FINAL REPORT 2018

For Public Release

Part 1 - Summary Details

CRDC ID:

Project Title: The platform for monitoring and analysis of cotton canopy nitrogen status and yield projection using calibrated aerial and satellite imagery

Project Start Date: 1/11/2017 **Project Completion Date:** 1/04/2018

Research Program: 2 Industry

Part 2 – Contact Details

Administrator: Anastasiia Volkova

Organisation: FluroSat Pty Ltd

Postal Address: 2-4 Cornwallis Str., Eveleigh, NSW

Ph: 0431003688 Fax: NA E-mail: Anastasia@fluorsat.com

Principal Researcher: Dr Phillip Hughes

Organisation: FluroSat Pty Ltd

Postal Address: 2-4 Cornwallis Str, Eveleigh, NSW

Ph: Fax: E-mail:

Supervisor: Anastasiia Volkova

Organisation: FluroSat Pty Ltd

Postal Address: 2-4 Cornwallis Str, Eveleigh, NSW

Ph:0431003688 Fax: NA E-mail: Anastasia@fluorsat.com

Researcher 2: Jon Baird

Organisation: Department of Primary Industries

Postal Address: 21888 Kamilaroi Highway Narrabri NSW

Ph: 0429136581 Fax: E-mail: Jon.baird@dpi.nsw.gov.au

Signature of Research Provider Representative:

Date submitted: 27 September 2018

Part 3 – Final Report

(The points below are to be used as a guideline when completing your final report)

Background

1. Outline the background to the project.

Cotton nitrogen and water use efficiency are one the of the main levers of efficient fibre production. Although there is body of research focusing on monitoring nitrogen and water stress with remote sensing technology, most of it, however, has been conducted in controlled conditions where extensive testing and validation was performed. Proposed crop canopy nitrogen and water stress diagnostic tool, FluroViewer, builds upon best research practices and seeks to provide near real-time nitrogen monitoring and water stress detection on both research and commercial farms, proving the viability and robustness of the solution. The produced crop nitrogen status maps and water stress maps generated from multi-/ hyperspectral imagery collected using drones and planes were cross-referenced to maps generated using satellite imagery and further calibrated using laboratory tissue testing to support variable rate fertiliser application. To develop the algorithms and models, and to validate the approaches to processing of the remote sensing data, extra tissue testing is required. The tissue testing is a part of standard practice for agronomists, and this is sufficient for the deployment stage. The time-series of nitrogen and water stress maps combined with farm management and weather information will be used to assess the potential of the developed algorithms and models to predict the yield in the next season.

Objectives

2. List the project objectives and the extent to which these have been achieved, with reference to the Milestones and Performance indicators.

a. Developed appropriate zoning methodology for N management in cotton fields using remote sensing vegetation indices and state-of-the-art clustering algorithms. Flurosat has found an appropriate combination of vegetation indices and a clustering algorithm to optimize the partitioning of cotton fields into management zones.

b. Developed a robust methodology for creating in-season N status maps for nutrient management in cotton. The developed methodology applies mathematical methods to analyse the remote sensing imagery and divides the field into representative management zones to increase the efficiency and reduce the cost of cotton tissue sampling and N mapping.

c. Identified the period in the season when end-of-season lint yield is most correlated with in-season remotely sensed vegetation indices. The range of identified points in the season is reasonable and plausible from the viewpoint of management decisions influencing end-of-season yield outcomes.

Methods

3. Detail the methodology and justify the methodology used. Include any discoveries in methods that may benefit other related research.

a. The primary outcome of this project is the launch of the FluroSense online crop management platform at the Australian Cotton conference on 7 August 2018 together with the algorithms and data analysis tools enabling agronomists to manage their fields optimally. The platform features the following functions: automatic fetching of satellite imagery, additional upload and processing of the aerial imagery (airplane, drone) and fusion of the data into a compatible time series.

The data processing algorithms developed to integrate aerial multispectral and hyperspectral allows for any image type uploaded or accessed through the platform to generate management zones, sampling points and nitrogen status maps. Development of these image processing and analysis tools allows remote sensing to be used to plan the upcoming agricultural season. This is done through the development of customised per-paddock cotton nitrogen and yield models that can be used to predict the crop development in the following seasons and inform agronomists' decisions on the application of fertiliser and water to improve yield.

The cloud-based data processing system enables agronomists to improve the analytics described above by applying their knowledge and calibrations, inputting planting dates, fertiliser rates and application dates, which allow to further improve the accuracy of the tools and access sampling schemes and yield analysis (see b, c).

b. The method to optimise cotton tissue test sample collection, developed in this study applied the zoning method developed above and a sampling scheme that integrates Latin hypercube. Latin hypercubes are a method of unbiased random sampling that maximizes the effectiveness of small data sets yet still covers the entire variation in the field. This covers the middle ground between accessibility of the information (farmers and agronomists would like to know how sample schemes relate to the zoning of their farms), and its comprehensiveness (any sampling regime must accurately represent the zone it was based on). The sampled tissue N are then regressed with the corresponding vegetation indices estimated from remote sensing. The regression model is then applied to the remote sensing vegetation indices to derive the N status map for the entire paddock. This N map is then used for N recommendations including variable-rate application.

From an agronomist's perspective, the potential of the optimised sampling schemes and resulting nitrogen maps can seen in providing customised nitrogen recommendations based on the produced N status maps, tailored to local management practices and scientific agronomic tools like NutriLOGIC.

c. An understanding of yield estimates or forecasts early in the growing season is necessary for decision making and planning geared toward resource use optimisation and profit maximization. A simple correlation coefficient between end-of-season cotton lint yield and time series of remote-sensing NDVI/NDVI was computed based on pixel-to-pixel comparison. The correlation coefficients were plotted against time. The earliest time in the season when the vegetation indices are well correlated with the end of the season yield, which is important for management interventions or planning, was determined from the plot. This time is defined as the transition phase in the time series correlation coefficient curve where the rapid rate of increase in correlation at the early stages of the season starts to decelerate. This point may or may not correspond with the maximum correlation in the growing period. Depending on management practices such as the use of growth regulators and considering that cotton has an indeterminate growth habit, it is possible that the peak correlation would occur much later in the growing season. Maximum correlation at the end of the growing season is of little value for planning influential management interventions targeted at yields improvement. Thus, early season correlation, particularly at the point when plant growth is rapid is more valuable for decision making.

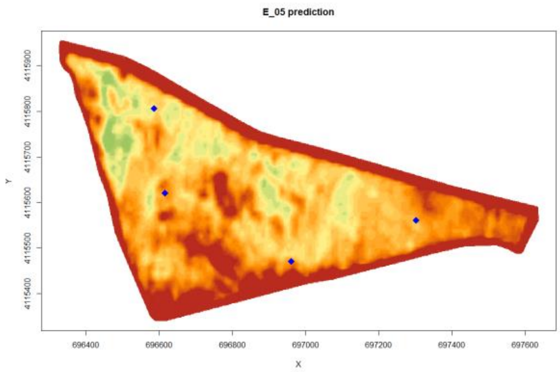
Results

4. Detail and discuss the results for each objective including the statistical analysis of results.

a. The analysis of the difference between the airborne hyper-/ and multispectral imagery in comparison with the satellite imagery has been recently published (see attachment) in IEEE WHISPERS and presented to the academic community at the workshop in Amsterdam on Sept, 22-26. The findings from the paper demonstrate the differences between the data captured using different platforms. It has been found that multispectral red-edge-enabled indices (from which vegetation indices are derived) can be reliably use for identification of areas with different nitrogen application. As the season progresses, around mid-January where cotton approaches the canopy closure stage, the multispectral imagery saturates resulting in little to no difference between the compared nitrogen treatments. This means that for variable application of nitrogen early in season, aerial imagery from a multispectral sensor can be used alongside the satellite imagery with the corresponding accuracy and precision trade-offs.

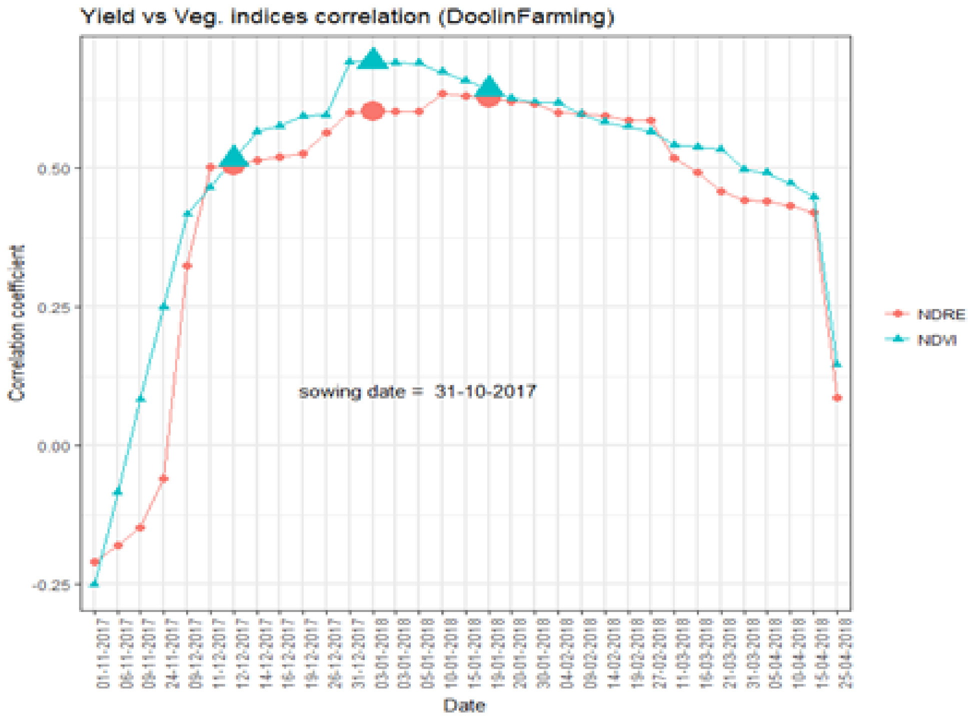
However, later in the season, from mid-January, the vegetation indices derived from the hyperspectral imagery continue to identify distinguishable differences between the observed cotton treatments. Thus hyperspectral imagery maintains a longer association with nitrogen fertiliser use efficiency (indirectly indicating the environmental impact of the fertilisation strategy). We foresee that future applications of the hyperspectral imagery at later growth stages include detection of stresses such as spray drift, disease or pest infestations.

b**.** The integration of the zoning tool with the Latin hypercube sampling tool improved the accuracy of the regression model used to derive the N status Map. For example, the regression model between tissue N and the remote sensing estimate of canopy chlorophyll content index (CCCI) used to produce the N status map shown below has a coefficient of correlation of R^2= 0.81. The model performance is considered to be satisfactory to enable further recommendation of nitrogen application rates based on the imagery with minimal amount of plant tissue testing.



N status map in a cotton field estimated from tissue N and CCCI relationship (R^2 of 0.81)

C. It was found that cotton lint yield was linearly correlated with the normalised difference red edge index (NDRE)/normalised difference vegetation (NDVI) at all points of the season. However, correlation of useful importance for management decision to influence yield and planning was generally greater or equal to 0.6, which is significant, and this was achieved between 57-90 days after planting. The time range for this decision point correlation covers the growth/development phases of leaf expansion and canopy closure, flowering, and boll development in cotton. The Figure below shows the result for one of the paddock's analysed and the point in the season when the vegetation indices is most related to end-of-season lint yield to informed management intervention was found to be 61 and 71 days after sowing for NDVI and NDR. The correlation coefficient at this point is 0.68 for NDVI and 0.63 for NDRE.



Based on the result from the analysis, it is recommended that correlation analysis to inform management decisions aimed at increase in lint yield in cotton to be done at 57-70 days, as decisions later than this period is less likely not to influence yield significantly. However, for planning of the fertiliser application rates related to preparation for harvest, the correlation analysis can be done between 57-90 days.

Outcomes

5. Describe how the project's outputs will contribute to the planned outcomes identified in the project application. Describe the planned outcomes achieved to date.

The FluroSense platform has been launched with the free trial access for cotton growers.
The imagery and analytics tools on the platform have been developed to provide information to inform pre-season and in-season nitrogen management decisions. Alongside the nitrogen management tools the platform allows users to monitor the performance of their crops across the season as well as analyse yield and electrical conductivity layers, which combined with the remote sensing imagery provide a comprehensive view of the field variability and its sources.

6. Please describe any:-

a) **technical advances achieved (eg commercially significant developments, patents applied for or granted licenses, etc.);**

Online platform for crop management using remote sensing imagery, FluroSense has been commercially launched and incorporates the learnings from the trials in the form of the link between the remote sensing imagery and plant tissue sampling through the management zones. Methods to normalise the plant tissue sampling data and combine it with vegetation indices to generate crop nitrogen status maps have been developed and successfully tested. FluroSat has applied for the trademark FluroSense™ prior to the product launch in August 2018.

b) other information developed from research (eg discoveries in methodology, equipment design, etc.); and

It was observed that remote sensing imagery of cotton fields is generally heavily affected by the irrigation and the visual pattern it induces in the imagery, which can be considered on the order of magnitude a significant anomaly to a less-pronounced spectral variability between the high- and the low-performing areas in the field. To address this variable irrigation patterns a method has been developed for automatic detection of the irrigation boom position for the circular irrigated fields.

c) required changes to the Intellectual Property register.

Not required.

Conclusion

7. Provide an assessment of the likely impact of the results and conclusions of the research project for the cotton industry. What are the take home messages?

The project results confirm that aerial and satellite data at key times in season can be used to inform fertiliser management decisions. Particular usefulness and suitability of the aerial data was shown in repeat flight campaigns around the key in-season fertilisation events in Narrabri/Moree region. The fusion of the remote sensing imagery has been used in an online workflow to create management zones and use statistics on the data for creation of the representative tissue sampling points. The use of the tissue sampling point information in conjunction with the aerial and satellite imagery allowed the generation of cotton canopy nitrogen maps using the sampling results and the imagery captured on the same or the closest date within a 2-day window. The demonstrated yield correlation with the remote sensing imagery was moderate and allows to use the imagery as a guidance for early in-season yield management. The developed tools and services that allow to improve nitrogen management in cotton are likely to be used by agronomic consultants and growers in the upcoming season to gain confidence and ultimately adopt variable rate nitrogen management strategies and reduce the environmental impact of the farming practice whilst improving its financial viability.

Extension Opportunities

8. Detail a plan for the activities or other steps that may be taken:

(a) to further develop or to exploit the project technology.
- the commercial offering of the FluroSense platform will be a direct way of exploitation of the technology developed in the project

(a) for the future presentation and dissemination of the project outcomes.
- scientific publications of the project outcomes (existing and future ones linked to it), product marketing brochures and case studies are direct ways in which the information has been disseminated.

(b) for future research.

- the future development of the platform and service includes integration of the FluroSat cotton mapping tools with the research previously conducted by CSIRO and CRDC, NutriLOGIC, to provide actionable recommendations to the cotton growers. This integration will include further trials for validation of the recommendations and scalability of the tools like NutriLOGIC coupled with FluroSat machine learning models.

9. A. List the publications arising from the research project and/or a publication plan. (NB: Where possible, please provide a copy of any publication/s)

- "Changing the game in cotton nitrogen management", The Australian Cotton Grower June - July 2018 Edition and MicaSense blog
- "Comparison Of Aerial Hyperspectral And Multispectral Imagery: Case Study Of Nitrogen Mapping In Australian Cotton" IEEE Whispers - 9th Workshop on

Hyperspectral Image and Signal Processing : Evolution in Remote Sensing, A. Volkova, et al. Amsterdam, 23-26 September 2018

B. Have you developed any online resources and what is the website address?

- FluroSat has developed and published a support section, including FAQ and Knowledge Base at https://www.flurosat.com/faq.
- Instructional videos have been published on YouTube at https://www.youtube.com/channel/UCZi5ClDTJjS1JW2rwgSmpyQ/videos

Part 4 – Final Report Executive Summary

Provide a one-page summary of your research that is not commercial in confidence, and that can be published on the internet. Explain the main outcomes of the research and provide contact details for more information. It is important that the Executive Summary highlights concisely the key outputs from the project and, when they are adopted, what this will mean to the cotton industry.

Research summary:

In the course of the study aerial and satellite image collection campaigns were conducted covering around 17.000 ha of cotton in the Narrabri/Moree area with revisits during the season. The multispectral and hyperspectral imagery collected in the study was utilised to map the nitrogen levels of cotton crop in periods of in-season nitrogen application and later to monitor the impact of the fertilisation strategy on yield. Correlations were established between the remote sensing imagery and the cotton canopy nitrogen content. Using the remote sensing estimate of canopy chlorophyll content index (CCCI), several management zones were defined in each of the research and commercial fields taking part in the study. The tissue sampling point selection was based on the management zones and was performed in a novel way that ensures robust results with minimal testing points.

The accuracy of the nitrogen map generated by the model has been defined through a correlation coefficient of $R2= 0.81$. The accuracy and the practicality of the method for automatic nitrogen map generation using an online software tool were validated for in-season nitrogen management to improve the Nitrogen Use Efficiency.

Main outcomes and industry benefits:

The developed research models linking remote sensing imagery and tissue sampling results have been incorporated into an online platform, FluroSense. The online platform is designed for crop management using remote sensing imagery, and incorporates the learnings from the trials in the form of the link between the remote sensing imagery and plant tissue sampling through the management zone definition, smart sampling and scouting tools, and ultimately crop canopy nitrogen map generation tool.

The FluroSense platform has been launched with the free trial access for cotton growers in recognition of the CRDC and grower community support.

The service consisting aerial and satellite imagery in combination with the online decision support platform are now offered to cotton growers in Australia. The service allows agronomists and growers to access the remote sensing imagery, the insights from the crop health analysis, guidance on ground-truthing the crop performance with tissue testing as well as tools for generation of the management zones and application maps for in-field use. Alongside the nitrogen management tools the platform allows the users to monitor the performance of their crops across the season and perform the analysis of the yield and electrical conductivity layers, which combined with the remote sensing imagery provide a comprehensive view of the field variability and the strategies for its potential improvement.

Contact details:

Anastasia Volkova
CEO, FluroSat
anastasia@flurosat.com