Office Use Only

Project Code	
Project Type	

FINAL REPORT 2017

Applicants must read the *SAGIT Project Funding Guidelines 2017* prior to completing this form. These guidelines can be downloaded from www.sagit.com.au

Final reports must be emailed to admin@sagit.com.au as a Microsoft Word document in the format shown ***within 2 months*** after the completion of the Project Term.

PROJECT CODE :	UA217

PROJECT TITLE (10 words maximum)
Use of drones to non-destructively assess wheat varieties

PROJECT DURATION

*These dates **must** be the same as those stated in the Funding Agreement*

Project Start date	1st July 2017					
Project End date	30th June 2018					
SAGIT Funding Request	2015/16	$	2016/17	$	2017/18	

PROJECT SUPERVISOR CONTACT DETAILS

The project supervisor is the person responsible for the overall project

Title:	**First Name:**	**Surname:**	
Dr	Rhiannon	Schilling	
Organisation:			
School of Agriculture, Food and Wine, The University of Adelaide			
Mailing address:			
Telephone:	**Facsimile:**	**Mobile:**	**Email:**

ADMINISTRATION CONTACT DETAILS

The Administration Contact is the person responsible for all administrative matters relating to the project

Title:	**First Name:**	**Surname:**
Ms	Chelsea	DuBois

Organisation:
The University of Adelaide
Mailing address:

Telephone:	**Facsimile:**	**Mobile:**	**Email:**

PROJECT REPORT

Provide clear description of the following:

Executive Summary (200 words maximum)

A few paragraphs covering what was discovered, written in a manner that is easily understood and relevant to SA growers. A number of key dot points should be included which can be used in SAGIT communication programs

High-throughput and non-destructive phenotyping methods are needed in agronomic and plant breeding research to assess the performance of wheat varieties in large-scale field trials. UA217 investigated whether drones fitted with red-green-blue (RGB), thermal and multispectral cameras could be used to accurately measure plant traits in field trial plots compared to using handheld devices and destructive measurements. In 2017, field trials of bread and durum wheat varieties at Mallala and Roseworthy were imaged at stem elongation and anthesis. Canopy height, NDVI, canopy temperature and leaf spectral values were measured on the day of imaging. Biomass cuts from a trial of 12 bread wheat varieties were also completed.

- RGB images were found to be more reliable than thermal and multispectral images because they were less affected by weather conditions
- Methods were established to extract useful data values from drone images to estimate canopy height, biomass and NDVI
- Values derived from RGB images for canopy height and biomass correlated well with ground measurements of plant height and biomass
- Changes in plant height and biomass between stem elongation and anthesis suggest drones fitted with RGB cameras will be useful to measure wheat growth through time non-destructively in the field

Project Objectives

A concise statement of the aims of the project in outcome terms should be provided.

The aims of this project were:

1. To refine methods for quantifying plot biomass, plant height, vegetation indexes (NDVI) and canopy temperature using non-destructive aerial imaging.
2. To use aerial imaging to phenotype field trial plots to assist with the identification of plant traits linked to higher grain yields at sodic sites.

Overall Performance

A concise statement indicating the extent to which the Project objectives were achieved, a list of personnel who participated in the Research Project including co-operators, and any difficulties encountered and the reasons for these difficulties.

The main aim of the project, to refine methods for quantifying plant traits in field trial plots using non-destructive aerial imaging, was achieved. Values for shoot biomass, plant height and vegetation indices (including NDVI) were obtained for each trial plot at two trial sites at two time-points. The values derived from the drone images for these plant traits were strongly correlated to ground measurements indicating the drone image results were reliable. The time-points of interest for crop measurements (stem elongation and anthesis), unfortunately, correspond to a time of the growing season that has highly variable weather including rain, wind and cloudy days. The use of RGB imaging was less affected by weather conditions and so proved to be a more reliable and robust method to assess growth than multispectral and thermal imaging. Repeated drone flights were made with the multispectral camera during the desired growth stage time-frame and some useful multispectral data was obtained. However, images obtained using the thermal camera, which is very sensitive to any slight change in wind or light, could not be used due to unreliable image quality.

The second objective, to use the values obtained from drone images to identify variation in plants traits at sodic sites, was also completed. Variation in shoot biomass, plant height, NDVI and leaf reflectance values was detected among 41 varieties of bread and durum wheat at two sites with sodic subsoils. This information was used in combination with data obtained in the GRDC-funded sodicity project (UA00159). For example, variation in shoot biomass was linked to differences in pre-anthesis and post-anthesis soil water use and the density of root DNA in the soil profile down to 1m. Varieties with small and large biomass were identified and varieties with slow and fast growth rates were apparent from changes in plant height between the two-imaging time-points.

The personnel involved in the project included: Dr. Rhiannon Schilling, A/Prof. Glenn McDonald, Dr Ramesh Raja Segaran (URAF) and Ms. Lucy Cunningham (technical support) all from The University of Adelaide and the support of growers for access to land for field trials.

Key Performance Indicators (KPI)

*Please indicate whether KPI's were achieved. The KPI's **must** be the same as those stated in the Application for Funding and a brief explanation provided as to how they were achieved or why they were not achieved.*

KPI	***Achieved (Y/N)***	***If not achieved, please state reason.***
Aerial imaging of two trial sites using drones fitted with multi-spectral, thermal and RGB cameras at two time-points throughout the growing season	Y	Thermal imaging was only completed at stem elongation as weather conditions were not suitable for image quality at anthesis.
Handheld measurements for calibrating images recorded for the two field trial sites at two time-points throughout the growing season	Y	

Software analysis of drone images completed	Y	
Final report submitted	Y	

Technical Information (Not to exceed **three** pages)

Provide sufficient data and short clear statements of outcomes.

In 2017, field trials at Mallala and Roseworthy, SA were imaged using drones fitted with RGB, thermal and multispectral (MicaSense) cameras at two-time points (stem elongation and anthesis). Both trials had 41 bread and durum wheat varieties with four replicate plots, a trial of Mace sown at 45, 90 and 180 plants/m^2 with four replicate plots and a destructive trial of 12 varieties (Bremer, Condo, Corack, Emu Rock, Gladius, Gregory, Janz, Mace, Magenta, Scout, Sunco and Wallup) with three replicate plots. 3DR Iris + quadcopters were fitted with a Sony RX100 III (20 megapixel) RGB camera and a MicaSense multispectral camera to collect images of each trial plot. Flights were conducted 20 m above ground level for an image resolution of approximately 0.5 cm. Fixed reference plates, known as ground control points (GCPs), were positioned at each site to link images obtained across time-points. Drone images were processed using Pix4D Mapper Pro and ArcGIS software packages. Pix4D Mapper software uses a photogrammetry algorithm called Structure from Motion (SfM), to overlap a series of drone images from each field site to generate a point cloud and three-dimensional models of the trial plots. For each plot, a value for plot canopy biomass and canopy height were derived from the drone images. At the time of drone imaging, handheld measurements of canopy density using a GreenSeeker™, plant height using a ruler, canopy temperature using an InfraRed thermometer and multispectral information using a FieldSpec™ (including NDVI and water stress indices) were recorded for each plot. Shoot biomass cuts (2× 50 cm rows) were collected on the day of drone imaging from each plot in the destructive trial at both imaging time-points.

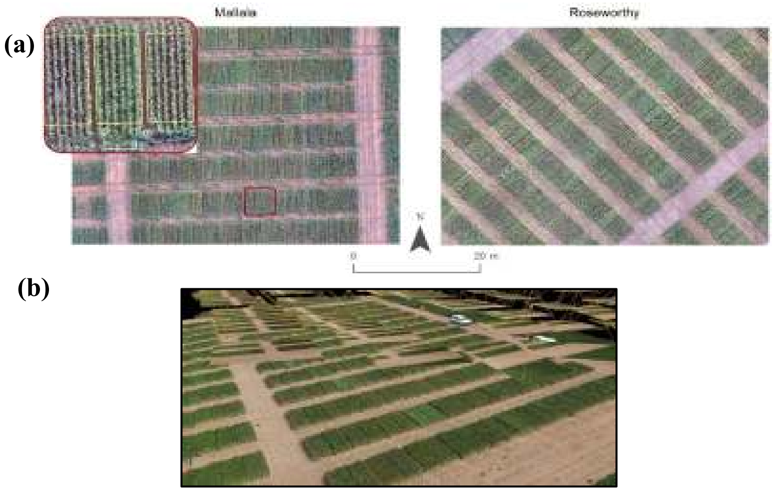

Figure 1: Example of field trial images obtained from a drone fitted with an RGB camera (a) The raw images from an RGB camera fixed to a drone at Mallala and Roseworthy, SA in 2017. The red insert at Mallala is an example of three plots showing visual differences in plant biomass detected using the drone and (b) A 3D model of Roseworthy, SA in 2017 from the RGB camera images showing the point cloud above the trial plots.

Variation among varieties for plot biomass (Figure 1), canopy density, plant height and leaf reflectance values were detected at both trial sites in the drone images. Imaging using the RGB camera was more reliable than the multispectral and thermal cameras due to the variable weather (wind, rain) influencing image quality.

Values derived from drone images correlated with handheld measurements for plant height and biomass at both sites (Figures 2, 3). Mean plant height measured using a ruler was correlated to mean canopy height obtained from RGB images with an $r^2 = 0.92$ at Roseworthy and $r^2 = 0.61$ at Mallala across both time-points of stem elongation and anthesis (Figure 2b, d). Although the correlation between the ruler and drone plant height values tended to be better at stem elongation than anthesis. The estimates of plant height obtained from the drone RGB images tended to be shorter than the absolute height values measured using a ruler, which is an observation reported in other studies in the literature using similar methods. Alternative image analysis techniques are currently being investigated to minimise these apparent differences. The relationship between ruler plant height and drone canopy height also tended to be more strongly correlated at Roseworthy than Mallala. This does suggest that each site may need to be individually calibrated for specific traits (although this will be determined in UA318).

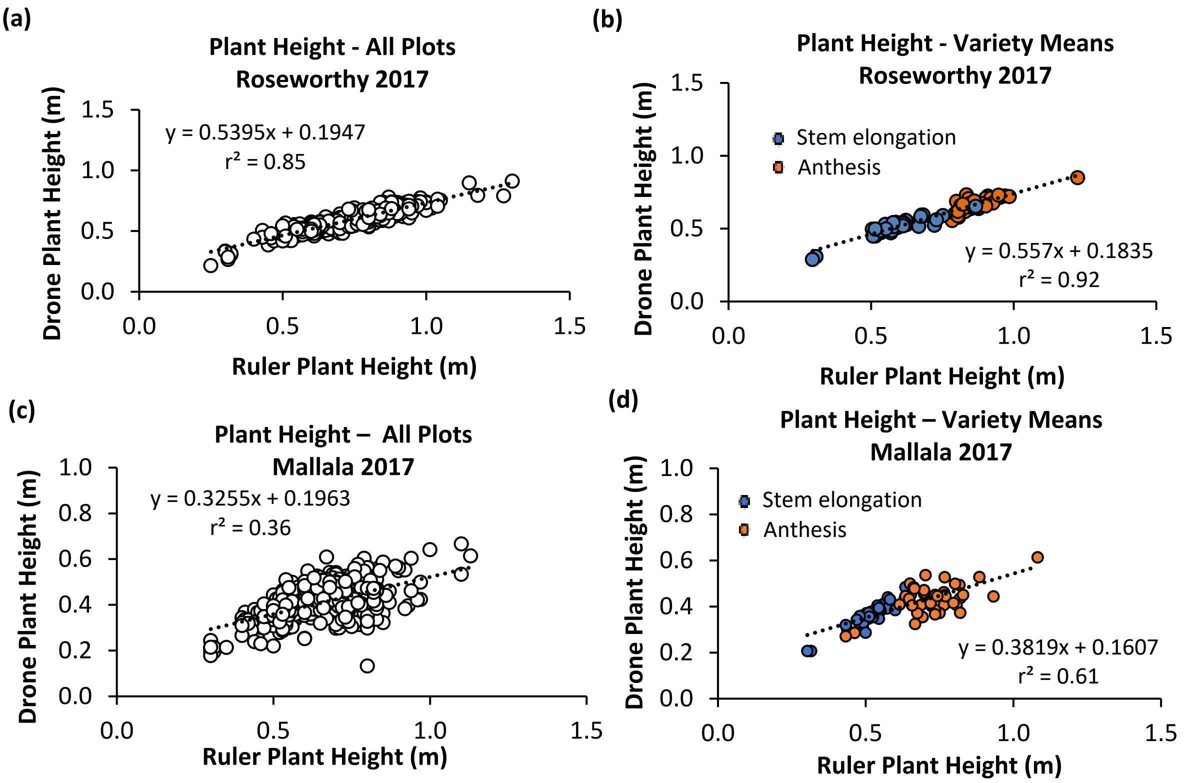

Figure 2: Correlations between ruler plant height and drone plant height measurements at Roseworthy and Mallala in 2017. Plant height measured using a ruler compared to the mean plant height measured using values derived from drone RGB images at (a) Roseworthy (all plots), (b) Roseworthy (variety means), (c) Mallala (all plots) and (d) Mallala (variety means) for bread and durum wheat varieties at stem elongation (blue) and anthesis (orange). Equations for the line of best fit are shown including the r^2 value.

The mean biomass fresh weight collected from the destructive plots was correlated to the mean canopy biomass values derived from RGB images of the destructive plot at stem elongation and anthesis with an $r^2 = 0.62$ at Roseworthy and $r^2 = 0.75$ at Mallala (Figure 3 b,d). Further work to investigate the way in which we derive a value for biomass from the plot images is required, such as using volume and density values rather than the sum of canopy values. There is also further statistical analysis required as biomass was estimated from only 0.25 m^2 of a plot with a total area of 7.5 m^2; linking the plot biomass values from the drone image with the actual biomass within the quadrat rather than the whole plot may also improve the relationship. Nevertheless, the correlations between the mean destructive shoot biomass and the mean drone biomass were significant allowing the line-of-best fit to be used to estimate the biomass of plots in the non-destructive trial based on the biomass value obtained from the drone images. This demonstrated that drone images can be used to generate calibration curves to estimate plot biomass.

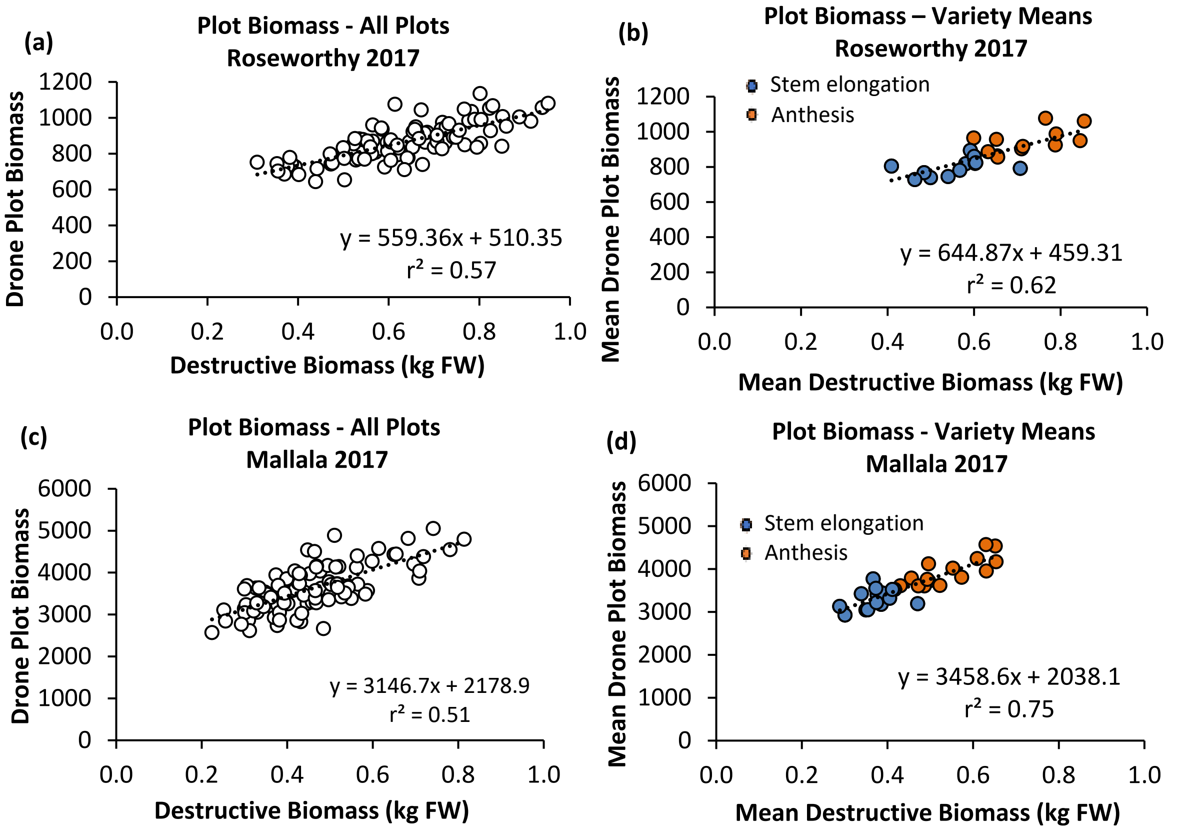

Figure 3: Correlations between quadrant biomass and drone biomass measurements at Roseworthy and Mallala in 2017. Shoot biomass from destructive plot measurements compared to the biomass of the plot obtained from drone RGB images at (a) Roseworthy (all plots), (b) Roseworthy (variety means), (c) Mallala (all plots) and (d) Mallala (variety means). Graphs are for bread and durum wheat varieties at stem elongation (blue) and anthesis (orange). Equations for the line of best fit are shown including the r^2 value.

Promisingly, changes in plant height and plot biomass between the two-imaging time-points for different varieties can be measured using the drone images. With more time-points, drone imaging could potentially be used to assess shoot growth rates of wheat in field trials. Detecting variation in shoot growth rates and comparing growth rates between environments with and without subsoil constraints could be used in the future to identify varieties or breeding lines that are more tolerant or sensitive than others (in-progress in UA318). Potentially this could also be used to measure spatial variation in crop growth rates within crops.

Multispectral data was also obtained for each field trial plot. NDVI was derived for each trial plot and was correlated with NDVI from a handheld GreenSeeker at Roseworthy ($r^2 = 0.56$) and Mallala ($r^2 = 0.55$) at stem elongation. However, NDVI measurements at earlier growth stages are necessary as the NDVI of most varieties was around 0.7. Various other plant indices, including R-NDVI, G-NDVI, NDRE, Normalised Water Index (NWI) NWI-1, NWI-2, NWI-3 and NWI-4 were also derived from the handheld FieldSpec multispectral data. There does appear to be a link between some of the water stress indices and grain yield, which we will continue to investigate in UA318. A large amount of multispectral data was collected in this project and will continue to be analysed in the future as this information could potentially be a useful selection tool (such as a quantitative measure to select for water stress tolerance in wheat).

Conclusions Reached &/or Discoveries Made (Not to exceed one page)

Please provide concise statement of any conclusions reached &/or discoveries made.

This project refined methods to extract useful data values from drone images for canopy height, biomass and NDVI values. The use of RGB images was found to be more reliable than thermal and multispectral images because they were less affected by weather conditions. The strong correlation between values for canopy height and biomass derived from RGB images and ground measurements indicates that drone images can provide reliable information on differences in growth among varieties and to monitor crop growth rates over time. By imaging two trial sites at two time-points, variation in canopy height, biomass, NDVI and leaf reflectance values were obtained for 41 bread and durum wheat varieties and this information will be used to value add to a current GRDC-funded project (UA00159) aiming to improve the yield of wheat in sodic soils. The project also identified that drones fitted with RGB cameras to monitor changes in plant height and biomass is likely to be of use to non-destructively measure wheat growth through time in the field.

Intellectual Property

Please provide concise statement of any intellectual property generated and potential for commercialisation.

IP generated includes field trial plot drone images (RGB, multispectral and thermal images) and handheld plot measurement data. No potential for commercialisation.

Application / Communication of Results

A concise statement describing activities undertaken to communicate the results of the project to the grains industry. This should include:

- *Main findings of the project in a dot point form suitable for use in communications to farmers;*
- *A statement of potential industry impact*
- *Publications and extension articles delivered as part of the project; and,*
- *Suggested path to market for the results including barriers to adoption.*

Note that SAGIT may directly extend information from Final reports to growers. If applicable, attach a list of published material.

Main findings

- RGB images were found to be more reliable than thermal and multispectral images because they were less affected by weather conditions
- Methods were established to extract useful data values from drone images to estimate canopy height, biomass and NDVI
- Values derived from RGB images for canopy height and biomass correlated well with ground measurements of plant height and biomass
- Changes in plant height and biomass between stem elongation and anthesis suggest drones fitted with RGB cameras will be useful to measure wheat growth through time non-destructively in the field

- Differences in biomass were detected for varieties in sodic field trial sites assisting with research in a current GRDC-funded project UA00159 focused on improving wheat yields in sodic soils

Potential industry impact

Large scale field trials are conducted each year by various organisations including plant breeders and researchers. Currently, there is limited measurements of plant traits in individual field trial plots each year due to the time and resources required to measure a large number of trial plots and the influence of destructive plot measurements on plot grain yields. This project refined high-throughput methods to use drone images to non-destructively assess plant biomass, plant height and NDVI in field trial plots without influencing grain yields. Values derived from RGB images for canopy height and biomass of trial plots were found to correlate to ground measurements of plant height and biomass. This technology will benefit pre-breeding and breeding research by allowing more detailed assessment of wheat varieties in field trial plots and growers with access to drone technology to assess their cropping paddocks. It also value-added to a current GRDC-funded project by providing additional information on variation in plant biomass, plant height and NDVI values for 41 bread and durum wheat varieties under evaluation at sites with sodic subsoils to assist with the development of wheat with tolerance to sodic soils.

Publications and extension of project

This SAGIT project was presented to over 30 growers at an annual field trial crop walk run by the South Australian Durum Growers Association (SADGA) at Roseworthy in 2017. An article outlining the project results was also prepared for the Crop Science Society SA newsletter in 2018. Project findings were presented by R. Schilling at the SAGIT update in 2018, to the Loxton Agriculture Bureau in 2018, and at a Waite Future Leaders seminar in 2017. R. Schilling is scheduled to present the project findings at the Regional Outlook Conference ABARES in September 2018, to secondary school students at the SAGIT CSI: Crop Science Investigators event at Booleroo Centre in September 2018 and at the 5th International Plant Phenotyping Symposium in October 2018.

Path to market

Based on the feedback we have received on the findings from this SAGIT project, there is strong interest in using drones fitted with various cameras to image field trials and grower paddocks. The methods developed in this project to obtain useful information from drone images are applicable to anyone growing wheat and can be used to assess the growth and NDVI of wheat in field trial plots or paddocks. We envision that the use of drone technology will become increasingly adopted by those in the agricultural industry as more methods to obtain useful information from drone images are established for different crop types. For this technology to be adopted, growers and researchers require access to drones, skills in flying drones to capture plant images and knowledge to process and analyse drone images. Many growers, advisors, breeders and researchers already have access to drones with RGB cameras and the skills required for flights and after some training should be capable of completing the image analysis process.

POSSIBLE FUTURE WORK

Provide possible future directions for the research arising from the project including potential for further work and partnerships.

In 2018, SAGIT project UA318 will focus on evaluating the accuracy of plant traits obtained from drone images and continue to refine image analysis parameters. The findings from UA217 suggest that plot biomass values obtained from drone images can be useful. A specific focus of UA318 is to assess shoot growth rates by measuring biomass across multiple growth stages of various wheat varieties.

We have developed the skills required to image field trial plots using drones fitted with RGB and multispectral cameras and, importantly, refined the methods required to analyse plot images obtained from drones to provide useful information. There are several potential options for future focus including (1) establishing a central hub at the Unmanned Research Aircraft Facility (URAF) where growers, consultants, plant breeders and researchers can be trained to use drones and to analyse drone images of their crops, (2) conducting some specific drone field phenotyping workshops to bring together those in the industry who are currently using (or would like to use) drones to establish future partnerships and to discuss the methods established in this project, (3) the use of drone images as a tool for plant selections is feasible and more emphasis on extracting useful information from the plant images, such as water stress indices from the multispectral data, should be a focus in the future and (4) establishing methods to use drones to non-destructively assess plant traits in other crops, such as lentils or canola, which involve different leaf architectures/growth habits.

AUTHORISATION
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Position: Acting Executive Director, Research Services
Signature:
Date:

Submit report via email to admin@sagit.com.au as a Microsoft Word document in the format shown ***within 2 months*** after the completion of the Project Term.