COGGO Council of Grain Grower Organisations Limited ACN 091 122 039	**Final Report** **COGGO Research Fund for 2015 projects** **A project completion report covering the project. The acceptance of a satisfactory report against the objectives of the project, and agreement on the sharing of any commercial returns and/or IP will trigger payment within 4 weeks, by COGGO for any outstanding payments.**

This Final Report should be completed with reference to the Research and Intellectual Property Agreement (the Research Agreement) signed between the proponent and COGGO Pty Ltd.

1. Project information

Project title	**Refining remote sensing technologies to give real-time estimation of crop nitrogen status for application in precision agriculture.**
Commencement Date	January 2015
Completion Date	December 2016

Name of Proponent	Halina Kobryn, Graham O'Hara, Felipe Burgos, Matt Bellgard and John Howieson
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Project Number	
Date Received	

2. Project results	This section provides a final report against the Project Aim and the Planned Outputs for the Project.

Achievement of the Project Aim	Brief statement of achievement in relation to the aim of the project

We have achieved the aim of providing a robust, accurate and efficient means for assessment of in-season nitrogen status in crops, allowing cereal growers to assess the need for any additional N application in relation to seasonal conditions. This assessment is based on a toolkit of selected remote sensing tools; sensor and UAV (drone technology), vegetation indices derived from the imagery and the web platform which facilitated data sharing. Use of these tools leads to updated data sets of the nitrogen crop status. Near-real time availability of these assessments as georeferenced maps results in the potential for more efficient, variable rate decisions on application of nitrogen fertilizers from early stages of plant growth.

The N status maps allow dosage adjustment and subsequently help reduce the environmental and economic impacts of over fertilizing, due to lower nutrient runoff and also improve cost savings for the growers.

Our proposed cost effective data acquisition components such as cameras (sensor) and platforms (drone) could be set up and operated by a range of users, from trained farmers that own and operate drones to regional businesses with the fly-over capacity.

Project Outputs		Please provide a report on the achievement, or otherwise, of the project outputs as per the planned outputs provided in the Project Proposal.
1	-	Output 1 (from Project proposal) Wide-scale validation of our hyperspectral sensor technologies to remotely estimate crop N status
		Comment: A set of chlorophyll targeted vegetation indices were selected based on their capacity to detect small variations in nitrogen content at canopy level, across cereal types and crop growth stages. The selection of the sensor/AUV combination was focused on a wide acre application. Data captured at different altitudes also defined an optimum pixel size assuring a stable performance of the vegetation indices.
2	-	Output 2 (from Project proposal) Data gathered during the season (June-September) to provide accurate advice on the earliest possible time for precise N estimation and intervention
		Comment: As a general rule, the earliest plant growth stage requires the smallest pixel size to capture crop spectral data, however, performance of the vegetation indices deteriorated when the imagery was captured at less than a 1 cm pixel size. In practical terms, from early stem elongation (Zaddock 29 - 30) it is possible to get precise data to guide nitrogen corrections within season.
3	-	Output 3 (from Project proposal) Coupling of hyperspectral data with digital agriculture platforms to allow growers real-time access to enable precision N applications in late winter, with budgetary savings on N supplements and reduced wastage.
		Comment: The implementation of a web based digital platforms to support crop nitrogen status maps represents an important step forward, thus reducing the data transfer time of critical information for growers. A better understanding of spatial and temporal variation on N status in the field improves the application efficiency and reaction time capacity, thus improving the N status management.

Project results	Please provide brief statements on the results of the Project

This section should cover aspects identified in *Section 7.3* of the Research Agreement

- the results of the Project, including discoveries made and other achievements (including any Project IP and Project Confidential Information);
- the potential application of the outputs of the Project to the Western Australian grains industry and broader community;
- the actual or potential economic benefits flowing to the Western Australian grains industry and broader community from the Project;
- the difficulties encountered;
- the conclusions reached;
- the Researcher's recommendations for any further research;
- a list of scientific papers or publications resulting from the Project; and
- attach copies of any photos, diagrams or other artworks (including, if requested by COGGO, negatives, bromides or the like) which the Researcher has and which may be of assistance to COGGO in the dissemination of information concerning the Project to COGGO's stakeholders.

The selection of the sensor, platform and indices (Table 1) were carried out at three locations (Figure 1). The resulting toolkit was composed by a combination of commercial camera / UAV, a free GIS Software (QGIS), a set of vegetation indices and a common data storage web-based platform. The toolkit allowed for the application of a cutting edge technology in a cost effective way, with a broad-acre operation capacity of the camera-drone setup and a consistent performance of the vegetation indices in cereal crops at early stages by keeping the sensitiveness to detect slight variations in nitrogen status (Table 2).

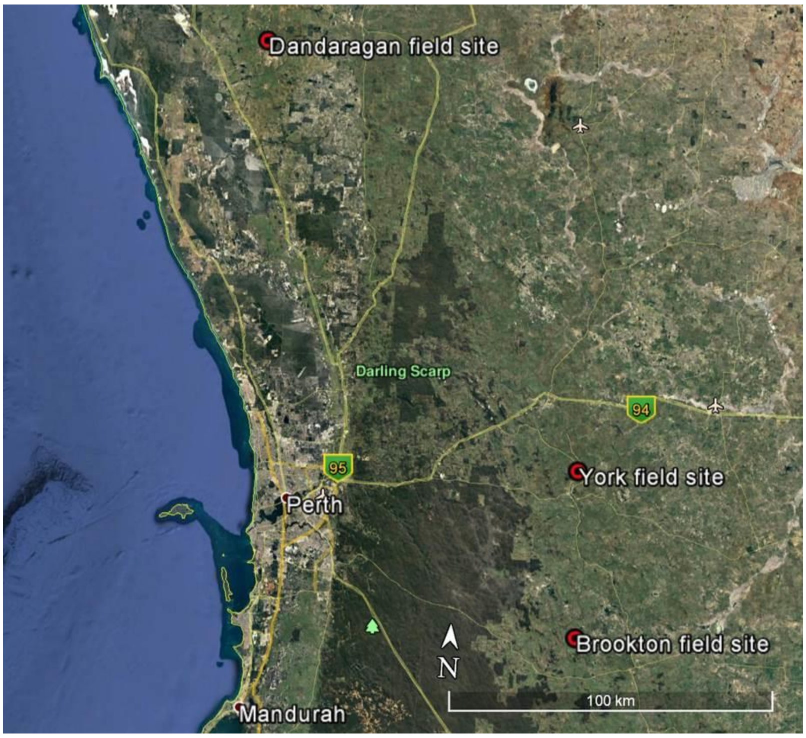

Figure 1. Field site locations used for testing sensor / platform combinations.

Table 1. Platforms and sensors tested over the field sites.

Platform	Field site	Season	Operator	Sensor	Type	Spectral Resolution	Capture Operation
Fix wing UAV and quadcopter	Brookton	2015 and 2016	Global Unmanned services (GUS)	MicaSense, Red Edge tm	Imaging	Narrow band	Broad acre coverage
Octocopter UAV	Dandaragan	2015	ArborCArbon	Cubert, UHD 185	Imaging	Narrow band	Medium scale coverage
Car mounted	All sites	2015	Murdoch University	ASD Radiometer	Non-imaging	Narrow band	Single measurement

Table 2. Selected vegetation indices and their main characteristics, indicating method of calculations and target variable.

Index	Formula	Target	Reference
MRENDVI **Modified Red Edge normalized vegetation index**	$\frac{\rho 750 - \rho 705}{\rho 750 + \rho 705 - 2 * \rho 445}$	Chlorophyll	Daniel A Sims, John A Gamon, Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages, Remote Sensing of Environment, Volume 81, Issues 2–3, August 2002
MRESR **Modified Red Edge simple ratio**	$\frac{\rho 750 - \rho 445}{\rho 705 - \rho 445}$	Chlorophyll	Daniel A Sims, John A Gamon, Relationships between leaf pigment content and spectral reflectance across a wide range of species, leaf structures and developmental stages, Remote Sensing of Environment, Volume 81, Issues 2–3, August 2002
RENDVI **Red Edge normalized difference vegetation index**	$\frac{\rho 750 - \rho 445}{\rho 705 - \rho 445}$	Chlorophyll	Gitelson, Anatoly, and Mark N. Merzlyak. "Spectral reflectance changes associated with autumn senescence of Aesculus hippocastanum L. and Acer platanoides L. leaves. Spectral features and relation to chlorophyll estimation." Journal of Plant Physiology 143.3 (1994): 286-292.
Vogel **Vogelmann Red Edge index 1**	$\frac{\rho 740}{\rho 720}$	Chlorophyll	Vogelmann, J. E., Rock, B. N., & Moss, D. M. (1993). Red edge spectral measurements from sugar maple leaves. REMOTE SENSING, 14(8), 1563-1575.

The multispectral camera used in the project was a Micasense (www.micasense.com) model RedEdge. This model has a key feature which is the incorporation of a band located within the Red Edge region of the electromagnetic spectrum, sensitive to nitrogen content in the canopy. Another important feature is that the camera sensor records spectral data in narrow bands (15 – 20 nm wide) having, under field conditions, similar performance (Figure 2) to a precise but significantly more expensive Analytical Spectral Devices (ASD) FieldSpec non-imaging spectrometer (Figure 3).

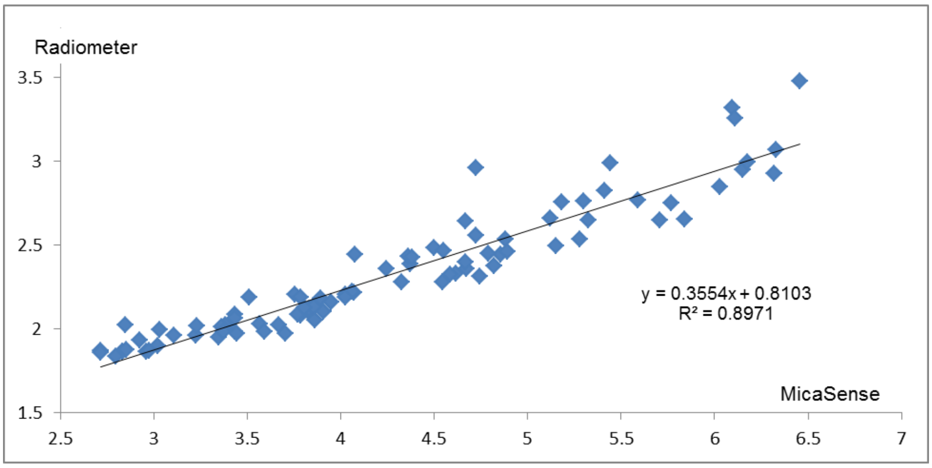

Figure 2. Scatter chart comparing two data set of Vogelman's Red Edge vegetation index from different sensors measuring the same plots of the wheat field trial at Brookton in August 2015. Ground measurements by an ASD field spectrometer compared with an UAV fly-over carrying a MicaSense RedEdge multispectral camera.

Figure 3 . Setup of the ASD non-imaging radiometer for field measurements in barley at York field site, 2015 .

The RedEdge camera model fits into commercial, fixed-wing drones such as eBee (www.sensefly.com) or PrecisionHawk (www.precisionhawk.com). These types of platforms cover large areas and at required fly-over altitudes to produce imagery with the specified pixel size for an optimum performance for calculating appropriate vegetation indices (Figure 4).

Figure 4. Preparation of the fly-over operation by the GUS survey company (www.gus-uav.com). Brookton field site, 2015.

Series of images resulting from these fly-overs were transformed into different formats. GeoTIFF format was used to transfer the geographically referenced data of nitrogen estimation maps to GIS software and precision farming devices. QGIS software (http://www.qgis.org) chose for this trialed was found suitable for displays and export of the data, also facilitating the storage of different data formats on the web-based platform (Figure 5)

Figure 5. Left: Data capture operation over wheat by GUS operator, using the quadcopter at Brookton field trial, 2016. Right: Resulting imagery in gray scale showing Vogelmann Red Edge index values from light to dark grey representing high to low chlorophyll content in the plants.

The web-based platform, Dropbox (www.dropbox.com) was used to store and share the data sets, and be controlled by an administrator in charge of the maintenance of the spatial data as well as connecting different end-users with all or part of the stored data. Dropbox is typically linked with the user through a Dropbox folder on the user's computer, the files are then synchronized with Dropbox's servers and with others user of Dropbox, keeping updated files on all devices.

In the selection process to find the optimal toolkit we tested different sensors and platform combinations. This selection was led by a search of a stable and high sensitiveness of the sensor.

In summary:

- It’s possible to estimate the nitrogen content in cereal crops at early growth stage at a broad-acre scale.

-The highest spatial resolution (smallest pixel size) isn’t necessarily the best choice to capture the targeted spectral data.

-The use of web-based platform as a geo-data hub allows an efficient and even distribution of strategic information for growers.

As a recommendation for further research:

1) A higher flyover frequency (we recommend once a week) to collect data from early stages to the grain fill stage, because we consider that there is still a time gap where the vegetation indices change from an assessment of canopy N status to a estimation of the nitrogen content in the grain.

2) Include other nutrients in the spectral analysis, in order to understand how their variation could affect the spectral status of the crops.

3) The use of remote sensing techniques tracking nitrogen flow on cropping system including legumes. From the analysis of the spectral imagery of field trials we have detected influence of legume background over cereal. We consider that this requires a better understanding of the legume role as part of cropping systems (Figure 6).

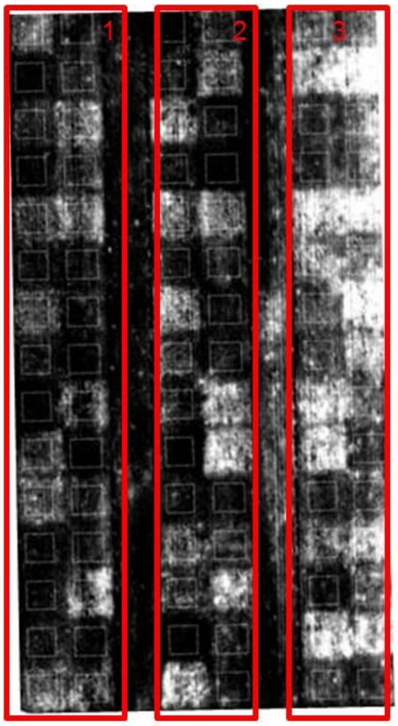

Figure 6. Modified Red Edge Simple Ratio index coverage as grey scale image from light to dark grey representing high to low chlorophyll content of wheat plots at Brookton, 2016. In red, three stripes with different background from the previous season's legume-bacteria nitrogen fixation performance from a serradela pasture trial. Stripe number: 1 Poor, 2 Non-legume and 3 Effective.

3. Project resources	This section describes use of the funding listed in the initial plan and any refunds due to COGGO

Expenditure of funds requested from COGGO	$ Total funds budgeted	$ Total funds expended (actual)	$ Total funds requested from COGGO*	$ Total COGGO funds expended	$ Refund due to COGGO of any unexpended COGGO funds
Salary/Contractors	70,000	69,420	70,000	69,420	0
Operating costs	25,000	25,600	25,000	25,600	0
Capital					
TOTAL	**95,000**	**95,020**	**95,000**	**95,020**	**0**

*Funding provided by COGGO.

IMPORTANT: Return of unused funds to COGGO is required as per *Clause 3.3* of the Research Agreement.

4. Commercialisation	Insert details of the proposed commercialisation process,as applicable, with reference back to the planned commercialisation plan in the project proposal) for any outputs from the project. This should include recommendations for the commercialisation of the results of the project and the registration or other protection of Project IP and Project Confidential Information as per the Research Agreement.

There are commercialisation prospects from this research and IP aspects need to be resolved. We would ask that this report be treated as Project Confidential Information until these IP conversations have been completed.

It is understood that this may require further discussion and agreement with COGGO via its' agent GIWA, as per the undertakings given and terms agreed, in the project proposal. This can be the subject of an appended letter and attachments. In all cases such discussion and subsequent agreements need to be governed by *Section 8 Project IP, Improvements and Project Confidential information* of the Research Agreement.

5. Communication/ Extension	Insert details of how the communication and extension of the project outcomes has been achieved to date and recommendations for future activities to disseminate and promote adoption of the results of the Project.

The project overview and an octocopter fly-over demonstration were presented in September 2015 as part of the West Midlands Group field day. The results from the experiments carried out using DAFWA field trials are under process to be published with the researchers.

Note: As per *Clause 7.3 (b) (ii)* of the Research Agreement COGGO may require the Researcher to produce an edition of the Final Report in a form suitable for general distribution. If so required by COGGO, the Researcher must produce a non-confidential version of the Final Report within 28 days of receiving a request to that effect from COGGO.

6. Certification

The Project Supervisor and the Research Organisation certify that all information contained in, and forming part of, this final project report is complete and accurate. The project supervisor and research organisation further warrant that the project complied with all the relevant guidelines affecting the conduct of research, for example in relation to ethics, bio-safety, environmental legislation, GMAC or National Health and Medical Research Council Codes.

Project Supervisor's signature Halina T. Kobryn _____

Name (in Capitals)

________Dr HALINA T. KOBRYN

22 June 2017

Research Organisation signature __ ___

Name and title of authorised signatory (in Capitals)

_Jane Crier, Research Grants and Contracts Services Manager______

______________________________ Date: 24 July 2017

Completed Final Project reports

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Or phone (08) 6262 2128

COGGO representative

For the purpose of this Project agreement contract, COGGO will be represented by Grains Industry Association of Western Australia (GIWA), or such other representative that is nominated by COGGO as authorised to operate on behalf of COGGO.

PROJECT SYNOPSIS SUITABLE FOR GENERAL PUBLICITY AND COGGO WEBSITE

Refining remote sensing technologies to give real-time estimation of crop nitrogen status for application in precision agriculture.

Halina Kobryn et al, Murdoch University, 2017

The project aimed to provide a cost effective suit of devices & technologies focused into provide updated cereal crop nitrogen status for growers through a web based platform.

We have achieved the aim of providing a robust, accurate and efficient means for assessment of in-season nitrogen status in crops, allowing cereal growers to assess the need for any additional N application in relation to seasonal conditions. This assessment is based on a toolkit of selected remote sensing tools; sensor and UAV (drone technology), vegetation indices derived from the imagery and the web platform which facilitated data sharing. Use of these tools leads to updated data sets of the nitrogen crop status. Near-real time availability of these assessments as georeferenced maps results in the potential for more efficient, variable rate decisions on application of nitrogen fertilizers from early stages of plant growth.

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