 34 shows the crop from ground level some hours later.



Canopy Ground Cover at Bulbing



Canopy Top Town towards Harvest

Figure 33. A comparison of canopy cover at bulbing (above) and top down as the crop nears harvest (below)

The top map shows high canopy cover (a big canopy) in dark blue and low or no canopy cover in dark brown. The bottom map is a false colour image that shows areas of top down as pale green and areas with erect plants as very dark brown. The pale grey areas are bare soil. The blue area at the right is green grass, the orange line to the right of A and B is the irrigator.

While this is relatively obvious to the human eye, we have not been able to automate image analysis to create top down zone maps and display top down progress over time.

Figure 34. A photo of the end of the paddock (right in Figure 33) shows where the canopy has reached top down and where the plants are still vertical. Drowned out areas (arrowed) are surrounded by growing plants

4 Crop Monitoring

4.1 Crop Monitoring Sites

Initial canopy maps do not collect all data required for crop growth modelling so replicated plot measurements are obtained. A process to determine monitoring zones and collect seasonal data was developed. This was tested in 2017-17 and 2017-18 at sites in Auckland, Hawke’s Bay and Canterbury.

At each site, a *CoverMap* crop survey was completed and data emailed from the paddock to Hastings for processing. Canopy maps were prepared and emailed back to the field. Areas where the young crop was larger and smaller were identified as alternative “zones” and replicated sampling plots established in each. Plots were bed width and 0.5 m long.

Plant population, mean leaf number and canopy cover assessments using the free smartphone application *Canopeo* were recorded for each plot at 3 leaf, 5 leaf and bulbing. These data were entered in the SmartFarm on-line calculator and Management Action Zone descriptors and yield predictions generated.

Immediately prior to lifting, each plot was harvested, bulbs counted and weighed. Onions from each of two plots in each zone were left to ground cure and reweighed when the crops were commercially harvested.

Final weights were used to correlate canopy map pixel values with yield, and the relationship used to convert canopy ground cover to tonnes harvested. Results were summed to get overall paddock yield.

4.1.1 Data collection – variations in maturation

The protocol developed recommended surveying at 3-leaf stage, a point at which most variability is already present. When different zones within a crop were investigated it was found that plants in the low ground cover areas also had fewer leaves. It appears that stresses slowing size increase also delay physiological maturation.

Alternatives to leaf counting include using a modelled leaf number calculated from Growing Degree Days GDD. This has been incorporated into the SmartFarm calculator.

4.1.2 Data collection – weed pressure

In several cases, continual wet weather and poor weed control resulted in green slime and weeds covering the trial plots.

The Auckland images were collected on the same date at all three sites, although crop physiological stage was different at each. It was difficult to include the data in the on-line tool which is predicated on physiological stage relationships. Subsequent versions allow for varying leaf numbers to be entered and use in calculations.

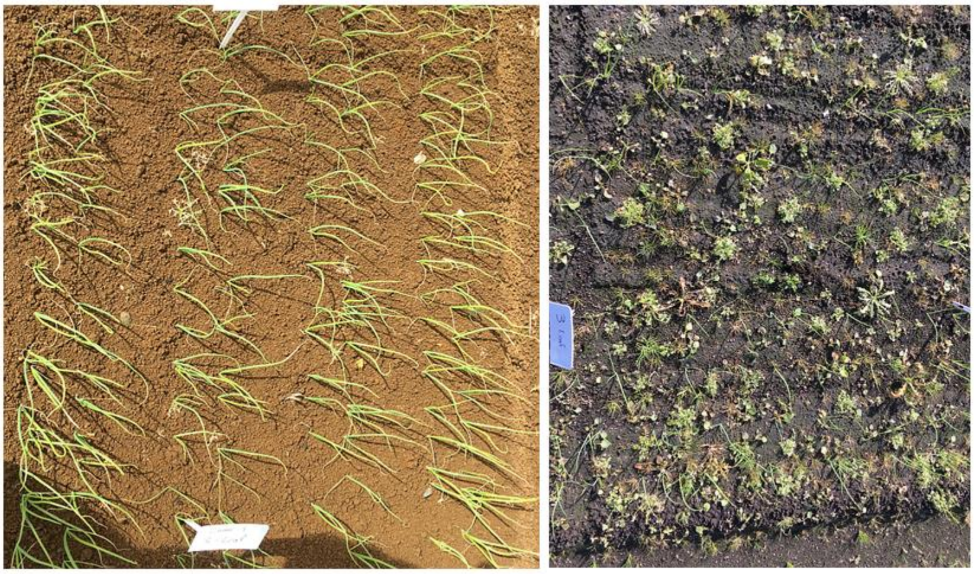


Figure 35. Comparison of a "clean plot" and a "weedy plot" showing onion plants that can be machine identified (clean) and those that cannot be filtered from the background noise (weedy)

4.1.3 Data collection – variations in human performance

Agronomists testing the system provided data of varying quality. This highlighted the need to provide clear directions and support for new users. Although the protocols were documented and provided, the importance of timing, plot condition and image capture were not understood.

Leaf number determination is difficult because first leaves wither and vanish. Even so, some counts were wildly incorrect. The main problem is in estimation of final yield rather than identifying zones that are developing differently. Use of modelled leaf number based on GDD should avoid this important source of error. It also sets “optimal” growth leaf number so should better identify low crop performance when a whole crop is affected.

4.1.4 Collecting harvest data

The action of crop lifting moves bulbs along the crop beds. To maintain data integrity the same bulbs monitored through the season must be counted and weighed at harvest. We manually lift bulbs immediately prior to mechanical lifting and count and weigh each plot. Samples are taken from each zone for ground curing and reweighed when the main crop is harvested.

5 SmartFarm Web-based tool

The *SmartFarm* webtool available at www.smartfarm.co.nz combines Plant & Food Research science and LandWISE field scale monitoring and assessment. While algorithms still require refinement, the tool has been helpful in developing our broader understanding of variability within and between crops.

The tool has capacity for individual farmers to set up their own paddocks and zones and give access to staff or others to enter field data as required. The booklet *"Benchmarking Onion Crops - Protocols for Commercial Farms (V3)"* explains the process for any other users.

As a website it works well, with registration, login and lost password functions performing correctly. Data entry is straightforward and as well as being viewable online, data can be exported in a variety of formats including email, csv and pdf.

We showed Management Action Zones can be identified at 3 leaf and 5 leaf, based on *CoverMap* surveys, processed population counts and smartphone images. However, these early zone definitions do not always agree with later results and early yield estimates have often been low.

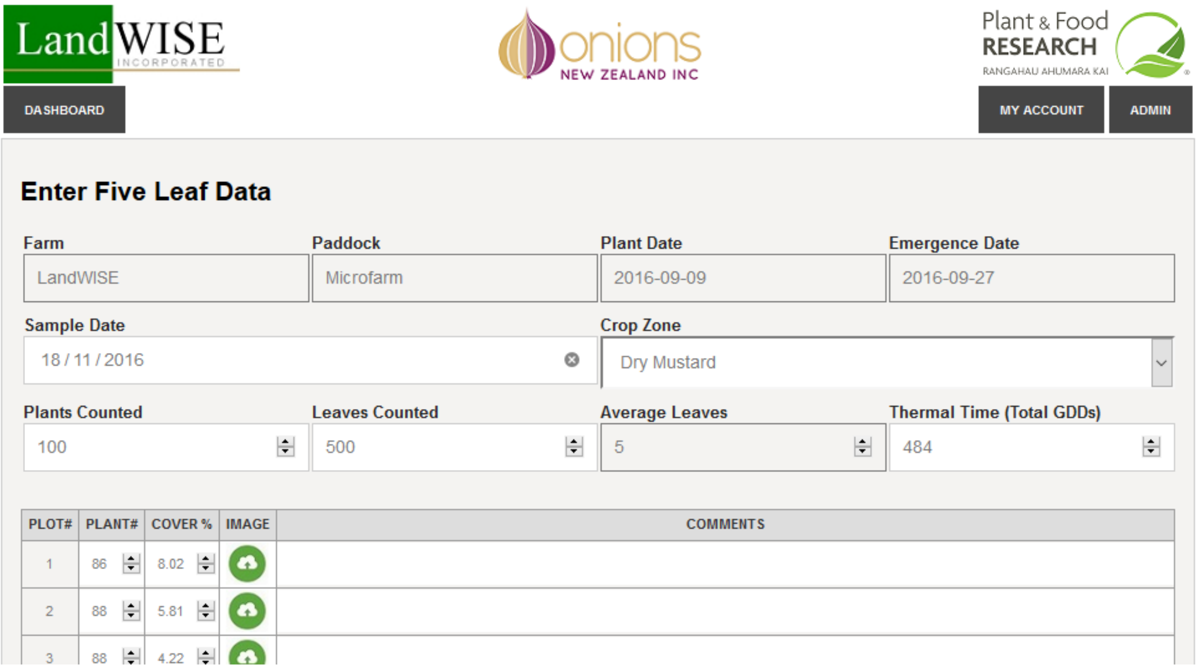
As our experience with crops developed, we adjusted the website and algorithms. Tightening the acceptable variation around crop population resulted in a wider range of Management Action Zone (MAZ) scores.

NOTE: *SmartFarm* has a "Public User" so anyone can preview data from the LandWISE MicroFarm. They cannot edit, add or otherwise corrupt to data set. The public Username is: public@smartfarm.co.nz; Password 12345678.

5.1 Data Entry

SmartFarm can be accessed via smartphone so, if a data connection is available, data can be entered directly from the field. We do not have plans to make separate phone apps.

Data are entered through screen templates for 3-leaf, 5-leaf, bulbing and harvest. An example is shown in Figure 36. Here we present large screen format such as from a larger tablet or an office computer.



Enter Five Leaf Data

Farm: LandWISE
Paddock: Microfarm
Plant Date: 2016-09-09
Emergence Date: 2016-09-27
Sample Date: 18 / 11 / 2016
Crop Zone: Dry Mustard
Plants Counted: 100
Leaves Counted: 500
Average Leaves: 5
Thermal Time (Total GDDs): 484

PLOT#	PLANT#	COVER %	IMAGE	COMMENTS
1	86	8.02		
2	88	5.81		
3	88	4.22		

Figure 36 Screenshot of SmartFarm web-calculator data entry template for measurements at 5-leaf stage.

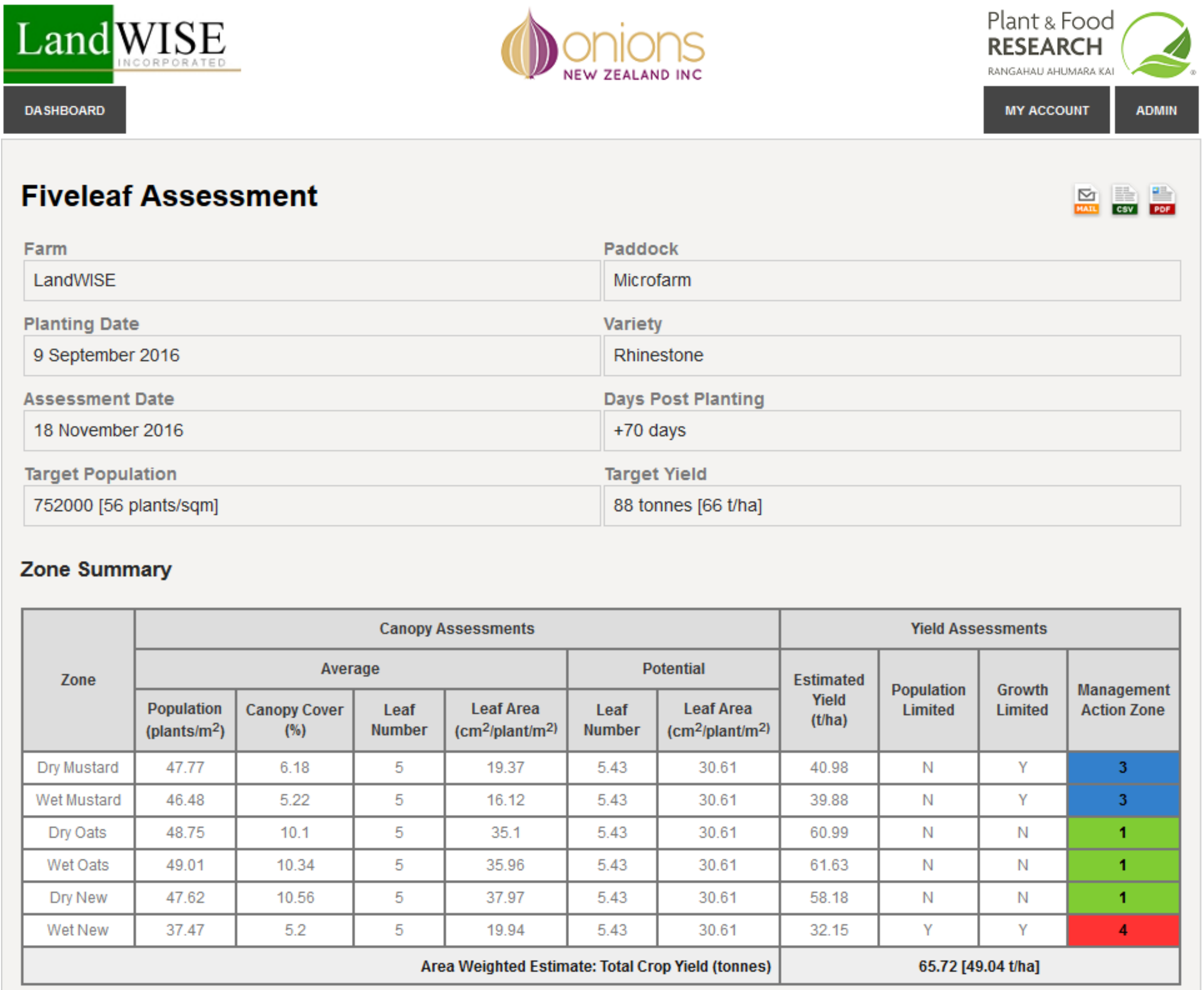
The latest version of SmartFarm has replaced leaf count with calculated leaf number based on average regional GDD accumulation from emergence. This needs refining as sites can be significantly different depending on factors such as aspect and elevation.

5.2 Data Reporting

The subsequent 5-leaf Assessment Report for the MicroFarm crop is shown in Figure 37.

The Paddock Zone summary from the Report shows the MicroFarm had:

- Three MAZ 1 zones neither population nor growth limiting (Dry Oats, Wet Oats and Dry New)
- Two MAZ 3 zones in which population was not limiting but growth was (Dry Mustard and Wet Mustard)
- One MAZ 4 zone in which population and growth were both limiting (Wet New)



Fiveleaf Assessment

Farm LandWISE	**Paddock** Microfarm
Planting Date 9 September 2016	**Variety** Rhinestone
Assessment Date 18 November 2016	**Days Post Planting** +70 days
Target Population 752000 [56 plants/sqm]	**Target Yield** 88 tonnes [66 t/ha]

Zone Summary

Zone	Canopy Assessments						Yield Assessments			
	Average				Potential		Estimated Yield (t/ha)	Population Limited	Growth Limited	Management Action Zone
	Population (plants/m^2)	Canopy Cover (%)	Leaf Number	Leaf Area (cm^2/plant/m^2)	Leaf Number	Leaf Area (cm^2/plant/m^2)				
Dry Mustard	47.77	6.18	5	19.37	5.43	30.61	40.98	N	Y	3
Wet Mustard	46.48	5.22	5	16.12	5.43	30.61	39.88	N	Y	3
Dry Oats	48.75	10.1	5	35.1	5.43	30.61	60.99	N	N	1
Wet Oats	49.01	10.34	5	35.96	5.43	30.61	61.63	N	N	1
Dry New	47.62	10.56	5	37.97	5.43	30.61	58.18	N	N	1
Wet New	37.47	5.2	5	19.94	5.43	30.61	32.15	Y	Y	4
Area Weighted Estimate: Total Crop Yield (tonnes)							65.72 [49.04 t/ha]			

Figure 37 Report for 5-leaf assessment of six zones at the MicroFarm showing estimated final yields and Management Action Zone determinations.

Figure 38 shows the Harvest Report, generated after actual plot weights have been collected in the field and entered into the website tool's database. The summary shows how the predicted yield stood at 3 leaf, 5 leaf and bulbing as well as the actual yields at harvest.

We would expect the model to predict the same final yield at each stage if sampling was done correctly at the right time, data were correctly entered, and the algorithms are correct. While the relative difference in yield prediction between zones is reasonably consistent, they were very (incorrectly) low at 3 leaf and slightly underestimated actual yields at bulbing.

Harvest Assessment

Farm LandWISE	**Paddock** Microfarm
Planting Date 9 September 2016	**Variety** Rhinestone
Assessment Date 27 February 2017	**Days Post Planting** +171 days
Target Population 752000 [56 plants/sqm]	**Target Yield** 88 tonnes [66 t/ha]

Zone Summary

Zone	Crop Assessments		Fresh Mass Yield Assessments			
	Average Population (bulbs/m^2)	Average Weight (kgs/m^2)	Three Leaf (t/ha)	Five Leaf (t/ha)	Bulbing (t/ha)	Harvest (t/ha)
Dry Mustard	45.82	8.12	43.72	40.98	58.54	81.15
Wet Mustard	41.47	6.77	39.88	39.88	55.44	67.67
Dry Oats	45.09	7.02	41.83	60.99	60.99	70.25
Wet Oats	42.16	6.65	42.05	61.63	61.63	66.53
Dry New	47.18	9.02	42.85	58.18	58.18	90.16
Wet New	34.91	6.65	32.15	32.15	36.03	66.50
Area Weighted Estimate: Total Crop Yield (tonnes)			**54.23** **[40.47 t/ha]**	**65.72** **[49.04 t/ha]**	**74.10** **[55.30 t/ha]**	**98.65** **[73.62 t/ha]**

Growth Stage Average Yield Estimate (t/ha)

Plot Yield Estimate (t/ha)

Figure 38. Screen shot of the SmartFarm website showing the Bulbing Assessment Report for the MicroFarm

6 Miscellaneous Observations

6.1 Varietal Differences

In plotting image derived canopy cover against laboratory fresh mass and leaf area index LAI, the crop at one farm showed a significantly different trend to the others which were similar to one another. On investigation it was determined that the variety was “Waikato” not “Rhinestone” as originally believed.

6.2 Top-Down

The progress of top-down is visible in time-series RGB images collected by our consumer level DJI Phantom 3 Pro UAV and camera. While preliminary work investigated image analysis to determine and potentially map top-down, resolving that will require significant and currently unavailable resources.

Observing top down in the whole field context suggests imposed stress may delay maturity as seen by time of top down. Areas of the MicroFarm that died out due to wetness were surrounded by rings of late top-down plants. The areas subjected to early drought (un-irrigated) stress were much smaller and also the last area to fall.

6.3 Prescribing Fertiliser Applications

A small trial compared the effect of delaying fertiliser where soil levels were adequate and halving fertiliser rate where canopy was significantly smaller. In neither case was a yield penalty observed. We note the trial was potentially impacted by disease and yields were below target across all treatments.

6.4 Assessing Disease Risk

The 2017-18 MicroFarm crop was significantly impacted by *Stemphylium*. The disease was first observed and was ultimately most severe in the areas mapped as having highest canopy. This suggests these areas be targeted when scouting. The reason for the early and severe infection is not known, but assumed related to canopy density and humidity, chemical cover and maybe crop tenderness.

7 Recommendations for Future Research and Development

7.1 Improve the Calculator

We have developed our tools and processes on a relatively small experience base in terms of region, season, cultivar, soil type and grower practice. The procedures and processes we have developed to make field scale maps of canopy cover appear to provide satisfactory assessments of variability but yield estimates are less robust. Future development should:

- Check the algorithms and work flows used are correct and robust across cultivars
- Improve methods to predict yield at any crop growth stage

7.2 Provide training and support for growers and agronomists

Our experience in 2016-17 showed additional support is needed to ensure data collectors (growers/agronomists/researchers) understand our protocols and collect data in a form and of quality that can be used.

- Continue to revise and refine the Guidelines/Protocols booklet
- Work individually with growers to train them in correct application

We believe the *CoverMap* surveying is best done by a specialist provider. The image capture is affected by variable light conditions, so calibrations are always required. GPS mapping requires expert knowledge and turning survey data into useful maps requires specialist GIS programs and trained users, neither common on farms. Consultants providing other mapping services would be ideal.

7.3 Attempt quality mapping

While we have shown we can identify areas within a paddock that are growing and developing at different rates, we have to date only sought to predict and calculate the distribution of yield. Mapping canopy development and top down may enable crop segregation for storage and sales timing.

The relative storage potential of onions in different zones should be compared:

1. Zones with better/larger canopies after establishment (which may be different populations or faster developing versus slower developing zones)
2. Zones subjected or not subjected to stress such as heavy rain events (over-irrigation) after planting
3. Zones where top-down is observed to occur earlier and later (apparently related to the above points).

7.4 Investigate use of alternative Crop Indices

As noted in Section 2.2.1 *MicaSense* records five spectral bands. Using GIS, these can be combined using different combinations of bands to create different images (Figure 9). These may provide insights into crop stress, disease or physiological quality not identified using NDVI or *CoverMap* canopy cover assessments.

7.5 Investigate impact of soil moisture stress on yield

Plant & Food describe the importance of maintaining high soil moisture leaves from germination through 3-leaf stage. Our crude estimates of whole crop Potential Soil Moisture Deficit impacts suggest that approach may be suitable, with a very rough calculation suggests that yield losses could be as high as 0.4%/mm PSMD.

8 Acknowledgements

Throughout the project we have received considerable in-kind support from many organisations and individuals. Without them we would not have achieve these results.

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Vigour Seeds
Centre for Land and Water
ASL Software
AgriOptics
Altus UAS
GrowMaps
BioRich Composting
Nicolle Contracting
FruitFed Supplies
Pukekohe Grower Supplies
PGG Wrightson
Seed and Field Services
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