Office Use Only

Project Code	
Project Type	

FINAL REPORT 2019

Applicants must read the *SAGIT Project Funding Guidelines 2019* 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 :	UA318

PROJECT TITLE (10 words maximum)
Investigating the accuracy of plant traits measured using drones

PROJECT DURATION

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

Project Start date	1 July 2018					
Project End date	30 June 2019					
SAGIT Funding Request	2019/20		2020/21		2021/22	

PROJECT SUPERVISOR CONTACT DETAILS

The project supervisor is the person responsible for the overall project

Title:	**First Name:**	**Surname:**
Dr	Rhiannon	Schilling

Organisation:
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:
Research Services Level 4, Rundle Mall Plaza, 50 Rundle Mall Adelaide SA 5000

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

In 2018, a DJI Phantom 4 Pro quadcopter with a red-green-blue (RGB) camera was used to image field trials of 16 bread wheat varieties at Mallala and Roseworthy at early tillering, stem elongation, booting, anthesis and grain filling. The RGB images were used to derive values of canopy height and biomass for each plot at each time-point, which were compared to ground measurements of plant height using a ruler and destructive biomass quadrat cuts. The major conclusions and achievements were:

- RGB images collected using drones can be used to quantitatively measure plant height and biomass of bread wheat in field trial plots.
- Canopy growth rates of bread wheat varieties in field trial plots were measured using non-destructive drone measurements of plot biomass from RGB images collected across a growing season.
- Variation in canopy growth rates was detected among 16 wheat varieties tested. This suggests pre-breeding and breeding trials could benefit from using RGB images for high-throughput screening of wheat lines across different environments.
- The accuracy of biomass and height values derived from RGB images was low in a dry growing season. This is likely due to a combination of factors, including that less variation in height and biomass occurred between varieties and/or that ground measurements in a dry season poorly represent the entire plot.

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, greenness and the growth rate of bread wheat varieties 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 first objective of this project was to refine methods for quantifying the plot biomass, greenness and the growth rate of bread wheat varieties using non-destructive aerial imaging was achieved. This project built on preliminary methods established in UA217 and has helped to develop protocols for analysing RGB images of cereal crops collected using a drone– which is now being used at Unmanned Research Aircraft Facility (URAF) by Australian plant breeding companies. We developed a protocol for the placement of ground control points at trial sites and the flight parameters necessary to capture good quality images of trial plots to allow repeated measurements of canopy height, plot biomass and plant greenness of wheat varieties at the same trial site throughout the growing season. It is now possible to non-destructively and quantitatively measure the canopy growth rate of wheat varieties in individual field trial plots.

The second objective was to obtain values of plant height and biomass from the RGB images to assist with the identification of plant traits linked to high grain yields at sites with sodic soils. We successfully obtained RGB images using a drone and derived quantitative values of plant height and biomass for each individual plot of 16 varieties (6 reps per variety). We detected differences in plant height, biomass and overall shoot growth rate among the varieties tested. However, it was not conclusive how these traits influence yield in sodic soils. We require a larger number of environments with sodic and non-sodic soils at which to test these varieties to make a clear assessment of their tolerance using the growth rate information obtained from this SAGIT project. This SAGIT project enabled the collection of imaging data at sodic sites at Mallala and Roseworthy on a core set of destructive trials that formed part of a larger National GRDC sodicity project. In this larger project, we had the same destructive trials as those in SA also conducted in QLD and NSW using the same bread wheat varieties from the same seed source. Over the last two years, our project collaborators in QLD and NSW sourced external funding to image their trial sites using drones at similar growth stages and using similar sensors. We have initiated discussions with our project collaborators and have formed an agreement to analyse the imaging data collected in QLD and NSW following the protocol established in this SAGIT project, particularly to assess the growth rate of the varieties and to assess the multispectral data collected. By combining, QLD, NSW and SA drone imaging data of a core set of varieties in sodic soils, we will increase the number of trial sites to 5 across two years (10 sites) and are expecting that this will increase our ability to identify any shoot growth related traits linked to the tolerance of varieties at sodic sites.

The personnel involved in the project included: Dr. Rhiannon Schilling, A/Prof. Glenn McDonald, Dr Ramesh Raja Segaran (URAF), Mr Dillon Campbell (URAF) and Ms. Lucy Porter (technical support) all from The University of Adelaide as well as 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 a field trial at Mallala, SA using drones fitted with RGB and multi-spectral cameras at four time-points throughout the growing season	Y	
Handheld measurements for calibrating images recorded for Mallala SA at four time-points throughout the growing season	Y	
Completion of remote pilot licence training	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.

(1) Aerial imaging of a field trial at Mallala, SA using drones fitted with RGB and multi-spectral cameras at four time-points throughout the growing season

Due to the low rainfall in 2018, and the particularly dry conditions at Mallala at sowing, we completed aerial imaging at the Mallala site (as listed in our KPI) and a second site at Roseworthy containing the same destructive trial. The results for the Roseworthy site are presented here. The destructive trials were sown as part of the GRDC-funded project UA00159 and contained 16 wheat varieties (Bremer, Condo, Corack, Emu Rock, Gladius, Gregory, Hartog, Janz, LPB-10-2555, Mace, Magenta, Scepter, Scout, Sunco, Trojan and Wallup) with 6 replicate plots each. These varieties were also imaged in 2017 in project UA217 and were selected based on greenhouse and field trial results for variation in tolerance to sodic soils (GRDC-funded sodicity project UA00159).

A DJI Phantom 4 Pro quadcopter containing a RGB camera was used to image both sites at five-time points (early tillering, stem elongation, booting, anthesis, late grain ripening) and consistent patterns in crop growth are evident throughout the year (Figure 1). The Roseworthy site was also imaged using a DJI Matrice 600 hexacopter fitted with an RGB, multi-spectral and thermal camera at grain-filling. By late grain ripening the destructive trial plots had a reduction in biomass due to quadrat cuts and soil sampling across the plots.

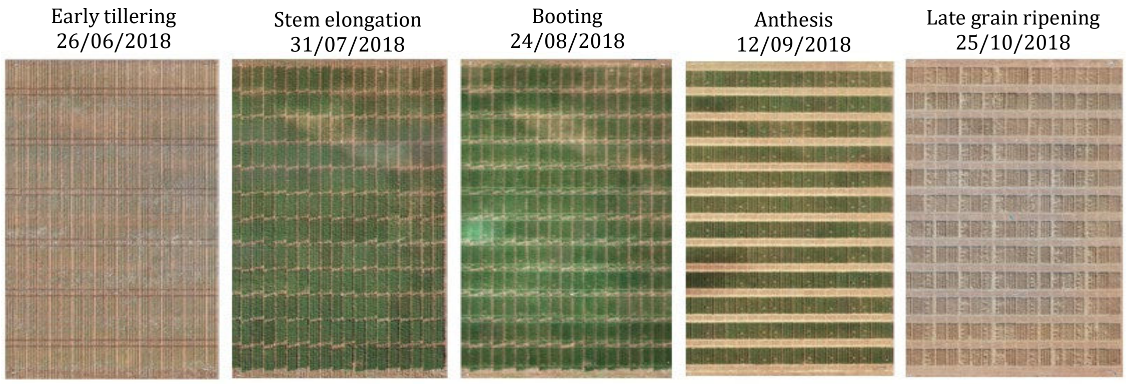

Figure 1: The five orthomosaics generated from RGB images captured using a DJI Phantom 4 quadcopter at 20 m above canopy height at five time-points for a bread wheat field trial at Roseworthy, SA in 2018.

(2) Handheld measurements for calibrating images recorded for Mallala SA at four time-points throughout the growing season

Handheld measurements of leaf greenness using a GreenSeeker, plant spectral data using a ASD Handheld 2 FieldSpec and plant height using a ruler were recorded at both Mallala and Roseworthy sites for each plot at three time-points (stem elongation, booting and anthesis). Plants were too small at the initial early tillering time-point for destructive sampling. Biomass cuts (2× rows of 50 cm) were collected from the destructive plots at the time of drone imaging and were used to determine the plot biomass and plant growth rates. In total, 16 varieties × 6 replicate plots × 3 time-points × 2 sites = 576 biomass cuts were completed including both fresh and dry weights recorded. Differences in the growth rates of varieties at the sodic sites were detected (Table 1).

(3) Completion of remote pilot licence training

R. Schilling completed a 1-week Remote Pilot Licence (RePL) (Multirotor up to 7 kg) and aeronautical radio operator certificate course run by URAF including a theory and practical examination based on the Civil Aviation Safety Regulations. She is now certified by the Civil Aviation Safety Authority (CASA) to operate remotely piloted aircraft (RPA).

(4) Software analysis of drone images

In 2018, more than 6,000 drone images were collected. Orthomosaics of RGB images collected at 20 m with 90% image overlap were generated for each time-point. Quantitative values of plant biomass, height (and greenness at anthesis only) were derived from each plot at stem elongation, booting and anthesis.

The mean ruler plant height was correlated to the mean canopy height derived from the RGB drone images across 3 time-points with an R^2 = 0.93 (Figure 2). The mean biomass obtained from a quadrat cut was also correlated to the mean canopy plot biomass across the 3 time-points with an R^2 = 0.93. This further supports UA217 that plant height and biomass values from drone images are accurate.

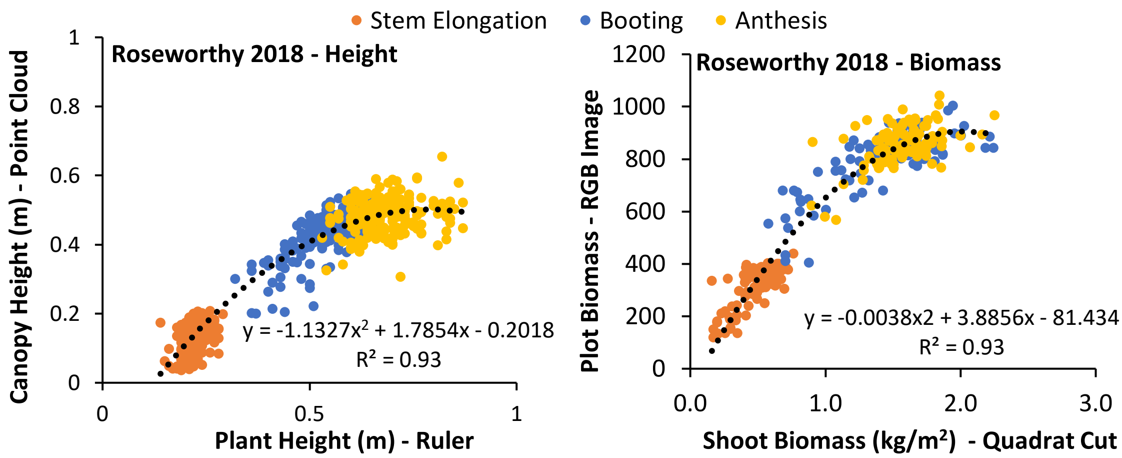

Figure 2: Correlations between plant height measured using a ruler with canopy height obtained from a point cloud and between shoot biomass from a quadrat cut and a biomass measurement obtained from RGB images from drone flights at Roseworthy in 2018.

However, in 2018, the correlation between the ground biomass measurements and canopy biomass values derived from the drone RGB images was low at the individual imaging time-points with an R^2 = 0.58 (stem elongation), 0.61 (booting) and 0.29 (anthesis) (Figure 3). Colleagues at The University of Queensland also reported a decrease in accuracy between ground measurements and values derived from RGB images at individual imaging time-points at their field trial sites in 2018 compared to previous years. It is likely that ground measurements in a dry season based on quadrat cuts poorly represents the entire plot (exaggerating effects that are present to a lesser extent in a year with adequate rainfall). It is also possible that the DJI Phantom 4 RGB camera is not accurate in when crop biomass is low or that the accuracy of extracting plant height and biomass from RGB images is limited by plant size. Several varieties imaged in 2017 were not included in 2018, including a landrace (very tall) and near isogenic lines (very short). The influence of a lack of these extremes is not known.

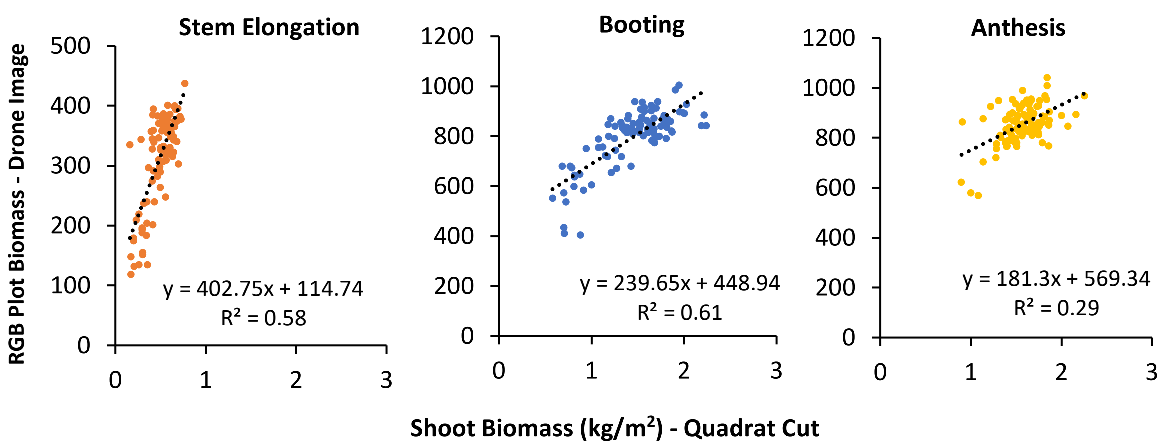

Figure 3: Correlations between shoot biomass from a quadrat cut and a biomass measurement obtained from RGB images from drone flights at Roseworthy in 2018 at stem elongation, booting and anthesis.

Nevertheless, given the strong correlation ($R^2 = 0.93$) between ground biomass quadrat cuts and canopy biomass values obtained from the drone images, it was possible to extract useful canopy growth rate information for the trial plots. An example of the canopy growth rate obtained from a linear regression of the mean canopy biomass values obtained at the three growth stages is shown in Table 1 and indicates the 16 varieties had a range in growth rates from 11.1 to 14.6 biomass units/day at Roseworthy in 2018.

Table 1: The canopy growth rate of 16 bread wheat varieties at Roseworthy in 2018 based on canopy biomass derived from RGB images of 6 replicate plots for each variety across 3 time-points (stem elongation, booting and anthesis) obtained using a drone.

Variety	**Plot Canopy Growth Rate (RGB biomass/day)**
Condo	11.1
Scepter	11.2
Hartog	11.4
Bremer	11.6
Emu Rock	11.6
Mace	11.9
Scout	12.1
Gladius	12.6
Janz	12.6
Sunco	12.9
Trojan	12.9
Wallup	12.9
Corack	13.0
Magenta	14.2
Gregory	14.5
LPB10-2555	14.6

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

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

This project used a drone with an RGB camera, which is readily available to South Australian growers, to image field trial plots at Mallala and Roseworthy at 5 time-points across the growing season. The RGB images collected through time were used to quantitatively measure plant height and biomass of bread wheat in field trial plots. The derived biomass values were then successfully used to determine the canopy growth rates of 16 wheat varieties. This project demonstrated that it is possible to measure non-destructively the canopy growth rate of bread wheat varieties using RGB images collected using a drone. Variation in canopy growth rates of the wheat varieties tested was observed suggesting our high-throughput and non-destructive measurements of canopy growth rates may benefit pre-breeding and breeding trials to assess the growth of wheat lines across different environments.

Intellectual Property

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

This project has generated IP including drone images (RGB, multispectral and thermal images) and handheld measurement data of trial plots at two field sites. 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 collected using drones can be used to quantitatively measure plant height and biomass of bread wheat in field trial plots.
- Canopy growth rates of bread wheat varieties in field trial plots were measured using non-destructive drone measurements of plot biomass from RGB images collected across a growing season.
- Variation in canopy growth rates was detected among 16 wheat varieties tested. This suggests pre-breeding and breeding trials could benefit from using RGB images for high-throughput screening of wheat lines across different environments.
- The accuracy of biomass and height values derived from RGB images was low in a dry growing season. This is likely due to a combination of factors, including that less variation in height and biomass occurred between varieties and/or that ground measurements in a dry season poorly represent the entire plot.

Potential industry impact

Each year, field trials are conducted throughout South Australia for the grains industry including those by agronomists, researchers, plant breeders and grower groups. Currently, very little quantitative measurements of individual plots (other than grain yield) are conducted, due to the time, costs and resources required to measure large numbers of plots, as well as the influence of destructive plot measurements on grain yield. This project focused on using RGB images from a drone to measure the canopy height and biomass of wheat varieties in field trials through time. Using these quantitative values obtained from the RGB images, this project non-destructively measured the canopy growth rate of bread wheat varieties and detected variation in this trait among varieties. This project suggests there is value in using a drone to obtain RGB images of field trial plots through time to measure crop growth rates and that this has the potential to benefit pre-breeding and breeding research by allowing more detailed assessment of wheat varieties in field trial plots. Growers with access to drone technology can also use RGB images obtained from their drones to assess the growth of wheat in their paddocks. The non-destructive and high-throughput measurement of biomass and crop growth rate has the potential to be used in various future scenarios, such as testing the effects of different managements (i.e. crop growth responses to grazing pressure, responses to fertilizer treatments) and to quantitatively assess the response of varieties/breeding lines to various environmental conditions (i.e. saline vs non-saline or low pH vs neutral pH soil) for more efficient pre-breeding and breeding of new crop varieties for South Australian growers.

The project also value-added to a current GRDC-funded project UA00159 by allowing more information to be obtained (such as crop growth rates) to assist with the development of wheat with tolerance to sodic soils. The full extent of this impact will only become apparent when the drone imaging data collected in this SAGIT project in SA is combined with the drone imaging data of the same trials conducted in NSW and QLD.

Publications and extension of project

This project has been extended at various engagements with growers and industry groups by R. Schilling including:

- The project was presented to over 30 growers at an annual field trial crop walk run by the South Australian Durum Growers Association (SADGA) and to the Loxton Ag Bureau on a visit to the Waite campus.
- Results were presented to growers at a Crop Science Society of SA meeting and a newsletter article outlining the project was published by the Crop Science Society.
- Findings were presented at the SAGIT annual update, as an invited presentation at the Australian Bureau of Agricultural and Resource Economics (ABARES) Regional Outlook conference and at a Ranked Set Sampling Symposium held by the University of Adelaide Biometry Hub and attended by international statisticians.
- A scientific poster on the use of drones to non-destructively assess wheat in field trials with dispersive subsoils was presented at the International Plant Phenomics Symposium (IPPS) held in Adelaide to world leading drone technology experts.
- An interactive educational display on the use of drone technology in agriculture was presented to 200 high school students at the SAGIT and AgCommunicators Crop Science Investigators (CSI) field day event at Booleroo.
- Discussions with high school teachers and career advisors on the use of drone technology and a research career also took place with participation in the 'More than Gumboots and Tractors' SAGIT-funded AgCommunicators event.

R. Raja Segaran presented this SAGIT project to researchers at the School of Agriculture, Food and Wine Research Day. He also conducted a two-day training workshop 'Mapping with drones for plant breeders' which was attended by the Australian Grain Technologies, Intergrain, SARDI and University of Adelaide staff.

The findings of this project have been published in several articles including:

- The Stock Journal newspaper article "Drones used in crop research" on 6th of July 2019: https://www.stockjournal.com.au/story/6259223/drones-used-in-crop-research/

- The Lead by Andrew Spence "Crop assessment project proves drone accuracy" on 29th of July 2019 http://theleadsouthaustralia.com.au/industries/primary-industries/crop-assessment-project-proves-drone-accuracy/
- The Waite Bulletin by Keryn Lapidge "Accuracy of drone measurements of crops determined" on 24th of July 2019 https://www.thewaite.org/accuracy-of-drone-measurements-of-crops-determined/

Path to market

This project helped to establish protocols at URAF to collect good quality RGB images of cereal crops and to analyse these images to obtain accurate quantitative values. The methods are applicable to anyone growing wheat and can be used to assess the growth of wheat in field trial plots or paddocks. In collaboration with URAF, Australian plant breeding companies are now using these methods.

For this technology to be adopted by growers and researchers, they require access to drones, skills in flying drones to capture good quality images and knowledge to process and analyse drone images (or access to a reliable company with these skills for outsourcing). A successful training course run by URAF in mapping with drones is now available to assist with increasing adoption of this technology: https://www.adelaide.edu.au/environment/uraf/training-and-education/mapping-with-drones

POSSIBLE FUTURE WORK

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

This project, along with UA217, enabled the development of protocols to use RGB images of wheat plots obtained through time via a drone to non-destructively measure the biomass and crop growth rate of wheat varieties. We envision that the use of drone technology will become increasingly adopted by those in the grains industry as more methods to obtain useful information from drone images are established for different crop types.

This project focused on wheat and it is not clear whether the protocols are applicable to other crop types. Methods using drones to non-destructively assess plant traits in other crops, such as lentils or canola, which involve different leaf architectures/growth habits, are needed. Our work to date, has focused on the use of one RGB camera fitted to a drone – it is possible that multiple RGB cameras on the same drone at different angles to the crop canopy could help to further improve the accuracy of measurements.

Future investment is needed to establish the accuracy and usefulness of different sensors fitted to drones, such as thermal, hyperspectral and LiDAR sensors. A greater emphasis on extracting useful information from the images of crops, such as refining water stress indices from the multispectral data or non-destructively measuring leaf nutrient concentrations with hyperspectral sensors fitted to drones, should be a focus in the future. The use of machine learning, including data fusion using deep learning, to assist with deriving maximum information from the images obtained by a drone along with other data layers available (such as soil EM38 or grain yield maps) should be investigated.