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Project Code	
Project Type	

FINAL REPORT 2024

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PROJECT TITLE	
Realising cereal yield potential using crop physiology and drone technology	

PROJECT DURATION						
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PROJECT REPORT:

Executive Summary

This project validated and fine-tuned outcomes related to sowing dates and optimal flowering periods from S/UA1021 in a dry and warm growing season of 2023 and used drone technology to develop a method for plant establishment counts and refined the use of drone technology for estimating cereal crop biomass.

Key outcomes from the project included:

- APSIM modelling suggests that the optimal flowering period (OFP) for wheat at Palmer is between the 25 August and 8 September, based on climatic data from 1973-2023.
- The mid to slow spring wheat (Rockstar and Denison) was more reliable across growing seasons for early sowing compared to winter wheat, although a new quick winter variety (Mowhawk) showed promise.
- The range in optimal sowing dates for current elite wheat varieties varied from the 2 April to 19 May depending on development speed and having access to sufficient soil moisture.
- APSIM modelling suggests that the OFP for barley at Palmer is between the 2 and 26 August, based on climatic data from 1953-2023.
- Very quick spring barley varieties have an optimal sowing range of the 12 April to 23 April in the Murray Plains region and this was significantly earlier than the same wheat phenology.
- Drone technology can be used to estimate plant establishment at standard sowing rates at the 1-2 leaf stage and the use of plant height was found to have the strongest correlation with aboveground dry matter estimates across species (barley and wheat) and among varieties.

Project objectives

The main objectives for the project were:

- To refine sowing times and the OFP for wheat and barley for the Murray Plains to inform on-farm decisions that enable crops to flower on time.
- Determine the potential for sowing early slow maturing wheat and barley varieties in the Murray Plains region.
- To identify and refine the physical growth components required for better modelling of biomass and growth rate of wheat and barley using non-destructive drone imaging.
- To develop a model and pipeline for the use of drone imaging to accurately count plant establishment after sowing.

Overall Performance

The key project objective was to fine tune the OFP and sowing dates developed from S/UA1021 across another season of field data. The 2023 season was again unique compared to the previous years with it being drier and much warmer than the previous seasons (2021 and 2022). This helped to more accurately define the start of the optimal sowing periods with plants developing quicker from warmer temperatures compared to previous growing seasons. It also helped with validating the observation of the barley OFP being earlier than the wheat OFP in the Murray Plains.

It is clear that there are limited opportunities for growers in the Murray Plains for early sowing opportunities from the heavy rain shadow of the Mt Lofty ranges. Supplementary irrigation was used to simulate an early break, which demonstrated that flowering dates and resultant yields from longer season varieties were competitive with main season varieties.

Plant architecture and phenology were the key components tested to determine if they were relevant to further fine tune biomass estimates made using images obtained from drones fitted with Red, Green and Blue (RGB), as well as multispectral sensors. Phenology differences between winter and spring wheats were detected in the drone images as differences in plant height and this was found to correlate very well with manual biomass cuts. Architecture differences in the barley, particularly with the variation in dwarfing genes creating prostrate and erect plant types in the spring types did show some variation. However, height was still a strong factor in estimates of biomass across these plant types.

Accurate plant counts could be achieved by a drone with strong correlations at standard sowing rates. A thresholding method was used to determine establishment counts, which required imagery to be taken at the 1-2 leaf stage for the most accurate counts. This method allows direct counting of individual plants instead of calibrating an NDVI curve to a plant number estimate, which would increase the accuracy for research trials in particular.

The personnel involved with the project and developed outputs included: Brendan Kupke, Melissa McCallum, A/Prof Rhiannon Schilling from SARDI. Dr Ramesh Raja Segaran, Dillon Campbell, Marnie Denlay, Molly Hennekam and Steven Andriolo from URAF. The Murray Plains farmers group were co-operators as well as host growers Scott and Zoe Starkey, and Adrian and May Bormann.

KEY PERFORMANCE INDICATORS (KPI)

KPI	Achieved	If not achieved, please state reason.
Initial model developed for plant establishment predictions	Yes ☒ No ☐	
Drone flights and biomass cuts completed	Yes ☒ No ☐	
Initial model of components developed for biomass prediction and growth rate over time	Yes ☒ No ☐	
Trial sown at Palmer for all times of sowing	Yes ☒ No ☐	
Drone flights and biomass cuts completed	Yes ☒ No ☐	
Final model developed for plant establishment predictions	Yes ☒ No ☐	
In season measurements, plots harvested, and data analysis completed with defined and validated OFP	Yes ☒ No ☐	
Final model of biomass prediction and growth rate over time completed	Yes ☒ No ☐	Number of parameters tested with height still being most accurate

TECHNICAL INFORMATION

The OFP for wheat in the Murray Plains is between the 25th August and 8th September and for barley between the 2nd August and 26th August.

The number of years of climate data used in the APSIM has proved important in determining the OFP timing for wheat and barley at Palmer. In Figure 1, the modelled relative grain yield curves using the last 30, 50 or 70 years of climatic data are displayed. This modelling shows, when using only the more recent years, that the OFP is shifting earlier, with an increasing yield decline from late flowering (Figure 1). Based off the past 50 years of climate data the simulated OFP for wheat was between the 25th Aug and 8th Sept, with a peak yield on the 3rd Sept. When comparing this to the actual field data (Figure 2), both 2021 and 2023 had peak yield on the 1st and 2nd Sept, demonstrating the accuracy of this wheat model across two individual growing seasons. The 2022 season defined by a decile 10 spring rainfall caused peak yield to occur a month later than predicted by the model. This highlights the limitations of a modelled OFP as it is an average of all seasons and appears to not well represent individual extreme seasons. The selection of years in barley was even more pronounced, with a modelled shift into the end of July using the past 50 and 30 years of data. This shift was dramatic when compared to the wheat and was something that could not be validated even with germination in the middle of April in this project, as the earliest actual in paddock flowering dates were only in early August. Therefore, the past 70 years of data was used with flowering dates in the project to validate a yield curve. This resulted in a barley OFP of 2nd to 26th Aug with peak on 17th Aug. Similar to the wheat, the peak yield for barley in the 2021 and 2023 seasons occurred within this range, but 2022 was much later (Figure 2). Importantly though, peak yield of the barley was earlier than wheat in every season.

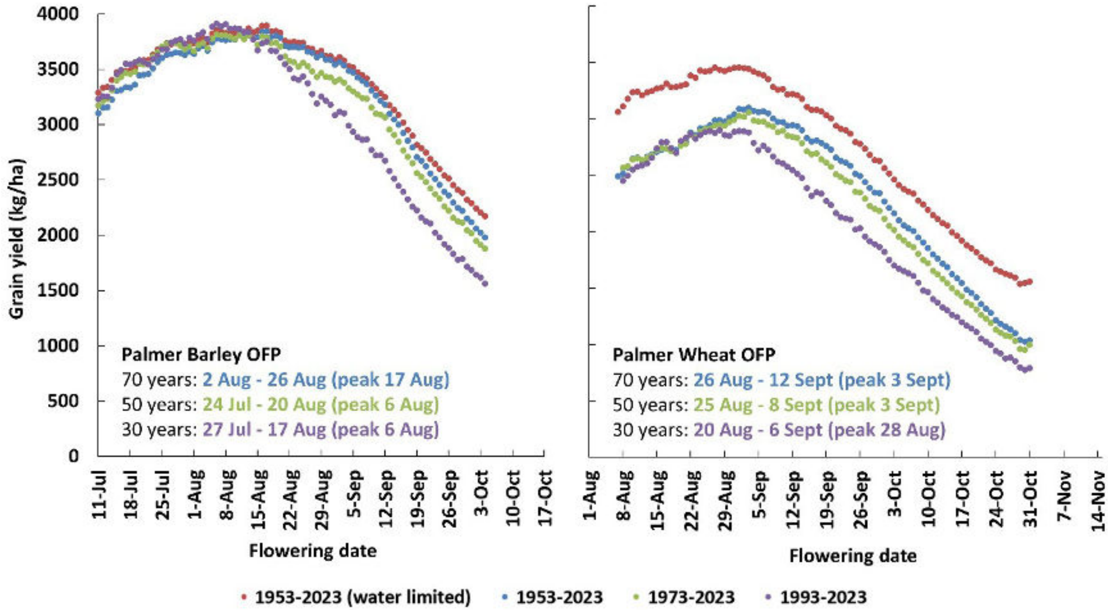

Figure 1 A simulation of the optimal flowering period (OFP) for a very quick barley variety Compass (a) and a quick-mid wheat variety Mace (b) at Palmer in the Murray Plains. The red dots show the water limited maximum potential yield using the past 70 years of climate data without any frost or heat reductions in yield. The green, purple and blue dots represent the frost, heat and drought 15 day running mean yield over the past 70, 50 and 30 years respectively. The flowering dates for the OFP are displayed as well as the flowering date of peak grain yield for each year run.

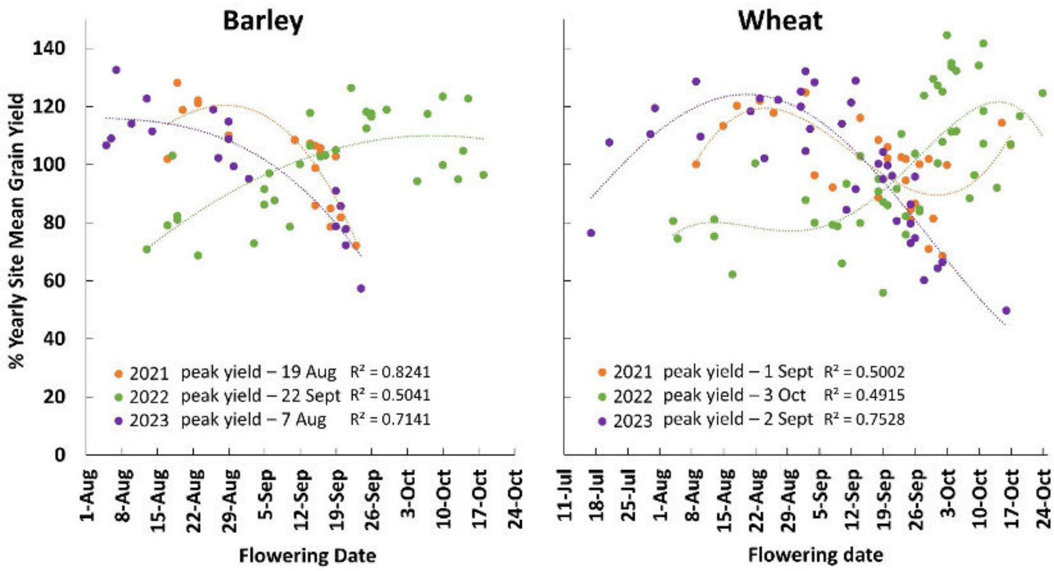

Figure 2 A comparison of the grain yield vs flowering date across the three seasons of field trials for all barley (a) and wheat (b) varieties and times of sowing at Palmer. A percentage of the yearly site mean yield is used to represent and compare relative grain yields across each season. The site mean yield for each season for barley and wheat respectively was: 2021 – 3.6 and 2.88 t/ha, 2022 – 4.24 and 3.07 t/ha, 2023 – 2.83 and 2.03 t/ha. The flowering date of peak grain yield for each year is shown. * mean yield of barley 2023 excluding Newton and Pixel winter barley due to crop failure.*

Optimal sowing periods for wheat and barley in the Murray Plains

To flower during the wheat OFP, a range of sowing dates are available for different spring phenology types. These start from the 2nd to 29th April for a slow spring (Denison) all the way out to the 6th to 19th May for Quick spring (Vixen). These ranges were developed by using field data from 2021, 2022 and 2023, which had different curves due to the seasonal variation in average temperatures. For the barley to flower in the OFP sowing times for the most common phenology type (Very quick spring barley) would be between the 12 April to 25 April in the Murray Plains. This is significantly earlier than current region practices of around early May, which would demonstrate a farming system shift for early sowing for barley could be beneficial. Further research trials with earlier flowering in July and August would help validate these conclusions.

April germinating slower spring wheat is higher yielding than winter phenologies

Slower spring developing wheats demonstrated an increase in yield over the winter types with April germination. All slower developing varieties took longer to reach flowering compared to Scepter, the benchmark and most popular variety for the region. However, few consistently matched it for yield, even with the quick-mid spring Scepter sown before its optimal sowing period (Table 1). Mid-spring variety Rockstar outyielded Scepter every season and flowered 5 to 9 days later. Denison also performed well but was lower yielding in 2022. Out of the winter wheats, the new variety Mowhawk (quick winter) matched Scepter in the two seasons it was evaluated. It also flowered 31 and 36 days later from the same sowing date. This shows promise in raising the yield potential of winter wheat in the low rainfall zone. DS Bennett was the only other winter wheat to outyield Scepter. This demonstrated that slow developing wheats in the Murray Plains could open-up the sowing window, however, the lack of early season breaks limits the opportunities to exploit these genetics.

Table 1 The mean grain yield and flowering dates for slower wheat phenology types across early times of sowing for the 2021, 2022 and 2023 seasons in comparison to popular varieties Scepter and Vixen. Z65 = flowering date, germ = germination

	2021 20th April germ		2022 12th April germ		2023 15th April germ		Mean Yield	Years out-yielding Scepter
	t/ha	Z65	t/ha	Z65	t/ha	Z65	t/ha	No. years
Vixen	2.88	9 Aug (-9)	2.28	4 Aug (-9)	2.17	21 Jul (-10)	2.44	0
Scepter (control)	*3.46*	*18 Aug*	*2.49*	*13 Aug*	*2.41*	*31 Jul*	*2.79*	-
Sheriff CL Plus	3.39	26 Aug (+8)	1.9	17 Aug (+4)	2.21	10 Aug (+10)	2.50	0
Rockstar	3.51	23 Aug (+5)	3.08	22 Aug (+9)	2.59	9 Aug (+9)	**3.06**	**3**
Denison	3.59	2 Sep (+15)	2.43	8 Sep (+26)	2.48	23 Aug (+23)	**2.83**	2
Valiant CL Plus	2.77	4 Sep (+17)	2.02	10 Sep (+28)	2.39	21 Aug (+21)	2.39	0
Longsword	2.65	8 Sep (+21)	1.71	19 Sep (+37)	2.11	2 Sep (+32)	2.16	0
DS Bennett	2.87	3 Oct (+46)	2.71	8 Oct (+56)	1.21	28 Sep (+58)	2.26	1
Mowhawk	-	-	2.78	18 Sep (+36)	2.42	1 Sep (+31)	-	**2**
Illabo	-	-	2.33	24 Sep (+42)	1.7	11 Sep (+41)	-	0

Plant establishment counts from drones show promise to increase accuracy and through-put

A mean accuracy of 88% was achieved in the first year of plant establishment counts extracted from drone imagery. GPS located plot centres were used to get still images across each plot, with imagery done at the 1-2 leaf stage, which proved important to identify individual seedlings. The thresholding method to determine individual plants from green pixels worked well and allowed for direct counting instead of calibrating an NDVI curve to a plant number estimate. This would increase the accuracy of these counts for research trials. This method was further tested in 2023 at reduced sowing densities (75%, 50%, 25%), which demonstrated that the error increased at lower plant densities, resulting in less accurate estimates (Table 2). Additionally, reducing the elevation of the drone from 10m to 5m when capturing the images increased the accuracy, without causing too much blur from wind turbulence on the plants.

Table 2 The relative accuracy and error of the thresholded drone imagery in counting wheat and barley seedlings in the sowing rate trial. The sowing rate percentage is of the standard rate of 112kg/ha for Scepter and 110kg/ha for Combat.

	Drone 10m elevation			**Drone 5m elevation**			**Handheld camera**		
Sowing rate percentage of standard	**Accuracy**	**Average Error**	**RMSE**	**Accuracy**	**Average Error**	**RMSE**	**Accuracy**	**Average Error**	**RMSE**
25	53%	0.47	35.47	64%	0.36	27.21	74%	0.26	32.18
50	60%	0.40	69.59	70%	0.30	53.62	80%	0.20	53.79
75	58%	0.42	116.64	73%	0.27	75.32	84%	0.16	46.75

Drone derived plant height most accurate parameter for dry matter estimates

Growth rates of different wheat phenologies do vary, especially between the spring Scepter and winter Longsword, with Scepter going through stem elongation a month earlier than Longsword. This difference in phenology can be detected with differences in plant height. There was a strong correlation between the height of all data measured across different sampling points and times of sowing against manually measured dry matter (Figure 3). This indicates that plant height is still a strong parameter for estimating dry matter, independent of different growth stages or even sowing dates. The two model barley varieties, Combat and Maximus CL, both had very strong correlations between plant height and manual dry matter in 2023 and were similar in their line of best fit even with different canopy architectures (Figure 3). Multiple other parameters extracted from the RBG and multispectral drone imagery were tested to determine if they could be useful for more accurately estimating dry matter in plots. Sum of heights, canopy volume, canopy cover and NDVI were compared but with limited success due to low correlations with dry matter. NDVI was useful for early season sampling dates with less than 1000kg/ha of dry matter (26th June r^2=0.947 for combat). However, this correlation was not consistent after canopy closure and further into crop senescence, whereas the height correlation to dry matter was consistently strong across the whole growing season.

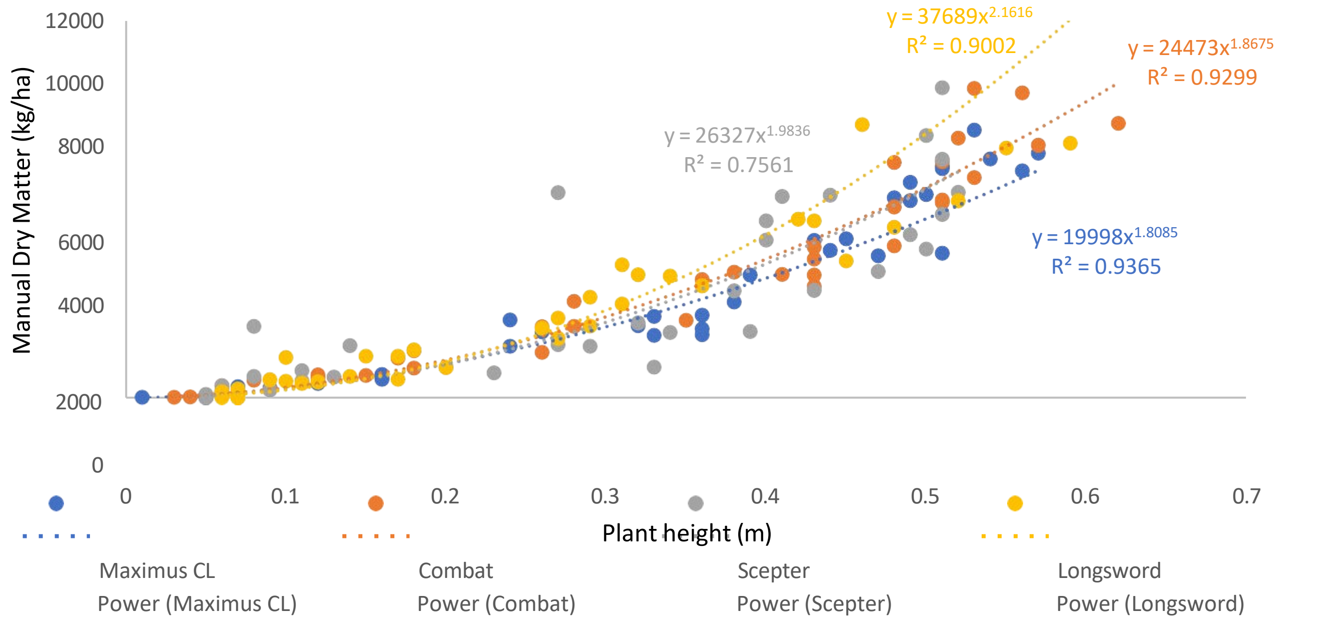

Figure 3 The relative dry matter of Combat, Maximus CL, Scepter and Longsword across times of sowing for the drone derived plant height. A line of best fit is fitted with the relative equation and R2 square value.

The main issue with using height as an indicator for dry matter, is that it can vary between seasons. This was evident in 2022 where trendlines were not as strong as in 2023 (Figure 4). The wet spring influenced late season growth, which resulted in excessive tillering in late sown plots, and benefited crops that were not yet senescing which could still benefit due to early times of sowing already senescing. The 2023 season had a steady drying at the end of the season with all times of sowing finished off uniformly and not influenced by late rainfall.

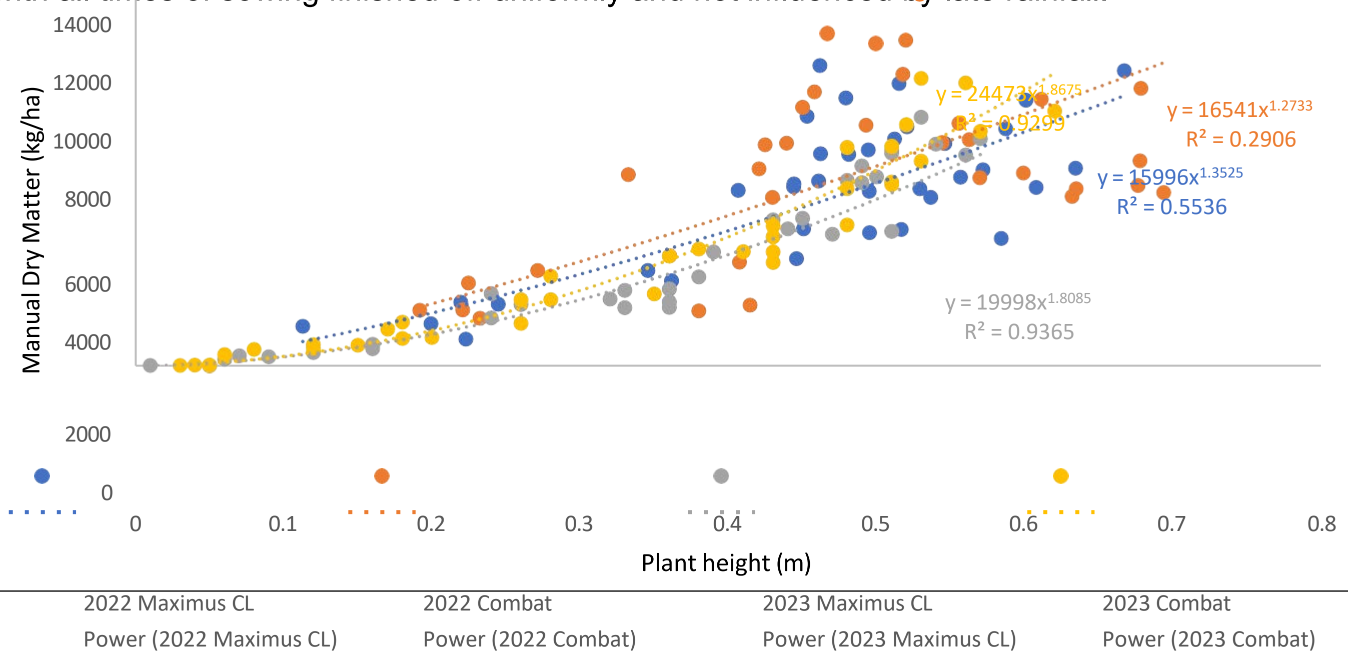

Figure 4 The relative dry matter of Combat and Maximus CL times of sowing for the drone derived plant height for the 2022 and 2023 season. A line of best fit is fitted with the relative equation and R2 square value which demonstrates a lower correlation in 2022.

CONCLUSIONS REACHED &/OR DISCOVERIES MADE

A key conclusion from the project is that the optimal time to flowering in barley is different compared to wheat. Consistently across seasons, barley outyielded wheat and did so at an earlier flowering time. APSIM was also in agreement with this, as the simulated OFP was two weeks earlier than the wheat. The difference in the time of peak yield in the field trial between barley and wheat was on average around two weeks. This resulted in the optimal sowing period for the most common very quick spring barley being much earlier than an equivalent wheat.

The slower spring wheat types seem to have the advantage over winter types in the Murray Plains with April germination dates. Rockstar and Denison were top performers from April germination. The new variety Mowhawk (quick winter) did perform well in the two seasons of testing and has potential to improve the winter wheat yield potential in the LRZ in general.
The absence of an early season break during the duration of the project does reduce the opportunity for local growers to exploit these phenology types. However, other low rainfall zones, particularly the upper EP would likely benefit from these outcomes who would have a similar frost, heat and drought risk, and want to open up the sowing window.

Plant counts for cereals using images derived from drones has often proved tricky due to overlap of plants, which has led to NDVI calibration methods being used. Timing of the drone flight proved important by targeting the 1-2 leaf stage so individual plants could be counted. Lowering the drone height improved accuracy of the counts, but as mentioned a higher relative error was observed at lower sowing rates with plants being more sparce.

Height derived from a drone was a strong parameter for dry matter estimation. This was independent of phenology type where both the winter type Longsword and spring Scepter both has strong correlations. This held true across sowing dates and growth stages during the season. The different barley canopy architectures did not influence the correlation with height and biomass estimation.

INTELLECTUAL PROPERTY

The project has not created IP with all outputs/industry reports available to growers. Further work needs to be done to validate drone-based establishment counts in cereals before it could have commercial value and across research programs.

APPLICATION / COMMUNICATION OF RESULTS

Main findings for the project included:

- APSIM modelling suggests that the optimal flowering period (OFP) for wheat at Palmer is between the 25 August and 8 September, based on climatic data from 1973-2023.
- The mid to slow spring wheat (Rockstar and Denison) was more reliable across growing seasons for early sowing compared to winter wheat, although a new quick winter variety (Mowhawk) showed promise.
- The range in optimal sowing dates for current elite wheat varieties varied from the 2 April to 19 May depending on development speed and having access to sufficient soil moisture.
- APSIM modelling suggests that the OFP for barley at Palmer is between the 2 and 26 August, based on climatic data from 1953-2023.
- Very quick spring barley varieties have an optimal sowing range of the 12 April to 23 April in the Murray Plains region and this was significantly earlier than the same wheat phenology.

Drone technology can be used to estimate plant establishment at standard sowing rates at the 1-2 leaf stage and the use of plant height was found to have the strongest correlation with above ground dry matter estimates across species (barley and wheat) and among varieties.

The key industry impact from the project was the production of locally relevant agronomic information on flowering and sowing time among different varieties in the Murray Plains and wider low rainfall zone. Growers and agronomists now have a greater understanding of how different phenologies grow and develop across different decile seasons. The engagement from the Murray Plains Farmers group members enabled growers to visibly see and understand the influence of time of sowing in relation to their own farms and the potential new phenology types that can be exploited in different seasons. Particularly the understanding of using longer season varieties with early break opportunities in wheat. Alternatively, the relatively lower risk for early sowing barley compared to wheat was also demonstrated with no reduction in grain yields due to frost from early sowing.

The addition of a dry sowing treatment from early April sowing, provided a useful comparison to waiting for the season break (TOS 3) in terms of yield, which has seen local growers have the continued confidence to dry sow in the Murray Plains.

The project had numerous extension opportunities with presentations and field walks conducted by Brendan Kupke including:

- Murray Plains Farmers spring crop walks and research updates
- Elders Murray Bridge research update and crop walk
- Crop Science Society SA presentation
- Tatiara Crop Competition presentation
- Nutrien Ag Strathalbyn crop walk

A number of trial reports and publications were produced from the results of the project which included:

- 2022 Industry report for Murray Plains farmers at research update; further distributed to local agronomists and plant breeders
- 2023 Industry report for Murray Plains farmers at research update; further distributed to local agronomists and plant breeders
- 2023 EP Farming Systems summary report for LRZ

The latest industry report from the start of the year will continue to be helpful for growers determining when to sow and what spread in flowering time across different seasons. Adoption of the project outcomes have already been quite positive with local growers changing their attitude to dry sowing and priorities around when to sow barley and wheat. Local agronomists have also been in contact this season to discuss barley options for early sowing from the project after a March thunderstorm in the Murray Plains. Having access to these reports will be important for growers and agronomists to compare options with the continued variability with seasonal breaks enhanced by climate change.

POSSIBLE FUTURE WORK

The unique part of the project was the combination of crop modelling and field trial work, to validate the modelling. This helped growers understand how models are developed but also provided a great extension opportunity through practical demonstrations at field trials, which has helped with uptake of results. A similarly designed project could be set up in other regions of SA that have not had local research done in the area of crop phenology, OFP and time of sowing. This has already been exemplified by Brendan being asked to present on these topics in other areas of the state, such as the Upper South East and the Fleurieu Peninsula. A lot of the outputs were transferable, but more detailed field trials and modelling like was done as part of this project would provide further benefit to these growers.

Another key outcome of the project was the early sowing opportunities and importantly the lower risk of flowering early in barley. Modelling and field trials have demonstrated that sowing barley early and flowering early is a better option than sowing quick spring wheat early which has shown a reduction in yield. Further understanding the relative frost risk of barley would help with giving growers confidence with early sowing barley. Work is being done currently through GRDC to quantify this risk from previous barley agronomy trials, but more demonstrations of early sowing in SA would be useful to help back up these outcomes. Additionally, to validate some of the barley OFP modelling, trials with earlier sowing and flowering dates that were produced in this project would be useful. Particularly sowing dates in early April and end of March, where in 2024 some Murray Plain growers had an opportunity to sow and germinate crops during this time frame from a March thunderstorm.

A model was developed and validated from the plant counts conducted by the drone. Different methods were tested to make the model as accurate as possible while still making the process as time-efficient as possible compared to manual counts. A larger data set would now be required to further develop these methods across seasons and environments, to ensure the accuracy of these estimates.