Northern NSW research results 2021

RESEARCH & DEVELOPMENT – INDEPENDENT RESEARCH FOR INDUSTRY

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Foreword

The Northern Cropping Systems Unit of NSW Department of Primary Industries (NSW DPI) is once again pleased to be able to offer you an overview of results from R&D undertaken in the Northern Grains Region of NSW. For over 10 editions the book has aimed to compile and extend the findings and outcomes of these experiments, which can then be used to guide and inform practice change throughout the region. Our audience includes grain growers, agribusiness, consultants and other research bodies.

The majority of this work is conducted in partnership with the Grains Research and Development Corporation (GRDC), using grower's and NSW government investment to address key production and sustainability constraints along with opportunities facing growers, across both summer and winter cropping systems of the region.

The NSW DPI Northern Cropping Systems Unit is based across the Northern Grains Region of NSW with the key research hubs at Trangie, Tamworth, Narrabri and Grafton, and satellite sites at Breeza and numerous on-farm locations. This geographical spread allows work to be replicated across environments creating greater rigor of the findings and recommendations.

The papers are based on scientifically sound and independent research and take into account the situation, location and season in which the work has been conducted. These experiments cover disciplines from agronomy to plant breeding, crop protection, along with phenology, soils and nutrition research. This is the 11th Edition, which in many cases provides updates on research that has been conducted over several years and locations.

The research reported on in this book is only possible through the cooperation of the many growers, advisors and consultants who collaborate with our research teams throughout the year. These collaborators are individually acknowledged at the end of each paper. NSW DPI is fortunate to partner with other organisations such as universities, CSIRO, grower groups and other state-based agricultural departments.

We hope you find the papers to have some value to your business and appreciate any feedback that will help improve future editions of the Northern NSW Research Results book.

Guy McMullen
Director Northern Cropping Systems
Tamworth Agricultural Research Institute
On behalf of the Northern Cropping Systems Unit
NSW Department of Primary Industries

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Northern farming systems – Spring Ridge site report, 2015–2020

Jon Baird[1], Matt Dunn[2] and Mike Nowland[3]

[1] NSW DPI Narrabri
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Key findings

- The lower crop intensity system resulted in a significantly lower overall system grain/lint productivity (t/ha) compared with the baseline (–4.8 t/ha) however, it performed very well in the economic evaluation (+$56/ha).
- Winter pulse crop choice (chickpea versus faba bean versus field pea) had little effect on the long-term soil nitrate dynamics.
- The higher legume system required less nitrogen (N) fertiliser inputs (114 kg N/ha vs 137 kg N/ha) and exported more N (428 kg N/ha vs 347 kg N/ha), while maintaining higher soil nitrate (+80 kg N/ha) than the baseline system at harvest 2020.
- Potassium (K) export in grain ranged from 34 kg/ha to 73 kg/ha between all systems. The highest removal was seen in the higher legume system. This K removal is concerning, particularly in the long-term, considering that currently there is no additional K applied to offset this removal.
- Short fallows (4–8 months) out of wheat gave the highest fallow efficiencies (20–53%) compared with the two short fallows (4–8 months) following pulse crops (0–17%) and the longer fallows after cereals (10–34 months) (12–22%).

Introduction

Growers face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems (FS). Change is needed to maintain FS productivity and profitability. Consequently, Queensland Department of Agriculture and Fisheries (QDAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are collaborating to conduct an extensive field-based FS research program, focused on developing FS to better use the available rainfall to increase productivity and profitability.

The project started in 2014 and will continue through to 2025 with sites in NSW and Qld. The experiment examined multiple aspects of a northern FS, including the effects modified systems have on water use, nutrient use, weed ecology and soil/root pathogens.

What was done

In 2014 research began in consultation with local growers and agronomists to:

- identify the key FS limitations, consequences and economic drivers in the northern region
- evaluate crop sequences that can meet the emerging challenges
- identify and to develop the systems with the most potential for use across the northern region.

Experiments were established at seven locations: a large factorial experiment at Pampas, and at six locally relevant sites (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red and grey soils)).

Site details

Location

"Nowley Farm" - University of Sydney research farm, Spring Ridge, Narrabri (Latitude 31°34'31.52"S, Longitude 150°10'53.44"E).

Farming system protocols at Spring Ridge

- **Baseline**: represents a standard cropping system for the local grains region. The planting trigger will be 50% of a full moisture profile.
- **Higher nutrients**: This system duplicates the crop sequence for the baseline system, but fertiliser application rates will be targeting a higher yield (90% of seasonal yield potential for N and 100% replacement for phosphorus (P)).
- **Higher crop intensity**: the trigger for planting will be 30% of full soil moisture profile.
- **Higher crop diversity**: This system is investigating alternative crop options to help manage and reduce nematode populations, disease and herbicide resistance.
- **Higher legume**: focused on soil fertility and reducing the amount of N input required through fertiliser. One in every two crops must be a legume.
- **Lower crop intensity**: designed to plant at a lower frequency when the soil moisture profile is greater than 80% full. High value crops are targeted.

Site characteristics

Nowley is a chocolate vertosol with plant available water content (PAWC) of 240 mm to a depth of 120 cm (Table 1). It is quite likely additional water could be available below the 120 cm depth level in the soil profile.

Table 1 Site soil chemical characteristics for 0–120 cm depth at Spring Ridge.

Characteristic	Soil depth (cm)				
	0–10	10–30	30–60	60–90	90–120
pH_{Ca}	6.18	7.35	7.96	8.26	8.37
Organic carbon (%)	1.09	0.66	0.67	0.52	0.31
Colwell-P (mg/kg)	66.40	18.70	5.22	6.07	11.30
Conductivity (dS/m)	0.10	0.16	0.18	0.25	0.33

Weather report

Rainfall was highly variable over the past six years at Spring Ridge, with only the 2020 calendar year exceeding the long-term average (LTA) rainfall (Table 2).

On three occasions the site received rainfall greater than the LTA. The 2016 winter, 2017 summer and 2020 summer.

Table 2 Spring Ridge summer and winter seasonal rainfall (2015–2020) and LTA rainfall.

Period	Rainfall (mm)						
	2015	2016	2017	2018	2019	2020	LTA
Preceding summer (December–May)	265	214	416	177	207	620	329
Winter (June–November)	186	340	123	210	165	178	257

System cropping sequence at Spring Ridge

The Spring Ridge FS experiment started in the winter of 2015, with wheat grown across all systems to establish a baseline (Figure 1).

During the project life:

- the baseline system (grower's practice), the higher nutrient, higher legume, higher intensity and higher diversity systems all had five crops planted

- the lower intensity system, with a conservative planting trigger of >180 mm PAWC, had only three crops planted during the life of the project.

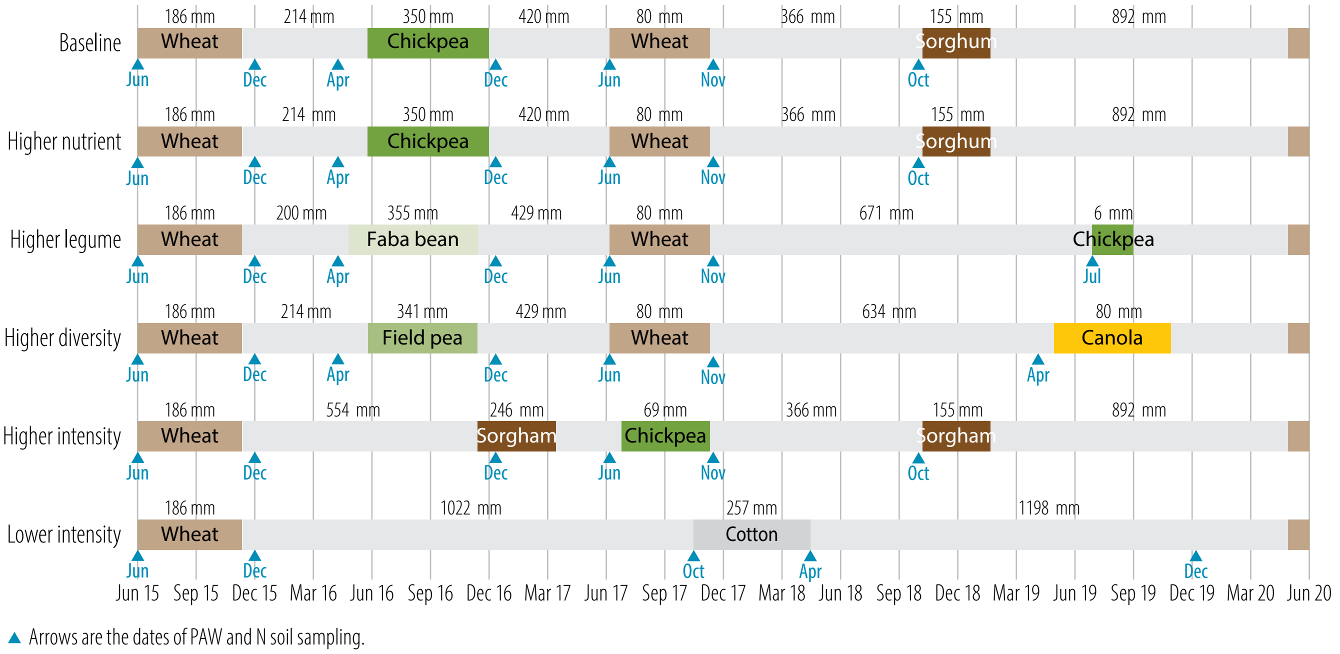

Figure 1 Crop sequences implemented in each of the FS, with the rainfall during each crop (in-crop rain) or during intervening fallow periods (grey).

Results

System grain yields

- The cumulated grain yields of the various systems at ranged between 16 t/ha and 10.7 t/ha (Figure 2). Increasing the legume frequency (higher legume), increasing cropping diversity (higher diversity) and applying greater amounts of nutrients (higher nutrients) resulted in similar grain yield to the baseline system (16, 15.5, 15.3 and 15.5 t/ha respectively).
- The higher intensity system had a lower grain yield than that of the baseline system. This can be attributed to the variable and lower than average rainfall over the project life.
- As expected, the lower intensity system with fewer crops planted had the lowest grain yield at the site with 10.7 t/ha.

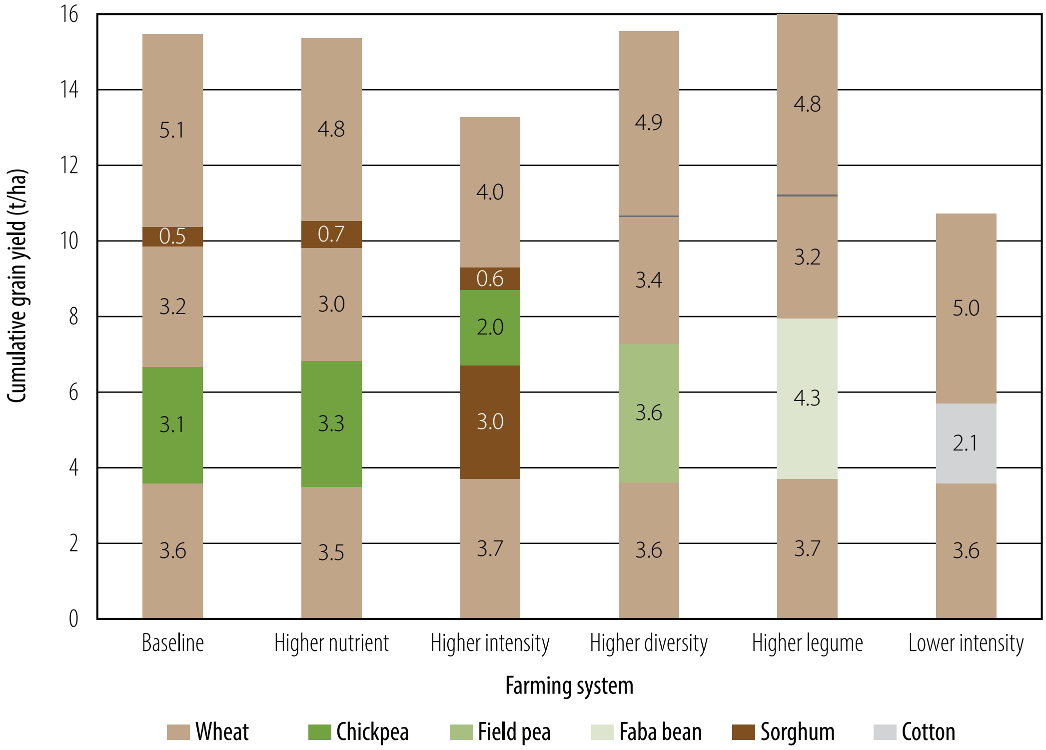

Figure 2 Cumulative system grain yield of the six farming systems treatments at Spring Ridge (2015–2020).

System gross margin

At Spring Ridge it was an advantage to extend the fallow periods and sow fewer, but higher, value crops (such as cotton), compared with sowing more frequently. This was due to the high value of the 2017 cotton crop ($1440/ha) in the lower intensity system and the failure of the 2018 sorghum crop in the higher intensity system. Growing diverse crop species (higher diversity) decreased system gross margins (GM) compared with the grower's practice (baseline). In the higher diversity system the 2016 low value field pea crop and the canola failure in 2019 lowered the cumulative system GM and resulted in the lowest return of all the systems (Figure 3).

System water and nutrient efficiency

Both the higher diversity and higher legume systems had the highest water use efficiency (WUE), 12.3 kg/mm and 13.2 kg/mm respectively, which was >3 kg/mm more than the baseline system (Table 3). When a dollar value was put against water use ($/mm), the lower intensity system with its high value grain crops was the best performer ($2.36/mm of rainfall).

A project outcome across all sites found that the shorter the fallow period, the greater the fallow efficiency. This was the case at Spring Ridge, with the higher intensity system having the best WUE compared with other systems.

Two methods were used to evaluate water use efficiency in this experiment: productivity (kg/mm) and economically ($/mm).

- Both higher diversity and higher legume systems had a better WUE than the baseline system (>3 kg/mm) for the first six years.
- The high value of cotton in the lower intensity systems resulted in the best $/mm return (>$0.5 /mm than the higher legume and >$1.5 /mm than the baseline system).

The higher legume systems had the greatest N use, as modern high-yielding legumes export high amounts of N in the harvested seed. While N exportation was high, growing a higher frequency of legumes decreased the system's reliance on synthetic N fertiliser, resulting in a lower drawdown of background soil mineral N compared with the baseline system.

Another aspect of modern legumes is the high exportation of K from the system. In this experiment, all systems that contained a legume had large K removal in the grain. Future management might require K application to ensure there is no K deficiency for future cropping sequences as there are no supplemental K inputs into these systems.

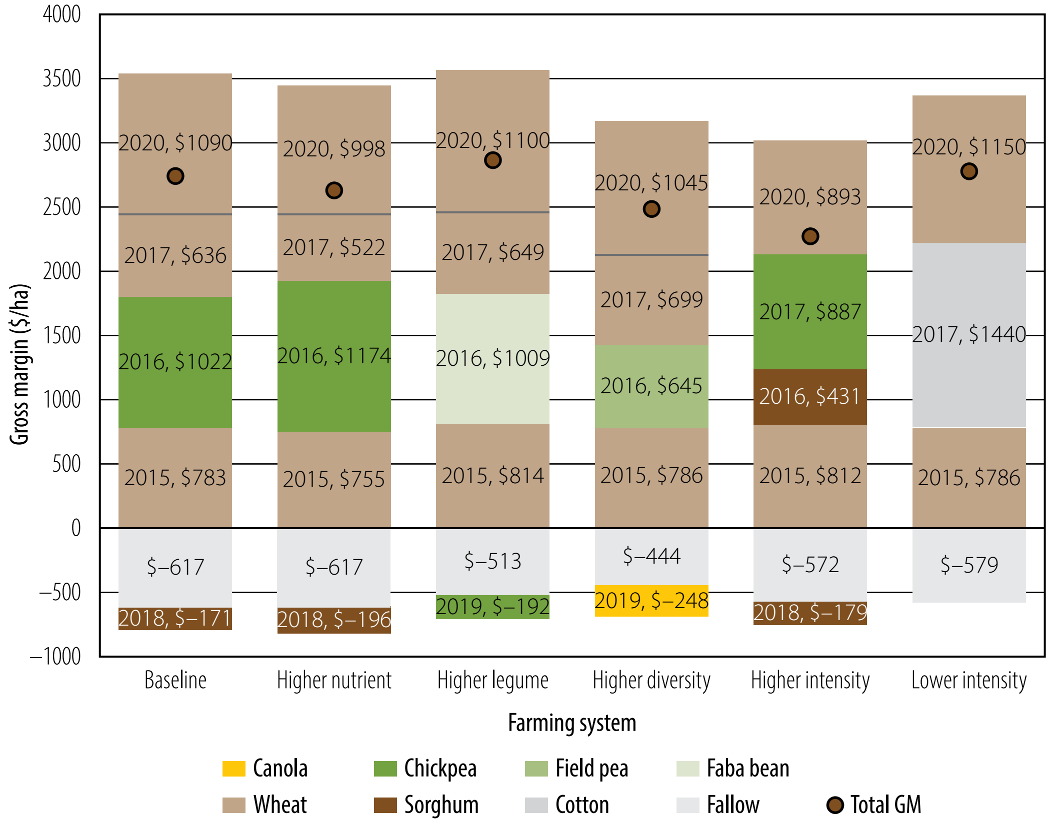

Figure 3 Farming system GM at Spring Ridge (2015–2020).

Table 3 System water and nutrient use at Spring Ridge (2015–2020).

System	System water use			System nutrient use			
	Grain WUE (kg/mm)	Fallow efficiency (%)	System WUE ($/mm)	Exported N (kg N/ha)	System NUE (kg grain/ kg N)	Grain P removal (kg P/ha)	Grain K removal (kg K/ha)
Baseline	8.9	16	0.72	347	1.32	38	62
Higher nutrient	9.0	17	0.72	358	1.27	37	63
Higher intensity	7.4	24	0.57	290	1.80	27	34
Higher diversity	12.3	14	1.68	378	1.31	35	63
Higher legume	13.2	14	1.80	428	2.68	40	73
Lower intensity	7.4	11	2.36	398	2.84	16	50

FE = ∑soil water ÷ ∑fallow rain
Grain WUE = ∑grain yield ÷ crop water use
System WUE = system GM ÷ crop water use
Exported N, P and K = grain yield × grain content (N, P or K)
System NUE = exported N ÷ ∑crop N use

System influence on crown rot

Eighteen soil and plant pathogens were monitored throughout the FS experiment, with sampling occurring pre-sowing and post harvest, and similar timings when in fallow, over the five years.

At Spring Ridge, the pathogen that had the largest affect on the various systems was crown rot, caused by the fungus *Fusarium pseudograminearum* (Fp). It is a stubble-borne disease of cereals and is endemic across northern NSW. Figure 4 shows the trends in Fp inoculum over the experiment for the six FS, sampled on the rows. Over this period, Fp disease risk levels have varied significantly between systems with four of the six systems reaching the high-risk category at various times. In 2017 applying higher fertiliser rates (higher nutrients system) resulted in greater Fp infestation – this result corresponds with recent data from NSW DPI pathologist Steve Simpfendorfer (2020).

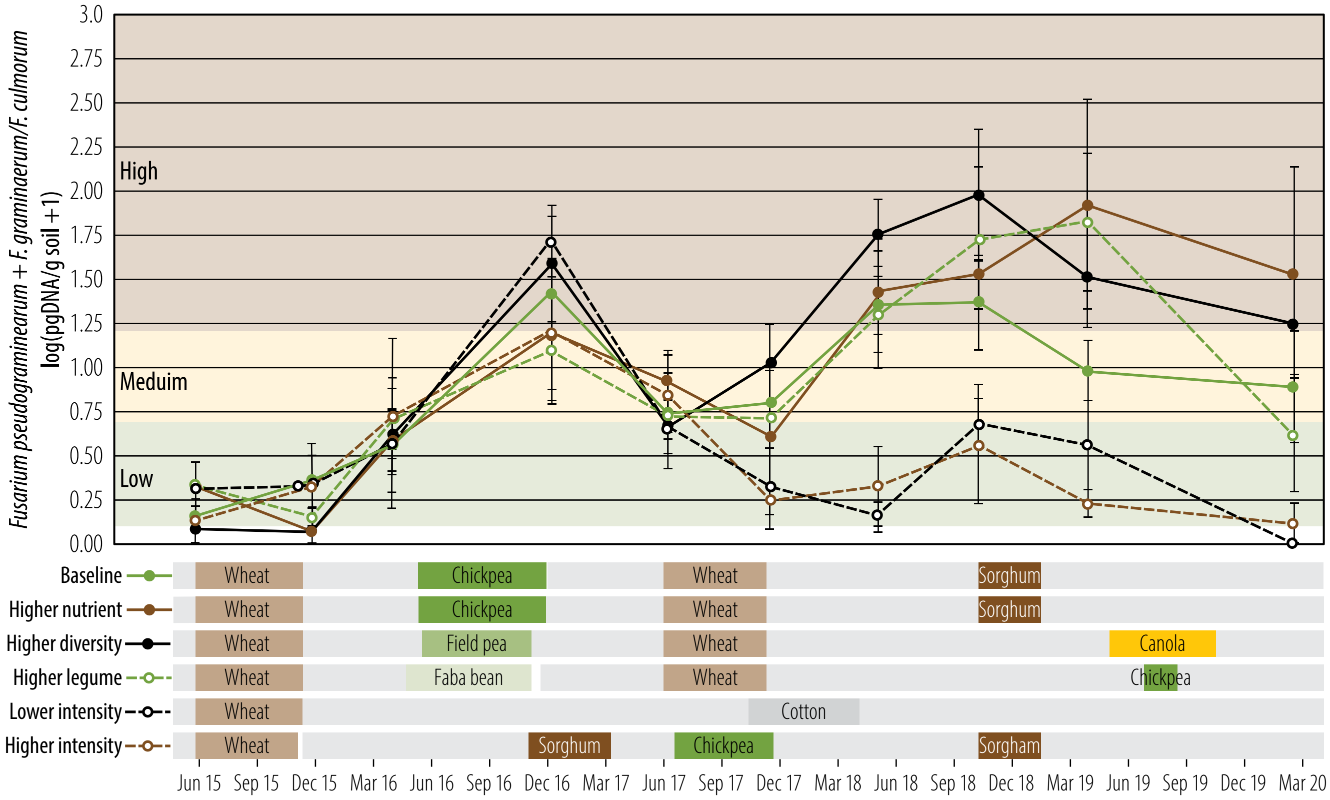

Figure 4 Trends in crown rot at Spring Ridge over time across the six systems.

Conclusions

- The lower intensity system had lower grain/lint productivity (t/ha), but it performed very well in the economic evaluation. The system productivity was more than 3 t/ha lower than the other five systems between 2015–2020, but the strong GM performance of the 2017 cotton crop ($1440/ha) resulted in a high system GM, which is equal to the highest performing systems. Also, the lower FS cost associated with low cropping frequency meant the lower intensity had the highest return on variable costs.
- Since 2017, the higher nutrient system (which had an additional 69 kg N/ha of fertiliser N applied) has maintained higher mineral N levels than the baseline system (101 kg N/ha compared with 60 kg N/ha) at harvest 2020.
- Growing a higher proportion of legume crops increased the N balance. The higher legume system has required less N fertiliser (114 kg N/ha versus 137 kg N/ha) and exported more N from the system as grain (428 kg N/ha versus 347 kg N/ha), while maintaining more soil nitrate (–46 kg N/ha versus –125 kg N/ha) than the baseline system.

- All systems are removing large amounts of K. Potassium export in grain ranged from 34 kg N/ha to 73 kg/ha between all systems. The highest removal was seen in the higher legume system. This K removal is concerning in the longer term considering currently there is no offsetting this removal with K inputs into any of these systems.
- Short fallows out of wheat crops achieved higher fallow efficiencies compared with both short fallows out of winter pulse crops and long fallows systems. Short fallows (4–8 months) out of wheat gave the highest fallow efficiencies (20–53%) compared with both short fallows (4–8 months) following pulses (0–17%) and longer fallows from cereals (10–34 months) (12–22%)

Acknowledgements

This experiment was part of the project 'Northern Farming Systems' (DAQ00190 and CSA00050), a collaborative research project between state agencies in Queensland and NSW. The project is jointly funded by NSW DPI, QDAF, CSIRO and GRDC. We would like to specifically thank the host at Nowley, The University of Sydney research farm, who have assisted us in implementing the experiment.

Reference

Simpfendorfer, S. 2020. *Cereal disease management in 2020 – from famine to moving feast!* GRDC update paper, July 2020. https://grdc.com.au/__data/assets/pdf_file/0026/430496/GRDC-Update-Paper-Simpfendorfer-Steven-July-2020.pdf

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Northern farming systems – Narrabri site report, 2015–2020

Jon Baird[1], Matt Dunn[2] and Gerard Lonergan[1]

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Key findings

- The three systems (higher nutrient, higher legume and higher intensity) had similar productivity and gross margins (GM) compared with the baseline system, which represents the typical grower's cropping rotation for the local area.
- The systems with lower cropping frequency (lower intensity) and those aimed at growing more diverse crops (higher diversity) had lower grain production compared with the baseline system.
- In 2016, nematode numbers (*Pratylenchus thornei* (Pt)) numbers were higher after chickpea compared with faba bean and field pea, while canola and cotton reduced Pt numbers that year. The higher Pt numbers after chickpea in 2016 continued through to December 2017, after that year's wheat crop.
- High yielding legumes exported more nitrogen (N) and potassium (K) from the farming systems (baseline, higher nutrient, and higher legume) compared with the systems that contained no legumes or lower yielding legumes (higher diversity, high intensity, and lower intensity).
- The high cropping diversity (higher diversity) system reduced soil pathogen levels over the five years compared with the baseline system.

Introduction

Growers face challenges from declining soil fertility, increasing herbicide resistance, and increasing soil-borne pathogens in their farming systems (FS), hence change is needed to maintain FS productivity and profitability. The Queensland Department of Agriculture and Fisheries (DAF), New South Wales Department of Primary Industries (NSW DPI) and CSIRO are collaborating to conduct an extensive field-based FS research program, focused on developing FS to better use available rainfall and to increase productivity and profitability.

The project started in 2014, and will continue through to 2025 with sites in NSW and Qld.

The experimental site at Narrabri examined multiple aspects of a northern FS, including the effects modified systems have on water use, nutrient use, weed ecology and soil/root pathogens.

What was done

In 2014, research began after consultation with local growers and agronomists to identify the key FS limitations, consequences and economic drivers in the northern region.

Experiments were established at seven locations including a large factorial experiment at Pampas, and local sites at six regional centres (Emerald, Billa Billa, Mungindi, Spring Ridge, Narrabri and Trangie (red and grey soils)).

Site details

Location

Llara, University of Sydney research farm, Narrabri, NSW (Latitude 30°11’37.99”S, Longitude 149°37’6.24”E).

Farming system treatments at Narrabri

- **Baseline**: designed to represent a standard cropping system for the local north-western grains region. The planting trigger will be 50% of a full soil moisture profile.
- **Higher nutrients**: This system duplicates the crop sequence for the baseline system, but fertilising will be targeting a higher yield (90% of seasonal yield potential for N and 100% replacement for phosphorus (P).
- **Higher crop intensity**: the trigger for planting will be 30% of a full soil moisture profile.
- **Higher crop diversity**: This system is investigating alternative crop options to help manage and reduce nematode populations, disease and herbicide resistance.
- **Higher legume**: The high legume system is focused on soil fertility and reducing the amount of N input required through fertiliser. One in every two crops must be a legume.
- **Lower crop intensity**: This lower intensity system is designed to plant at a lower frequency when the moisture profile is greater than 80% full. High value crops are targeted.

Site characteristics

Llara: chocolate vertosol with plant available water content (PAWC) of 210 mm to a depth of120 cm. The soil is slightly alkaline at the top-soil and increases in pH at depth, as does the calculated sodicity (ESP) (Table 1). These characteristics are common for Northern NSW grain soils.

Table 1 Site soil chemical characteristics for 0–120 cm depth at Llara.

	Soil depth (cm)				
	0–15	15–30	30–60	60–90	90–120
pH_{Ca}	7.44	7.93	8.21	8.43	8.55
Organic carbon (%)	0.79	0.63	0.54	0.39	0.25
Exchangeable sodium percentage (ESP)	3.3	5.8	11.0	16.0	23.0
Colwell-P (mg/kg)	24.0	8.0	10.0	16.0	20.0
Conductivity (dS/m)	0.12	0.15	0.22	0.29	0.34

Weather report

- Climatic conditions during the experiment were generally hotter and drier than average, receiving lower than average rainfall for Narrabri (Table 2).
- The project experienced more days over 35°C than the 17-year average of Narrabri.
- Within the project four out of six years had a 200 mm deficit of rainfall compared to cumulative annual average (Figure 1).
- The conditions did influence system performance as the 2016/17 cotton crop was impacted by severe heat and the low rainfall in 2018-2019, resulting in several crop failures (2018 sorghum, 2018 mungbean, 2019 chickpea and 2019 durum).

Table 2 The number of days recorded at the site greater than 35 °C and below 0 °C (1 June 2015 to 30 November 2020).

	2015	2016	2017	2018	2019	2020	Site mean
Days <0 °C	10	1	21	24	9	3	13
Days >35 °C	21	62	66	64	86	41	53

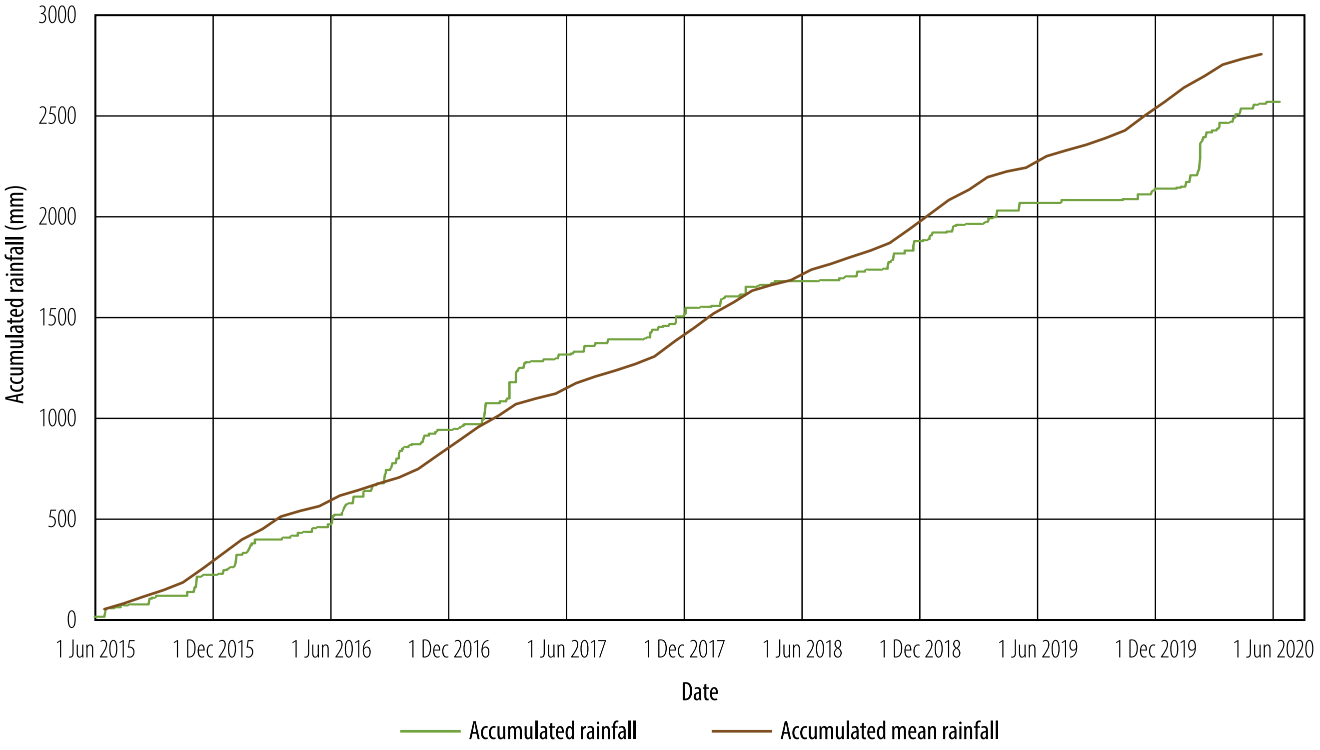

Figure 1 Accumulated rainfall at Narrabri between 2015 and 2020.

System cropping sequence at Narrabri

The six FS treatments at Narrabri had varying cropping sequences over the last five years with:

- The baseline planted to five crops (three wheat, one chickpea and one sorghum) (Figure 2).
- The higher intensity system had the greatest crop number (six or 1.2 crop/year), due to a double cropped chickpea, following sorghum (2018/19).
- The lower intensity systems had the lowest harvested crop number with three (two wheat and one cotton crop), with a cover crop planted following the cotton crop to maintain stubble cover across the treatments.

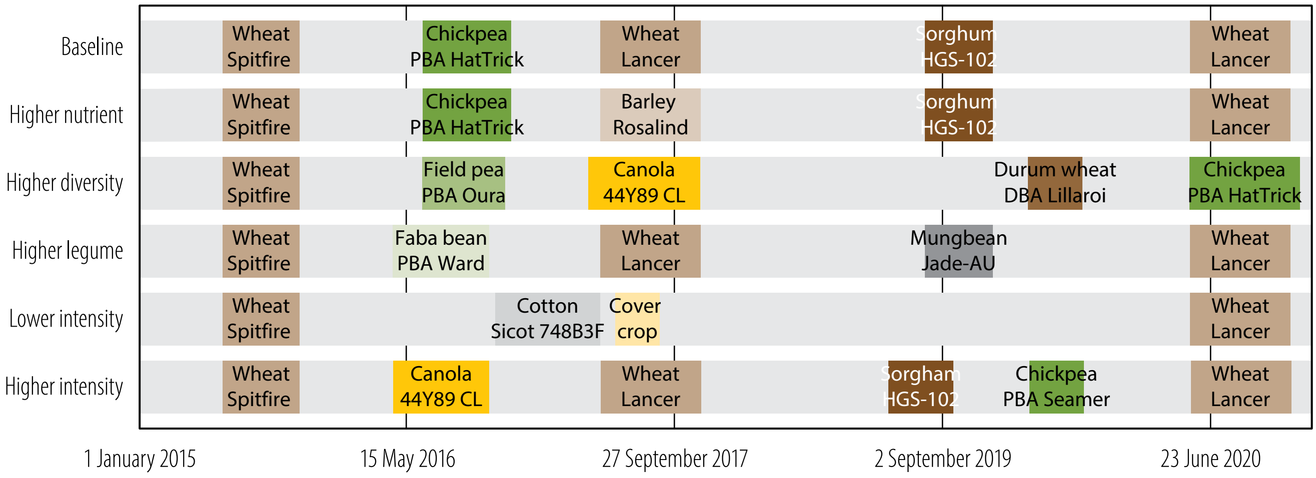

Figure 2 Cropping sequence and fallow length of the six farming systems at Narrabri.

It is noted that between 2018 and 2019 there was minimal grain production during the prolonged dry at Narrabri. The 2020 winter crops were the first profitable grain crops since the winter of 2017 (Figure 3). In 2018/19, sorghum yields ranged between 0.4 t/ha and 0.6 t/ha (baseline, higher nutrients and higher intensity). The mungbean (higher legume), chickpea (higher intensity) and durum (higher diversity) crops failed to produce grain.

Results

System grain yield

After five years of the experiment, the baseline, higher nutrient, higher legume and higher intensity systems resulted in similar cumulated grain yields of 11.1, 10.6, 10.8 and 10.4 tonnes/ha respectively (Figure 3).

The four systems (baseline, higher nutrients, higher legume and higher intensity) produced significantly more total grain (or grain and lint) than both the higher diversity and lower intensity systems (7.6 and 7 tonnes/ha). This is attributed to two failed crops in the higher diversity systems (2017 canola from frost damage, and 2019 durum from moisture stress), and the fewer grain producing crops in the lower intensity system (3) compared with the baseline system (5).

Cumulated yields indicate there was no advantage in applying additional N and P fertiliser between 2015 and 2020, as no crop within the higher nutrient system outperformed a baseline crop. The system performance results suggest that nutrition was never limited during the project and that other factors (most likely plant available moisture) limited crop response to the applied nutrients.

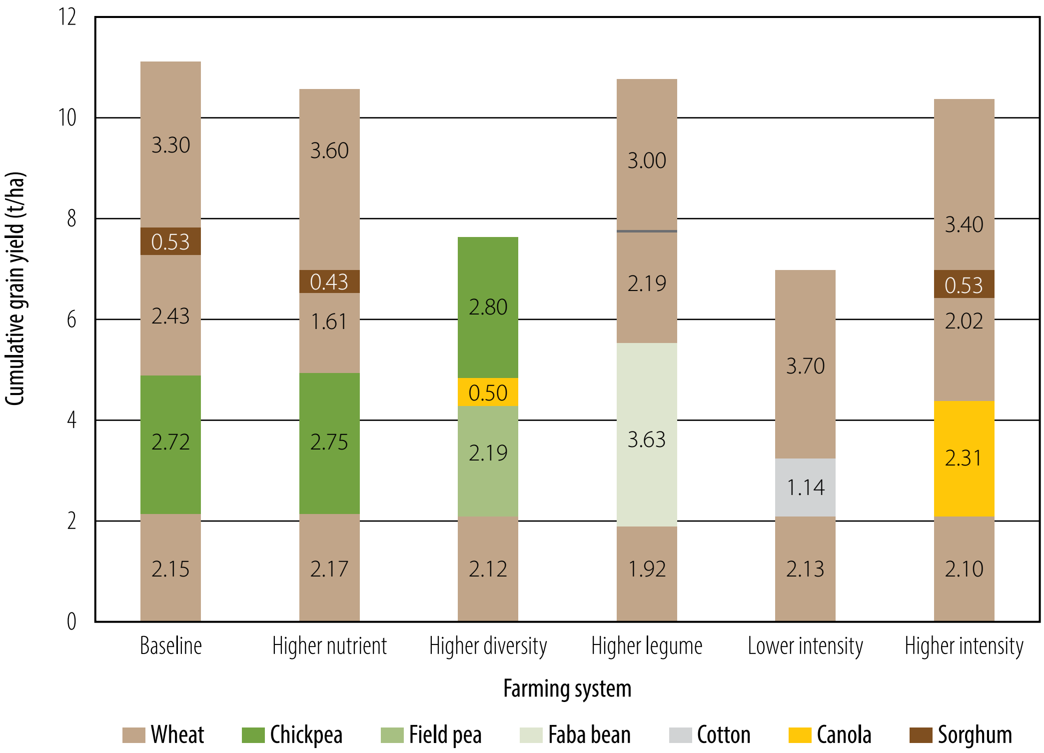

Figure 3 Cumulative system grain yield of the six farming systems treatments at Narrabri (2015–2020).

System gross margin

- The baseline and the higher legume systems had the greatest accumulated system GM with $1313/ha and $1324/ha respectively (Figure 4).
- The baseline system had higher crop income (+$132/ha) and higher crop associated costs (+$143) than the higher legume system. When evaluating the return on variable costs (ROVC) for the systems, the higher legume system had the highest return with 2.11 compared with 1.99 for the baseline system.

- The higher nutrient system had a lower GM compared with the baseline system ($701). This was due to the additional fertiliser costs (+$311/ha), which did not result in greater grain productivity (Figure 4). The added expense of additional fertiliser reduced the ROVC for the higher nutrient system to 1.37, which is 0.42 below the baseline system.
- Varying the cropping intensity to either more frequent cropping rotations or decreasing the cropping frequency had similar GM at Narrabri, $808/ha for the higher intensity and $858/ha for the lower intensity. But both systems achieved their respective GM in a contrasting way. For example, the higher intensity had higher system income (>$500/ha) and costs (>$550/ha) compared with the lower intensity system. Consequently, the lower intensity system is seen to be more efficient at converting income to profit as it had a ROVC of 1.9, which is 0.36 higher than the higher intensity system.

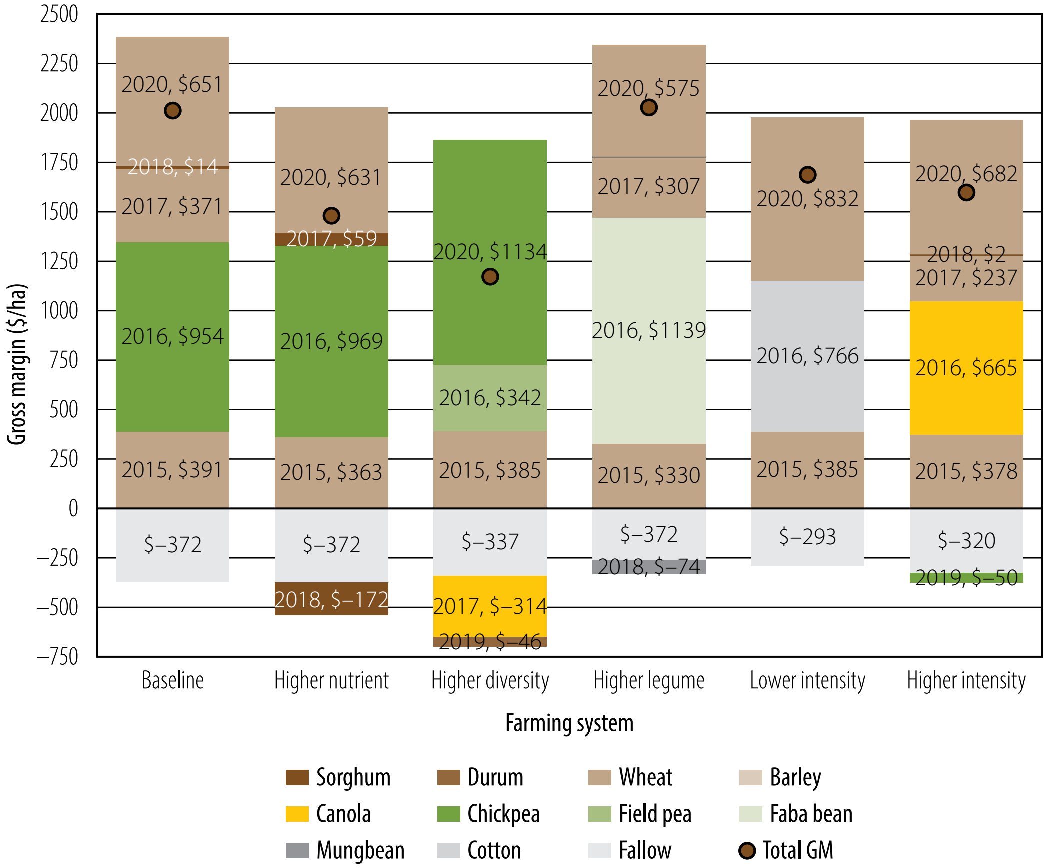

Figure 4 Cumulative system gross margins for each farming system and crop at Narrabri (2015–2020).

System water and nutrient use

The FS cropping intensity system had the greatest influence on the fallow efficiency at Narrabri between 2015 and 2020 (Table 3). The FS treatments that were in-crop the highest crop frequencies that led to consistent levels of cereal stubble, had the highest fallow efficiency (FE) The higher intensity system had an FE of 32%, the baseline was 30% and the higher nutrient system 26% FE. The fourth system that had the same time in-crop, the higher legume system, had a lower FE of 25%. This indicates the lower amount of ground cover from legume residue resulted in poor FE compared with higher coverage with the carbon rich, cereal stubble. The high N:C ratio of legume stubble promoted greater dry matter degradation, resulting in less stubble cover and poor moisture retention during the fallow periods.

The higher legume system resulted in the greatest water use efficiency (WUE) of 4.9 kg/mm/ha. This was 0.5 kg/mm/ha greater than the baseline system at 4.4 kg/mm/ha. Interestingly, the higher intensity system resulted in identical WUE to the lower intensity system (3.7 kg/mm/ha). Therefore, a similar productivity was achieved per millimetre of moisture from decreasing the cropping intensity compared with systems with greater cropping frequency. Additionally, the income per millimetre of used moisture was similar between the lower intensity, higher intensity and the baseline systems. These results show that Narrabri grain producers can be versatile with their cropping frequency and maintain system profitability.

The lower intensity treatment has:

- different/bigger planting triggers than the baseline and higher intensity treatments, i.e., sown into a conservative soil moisture profile
- a similar $/mm compared with the baseline treatment
- a higher GM/mm than the higher intensity treatment

The above highlight that the low intensity treatment has a the greater rainfall:grain production conversion than the other systems.

Implementing a greater frequency of legume crops into the FS did increase key nutrient export: N, P and K, from the cropping system, compared with the baseline system. This is due to legume seeds having a higher nutrient concentration than cereal grain. Moving forward, growers need to be aware of the exported nutrients from their system, in particular P and K, as they will need to be replaced and some constrained soils could possibly need increased application to ensure a full yield potential.

Table 3 Narrabri cropping systems water and nutrient use efficiency (NUE), 2015–2020.

System	Water use			Nutrient use			
	Average FE (%)	Average grain WUE (kg/mm/ha)	System ($/mm)	Exported N (kg N/ha)	System NUE (kg grain/kg N)	Exported P (kg P/ha)	Exported K (kg K/ha)
Baseline	30	4.4	0.62	176	1.65	26	42.1
Higher nutrient	26	3.7	0.29	159	0.79	24	41.5
Higher legume	25	4.9	0.63	230	2.54	34	54.3
Higher diversity	26	3.1	0.0	139	-1.87	21	31.6
Higher intensity	32	3.7	0.39	160	0.71	31	29.5
Lower intensity	11	3.7	0.59	99	-1.46	17	19.6

FE = ∑Soil water ÷ ∑fallow rain
Grain WUE = ∑grain yield ÷ crop water use
System WUE = system GM ÷ crop water use
Exported N, P and K = grain yield × grain content (N, P or K)
System NUE = exported N ÷ ∑crop N use.

During the FS project, Predicta B ® testing for disease, including *Pratylenchus thornei* (Pt) occurred biannually, pre and post every crop. At Narrabri, Pt nematode numbers indicated a strong correlation with FS treatments (Figure 5). In 2016 the crop choice had a large effect on Pt numbers. Chickpea planted in the baseline and higher nutrient systems increased Pt numbers by up to five times over the 2016 pre-sowing numbers. The other legumes planted in 2016, field pea in the higher diversity plots and faba bean in the higher legume system, also increased Pt numbers, but not to the extent in chickpea. Although Pt numbers did increase to moderate levels in 2016 within the baseline and higher nutrient systems, there was no yield effect – chickpea yields for both systems was 2.7 t/ha.

P. thornei numbers reduced across all six systems during the 2016–17 summer fallow. Numbers in both the baseline and higher nutrient systems increased slightly during the 2017 wheat crop (LongReach Lancer$^{⯑}$). As a result, both these systems had more than three times the Pt numbers than the other four farming systems by the end of 2017. Conversely, in the other four farming systems treatments, Pt numbers reduced during 2017 with levels less than 1.3 nematodes/g soil (Figure 5) by the end of 2017. With drought-like conditions starting in the winter of 2018, Pt DNA numbers dropped across all treatments and remained in the low population category until the end of the project (May 2020).

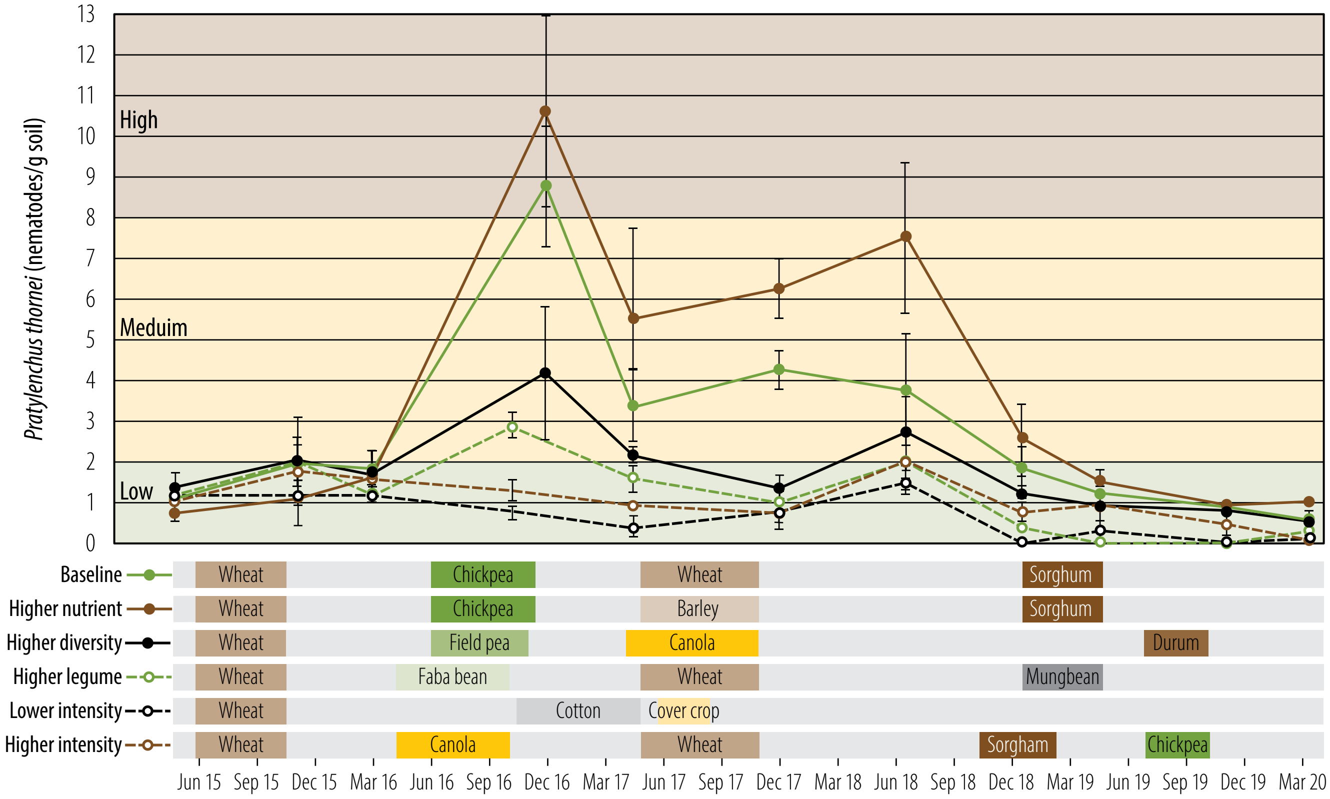

Figure 5 Root lesion (*P. thornei*) nematode numbers at Narrabri between 2015 and 2020.

Conclusions

In terms of grain productivity and systems gross margin, both the baseline and the higher legume systems performed above the other four systems during the five-year experiment. Both systems (baseline and higher legume) had high grain yields during the favourable seasons, in addition the selected crops had high grain value which improved the gross margins.

There was no increase in grain production for the higher legume system over the baseline treatment. These results show that there was not a nutrient deficiency in the years of this experiment for the Narrabri crops, but that water limited yield potential. As this research continues, it will be interesting to analysis if the additional fertiliser added to the higher nutrient system will generate more yield in favourable conditions.

The crop sequence for the baseline system (wheat–chickpea–wheat) had implications for soil-borne disease and nematode numbers. Of particular concern were the long-term effects on nematode numbers (especially *P. thornei*). Future crop selections for the baseline and higher nutrient systems will need to consider the varieties' nematode susceptibility. The system required a species to decrease nematode numbers, with sorghum chosen for this experiment.

The increased frequency of legume crops within the cropping system at Narrabri has not improved soil fertility. Conversely, the modern, high yielding legume cultivars can create a nutrient deficiency within the cropping system. Both faba bean and chickpea crops decreased soil mineral N and K levels in the immediate fallow period post harvest, mainly due to the high nutrient exportation in the seed. Future systems will need to apply more fertiliser to take into account this high nutrient exportation.

Although grain productivity and system income were lower in the lower intensity system, it did have a high conversion of rainfall to income and ROVC. This was evident during the low rainfall seasons at Narrabri, proving that a conservative approach to cropping intensity is beneficial when growing conditions are not ideal. Similar to northern NSW, Narrabri received low rainfall during the 2018-2019 seasons which compromised any benefits of aggressive cropping frequencies (such as the higher intensity systems)

Acknowledgements

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Assessing the interaction between acid-tolerant strains of rhizobia and field pea, Tamworth 2020

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Key points

- New rhizobial strains need to be stringently tested in a wide variety of environments before any recommendations can be made about their potential use.
- The field pea variety Sturt$^{\Phi}$ was inoculated with two acid-tolerant strains of rhizobia (SRDI969 or WSM4643) and grown over the 2020 winter season at Tamworth in an alkaline red–brown soil. The root nodulation and grain yield of these inoculated peas was compared to that of uninoculated peas and of peas inoculated with the current Group F, commercial inoculant (WSM1455). The highest recorded nodulation score was where peas were inoculated with the acid-tolerant rhizobia strain SRDI969.
- Field pea yields in 2020 were low, most probably limited by the hard-setting, red-brown soil in which the crop was grown.
- Results from this trial will contribute towards efforts to deliver improved rhizobial strains to industry that can increase grain legume adaptation and production.

Introduction

Pulse crops can obtain a significant amount of the nitrogen (N) they require through the association they form with symbiotic, N-fixing bacteria – rhizobia. The N fixation process occurs in nodules, which are specialised structures that pulses form once the bacteria have penetrated the roots. Where pulses are not adequately nodulated, or a less than optimal symbiosis is formed, N fixation, crop growth, grain yield and N carryover to subsequent crops can be compromised. Rhizobia can be limited by factors that affect their survival and effectiveness including soil acidity, soil texture, soil moisture and the genetic stability of rhizobial strains (Rigg et al., 2020).

Most of the currently available commercial rhizobia strains are sensitive to acid soils, being generally more persistent and effective in neutral to alkaline soils. For example, the current Group F commercial inoculant strain (WSM1455), recommended for faba bean and lentil, was isolated from a soil in Greece with a pH_{Ca} of 8.0. This strain exhibits a significant decline in its ability to nodulate plants where soil pH_{Ca} drops below 6.0, with plants generally inadequately nodulated where soil has a pH_{Ca} <5.0 (Yates et al., 2016; Ballard et al., 2019). A range of new acid-tolerant rhizobial strains short-listed by the South Australian Research and Development Institute (SARDI) and the Centre for Rhizobium studies (CRS), Murdoch University, Western Australia, are currently in development. These strains were isolated from acid soils (pH_{Ca} 4.5–5.5) and have been assessed in experiments conducted in Western Australia, South Australia and southern New South Wales (NSW). The main reason for developing these strains has been the potential expansion of the pulse industry where high value pulse crops are increasingly being grown in <5.5 pH_{Ca} soils.

Field pea is a highly adaptable pulse crop that is a valuable rotation option in cereal farming systems. Field pea can grow in soils ranging from sandy loams to heavy clays (pH_{Ca} 5.5–9). Field pea can be profitable on their own, but also provide growers with disease break options and potential N benefits to subsequent cereal and oilseed crops. In 2020, an experiment was conducted in northern NSW where field pea was inoculated with specific acid-tolerant rhizobia strains and grown in an alkaline, red–brown soil. Even though the soil was not acidic, the experiment aimed to generate data that would contribute towards the understanding of the interactions that acid-tolerant rhizobia strains form with pulses in a range of environments, specifically, the ability of these strains to nodulate roots. The experiment also looked at any effects the strains have on crop yield.

The overall aim of this research is to deliver strains to industry that increase grain legume adaptation and production, with a focus on acid soil tolerant strains. Before any potential recommendations to changes in the rhizobia strain used, it is important that several field experiments are conducted over multiple seasons, in different soil types with differing pH ranges using various crops.

Site details

Location	Tamworth Agricultural Institute, Tamworth, NSW, 2340. 31°15′00.38″S; 150°96′61.47″E.
Paddock history	2019: Oats. 2018: Canola.
Soil type	Red-brown soil (chromosol). Soil chemical characteristics are presented in Table 1.
Starting soil moisture	129.5 mm, PAWC
Rainfall	• 2020 rainfall: 699 mm. • In crop rainfall:192 mm.
Experiment design	Randomised complete block design, four replications.
Sowing date	10 June 2020.
Fertiliser	125 kg/ha single superphosphate (0 % N, 8.8 % P (phosphorus), 0 % K (potassium), 11 % S (sulfur), 19 % Ca).
Weed management	• Pre-sow, fallow weed management: 3 L/ha Roundup Ultra® MAX (570 g/L glyphosate), 6 June 2020. • In crop weed management: 100 ml/ha Verdict® 520 (520 g/L haloxyfop), 14 August 2020.
Harvest date	16 November 2020.

Table 1 Site soil chemical characteristics for 0–30 cm depth at Tamworth in 2020.

Characteristic	Depth (0–10 cm)	Depth (10–30 cm)
pH_{Ca}	6.9	7.3
Ammonium nitrogen (mg/kg)	2	1
Nitrate nitrogen (mg/kg)	23	14
Phosphorus, Colwell (mg/kg)	13	3
Organic carbon (%)	1.56	0.84
Potassium, Colwell (mg/kg)	418	195

Treatments and assessment

The field pea variety Sturt$^{\phi}$ was the chosen variety for this experiment. Sturt$^{\phi}$ is a white field pea, adapted to a broad range of environments. It performs reliably in low rainfall cropping zones, particularly in south-western NSW. The varieties Maki$^{\phi}$ (blue pea) and Yarrum$^{\phi}$ (dun pea) are more commonly grown in the northern region, but Sturt$^{\phi}$ was grown at Tamworth in order to complement experiments being conducted in southern NSW in the same year.

Field pea was sown with a series of treatments (Table 2).

1. Commercial practice: Inoculation with the current commercial Group F rhizobia strain (WSM1455). Although the commercial Group E (SU303) inoculant strain is recommended for field pea, the commercial Group F can be used. Inoculum was applied to the seed as a peat slurry.
2. Experimental strains: Inoculation with one of two acid-tolerant rhizobia strains was applied to seed as a peat slurry.
3. Nil-inoculation.

The two acid-tolerant strains used in this study were developed by Murdoch University (WSM4643) and SARDI (SRDI969) respectively. Canola was grown alongside field pea as a non-legume crop in rotation.

- Plant roots from each treatment were scored for nodulation using scores of between zero (absent) and eight (extremely abundant).
- Nodulation scores of 15 plants per treatment were taken approximately 10 weeks after sowing measuring the:
    - Number of nodules
    - Nodule size
    - Nodule activity
    - Nodule location on the roots.
- A score of four is considered adequate with the plant having 21–40 small and/or three–four large, effective nodules (Howieson and Dilworth 2016; Yates et al., 2016).
- Each treatment was harvested and grain yield calculated.
- Root nodulation and grain yield data were analysed using analysis of variance (ANOVA) with Genstat for Windows, 19th Edition (Genstat 2018).
- Treatment means were compared using least significant difference (l.s.d.) with significant differences accepted at *P*<0.05.

Table 2 Treatments established at Tamworth, 2020.

Pulse crop	**Treatments**
Field pea (Sturt$^{\phi}$)	**Nil** **WSM1455*** **WSM4643*** **SRDI969***

* Recommended commercial rate of inoculation

Figure 1 The aerial view at Tamworth in 2020 where field pea was inoculated with acid-tolerant strains of rhizobia as well as the currently available commercial Group F strain. The experiment area also hosted plots of lentils and chickpea, data of which is not discussed in this report.

Results

Root nodulation

The highest nodulation score recorded was from plants inoculated with SRDI969 (Figure 2). This was significantly higher than the nodulation score recorded from the nil treatment and those inoculated with either the current Group F strain WSM1455 or the acid-tolerant WSM4643 strain. Nodulation scores of all inoculated plants were significantly higher than scores recorded from the nil treatment.

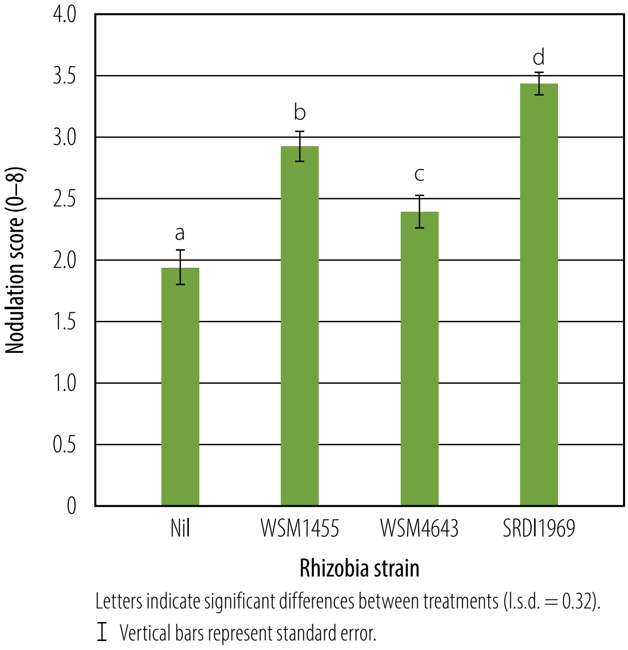

Figure 2 The average nodulation score of field pea plants at Tamworth in 2020. A score of four is considered adequate.

Grain yield

No significant differences in yields were recorded between uninoculated field pea and inoculated field pea (Figure 3). The average yield recorded across treatments was 0.86 t/ha.

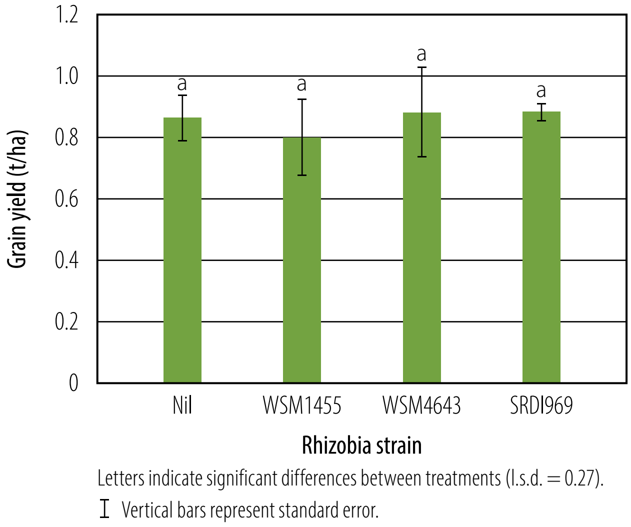

Figure 3 The average grain yield of field pea at Tamworth in 2020.

Conclusions and future work

Field pea plants inoculated with the acid-tolerant rhizobia strain SRDI969 had significantly higher nodulation than the plants inoculated with the currently recommended Group F strain (Figure 2). Root nodulation reflects a healthy plant-rhizobia association and active nodules. This result indicated that SRDI969 was better able to colonise field pea than the commercial strain.

The acid-tolerant rhizobia strains used in this experiment are being developed primarily for use in acidic soils. However, this result indicated that some of these strains could also be more efficient at root nodulation than the commercial strain in non-acidic soils. In experiments conducted at Condobolin in 2019 and 2020 in a relatively similar soil type, the highest nodulation scores were recorded where field pea was inoculated with WSM4643, the commercial strain (Rigg et al., 2020). It is imperative that experiments are conducted over multiple seasons and in multiple environments before recommendations are made.

The nodulation score of 3.45 of plants inoculated with SRDI969 was the closest score to four, which is considered adequate nodulation.

All nodulation scores recorded in this experiment were below four. Similar nodulation scores were recorded from experiments involving the acid-tolerant strains that were conducted at Griffith, Condobolin and Canowindra in 2019 and 2020 (Rigg et al., 2020). Various factors can influence the extent of nodulation including limitation by the host plant itself. Even though the association formed between legumes and rhizobia is symbiotic, there is an energy cost to the plant; plants can limit the bacterial colonisation, especially if nutrients are readily available. Field pea plants from the nil treatments also had comparatively high nodulation scores, but the scores for this treatment were significantly lower than those where field pea was inoculated with either the commercial or acid-tolerant strains. This nodulation most likely resulted from background rhizobia in the soil, sometimes referred to as 'cheater' rhizobia. These nodules were also often inactive. Starting concentrations of N in the soil were not excessively high, but could have been high enough to limit nodulation.

Grain yields were similar across treatments (Figure 3). Inoculation had no effect on yield with the commercial or the acid-tolerant strains, compared with the nil treatment. Yields recorded at Tamworth in 2020 (0.86 t/ha) were low, especially considering that Sturt$^{\Phi}$ has high yield potential. The national average for field pea yield in 2020–21 was 1.4 t/ha (ABARES 2021). The reasons behind the low yields were not clear. The experiment was established using recommended field pea management practices with above average rainfall at Tamworth in 2020. However, the paddock in which the field pea was grown could have been yield-limiting, being a hard-setting, red-brown soil. Though field pea is often grown in paddocks of a similar nature in other areas of NSW, such soil characteristics can reduce the likelihood of a response to inoculation, including loam/clay soils with neutral or alkaline pH (Drew et al., 2012).

The aim of this project is to deliver rhizobial strains to industry that increase grain legume adaptation and yield, particularly in acidic soils. Though the soil in which this experiment was conducted was not acidic, the experiment still demonstrated that one of the acid-tolerant strains tested was better able to nodulate field pea in a red-brown alkaline soil. The interactions of the acid tolerant strains with pulse crops compatible with Group E/F inoculant groups will continue to be investigated.

Future work will also investigate the potential carryover benefits of the pulse–rhizobia association to subsequent crops in rotation, more specifically, potential N benefits.

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Durum crop emergence from deep sowing in 2020

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Key findings

- Three experimental lines were evaluated for the effects on grain yield from deep sowing. These lines had up to 75% longer coleoptiles than Caparoi$^{\Phi}$ (check variety) sown at 4 cm, 7 cm and 12.5 cm depths.
- The long coleoptile lines showed small, statistically non-significant improvements in emergence from deep sowing and yield in the deep sown treatments relative to Caparoi$^{\Phi}$.
- The lack of significant differences could be due to the excellent soil moisture conditions at sowing in this experiment, which reduced the adaptive advantage of the long coleoptile lines. Further work is needed to assess the value of the long coleoptile lines and the ability of commercial durum varieties to emerge from deep sowing under dry sowing conditions.

Introduction

Durum wheat (*Triticum durum*) is an important crop in the northern grains region of NSW. Durum grain from this region has gained a worldwide reputation for its high quality and it commands a premium price. However, production from the northern region has suffered enormous fluctuations in recent years due to very wet conditions in 2016 followed by drought conditions in 2018 and 2019. While accurate statistics are not available, NSW durum production most likely exceeded 500 000 t in 2016 and shrank to 50 000–60 000 t in 2018 and 2019. Such fluctuations are harmful to the viability of the NSW durum industry because the export markets depend upon reliable supply. Such fluctuations are also difficult to manage for growers from a cash flow perspective.

It is therefore important to develop agronomic and genetic solutions to stabilise grain production. An agronomic approach to achieve more stable grain production is to make better use of the moisture stored in the soil profile from conservation tillage practices. Currently, this valuable stored moisture is used sustaining crops in drought years where in-crop rainfall is limited. This experiment looks at using the stored moisture to establish crops as well in situations where the autumn break is delayed. This could be achieved by sowing deeper than the normal 4–7 cm depth to place seeds into moist soil, but there are no previous studies of the ability of durum to emerge from deep sowing.

The long coleoptile trait has been studied as a likely solution for emergence from deep sowing in durum (Condon et al., 2004; Pandey et al., 2015; Trethowan et al., 2001). Bread wheat research by CSIRO has shown coleoptile length as the key trait required for emergence from deep sowing (Rebetzke et al., 2007 and 2019; Kirkegaard and Hunt, 2010). However, other research conducted overseas (Mohan et al., 2013) and locally by AMPS Research (Matt Gardner, personal communication), has indicated that seed size has a substantial effect on its ability to emerge from deep sowing. In this experiment, the effect of the long coleoptile trait on emergence from deep sowing was evaluated, using experimental long coleoptile durum varieties.

Site details

Location	Tamworth Agricultural Institute, Calala, NSW (31°147’89.1”S, 150°98’250.5”E)
Paddock history	• sorghum • 12 month fallow • 2020 durum.
Soil type and nutrition	The soil type was grey cracking clay with pH value close to neutral (7.29 pH_{Ca}). Granulock (N:P:S:Zn:11:21.8:4:1) applied at 50 kg/ha. 100 kg N was applied as urea to provide for 13% grain protein at 4 t/ha yield based on soil tests.
Rainfall	A total of 238 mm rainfall was recorded at Tamworth during the growing season (GSR) from 1 May to 30 November 2020 (Figure 1). The long-term average GSR for Tamworth is 357.6 mm (http://www.bom.gov.au/climate/averages/tables/cw_055054.shtml).
Experiment design	• split plot design • three replicates • sowing depth as main plot, varieties subplots • plots 6 m long, 5 rows 35 cm apart. Upon emergence the plots were trimmed by 1 m on both ends to achieve a final plot length of 4 m.
Sowing	3 July 2020. Moisture conditions were ideal with good moisture at all three depths: 4 cm, 7 cm and 12.5 cm.
Fertiliser	40 kg/ha Granulock (N:P:S; 11:21.8:4) placed 50 mm below the seed.
Sowing rate	Plots sown at 50 kg/ha.
Weed management	Roundup (pre-sowing) and Starane™ (post emergent) used for broad leaf weed control.
Insect management	None.
Disease management	None.
Harvest date	8 December 2020.

Measurements

Emergence was counted in random quadrats (0.3 m long × 1.05 m wide) 14 and 21 days after sowing. Crop establishment was also assessed as dry matter (DM)/m^2 at growth stage (GS) 30 in random quadrats.

Coleoptile length of lines was evaluated as per Pumpa et al., (2009) with three replicates in a growth cabinet at UNE. Each replicate involved eight individual seeds. Coleoptile length was recorded after incubation for 14 days at 21°C.

Treatments

- Three sowing depths: 4 cm, 7 cm and 12.5 cm.
- Four varieties (Table 1).

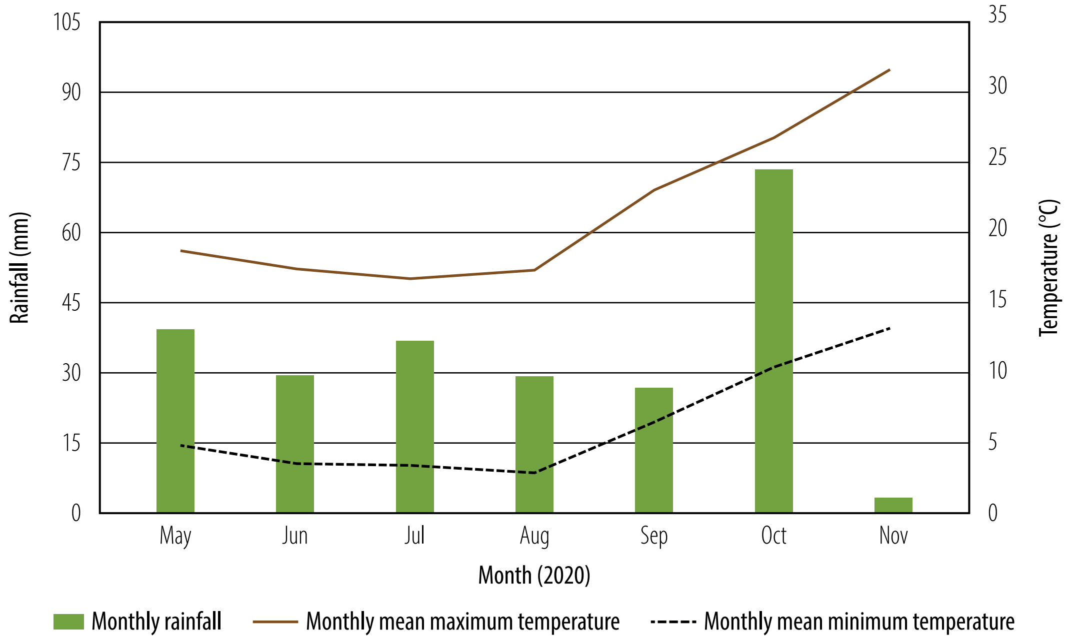

Figure 1 2020 Rainfall and temperature summary for Tamworth (orange = monthly mean maximum temperature, grey = monthly mean minimum temperature).

Table 1 Details of the lines included in the study and their coleoptile lengths.

Name	Pedigree	Breeder	Coleoptile length (cm)*	Status
V189631-3	ICARO/260379	DBA	14.34	Experimental line
V189586-4	ICARO/260379	DBA	13.77	Experimental line
V190245-6	ICARO/260204.	DBA	12.82	Experimental line
Caparoi	LY2.6.3/ 930054	DBA	8.00	Released – check variety
LSD (0.05)			1.03	

* Unpublished data, Devkota, Kadkol and Warwick.

Results

Establishment

The three experimental, long coleoptile lines used in this study contain Icaro in their pedigree. Icaro is an Italian line containing the Rht18 gene, which is responsive to the plant hormone gibberellic acid unlike the Mexican semi-dwarfing genes (Rht1 and Rht2). Rht18 is considered to be conducive to the long coleoptile trait although there are varieties with a long coleoptile in the Rht1 background. All the current Australian durum varieties (data not presented), including Caparoi⁽ᶲ⁾, possess the Rht1 gene and they have a significantly shorter coleoptile length than the three Rht18 lines (Table 1).

Results from the experiments showed sowing depth significantly affected crop emergence with all varieties showing a marked decrease in emergence in the 12.5 cm sowing depth treatment (Table 2). However, while there was a small improvement in emergence from deep sowing in the long coleoptile lines no significant effect was observed due to the varieties or varieties × sowing depth interaction, despite the significant differences between varieties for coleoptile length.

Table 2 Mean values for emergence (21 days after sowing), DM at GS30 and yield for three long coleoptile lines and Caparoi$^{\Phi}$ at three sowing depths.

Variety	Emergence 21 DAS (seedlings/m^2)				DM at GS30 (g/m^2)				Grain yield (t/ha)			
	Sowing depth				Sowing depth				Sowing depth			
	4 cm (control)	7 cm	12.5 cm	LSD (5%)	4 cm (control)	7 cm	12.5 cm	LSD (5%)	4 cm (control)	7 cm	12.5 cm	LSD (5%)
V189631-3	100.7	101.7	83.0	12.0	300.7	261.3	122.3	88.6	3.213	3.258	2.069	0.624
V189586-4	104.0	102.0	73.7	12.0	355.6	324.5	154.5	88.6	3.302	3.134	2.352	0.624
V190245-6	95.3	97.7	80.0	12.0	294.5	286.2	115.1	88.6	3.128	2.794	2.142	0.624
Caparoi	91.0	87.0	70.7	12.0	288.2	255.1	96.4	88.6	3.331	3.390	2.274	0.624
LSD (5%)	23.6	23.6	23.6		75.0	75.0	75.0		0.423	0.423	0.423	
CV(%)	15.2				18.4				8.5			

Dry matter at anthesis

Similar to emergence, the deep sowing treatment produced a significantly reduced DM in all four varieties. Two long coleoptile varieties showed a trend for improved emergence from the 12.5 cm sowing depth, but the differences between the varieties was not significant (Table 2). V189586-4 produced the highest DM from the 12.5 cm sowing depth treatment.

Yield

Sowing depth affected grain yield with the deep sowing treatment reducing yield by more than 30% in all lines except for V189586-4. However, this difference was statistically not significant.

Conclusions

Increasing sowing depth to allow the seed to be placed into moisture will have an important role in mitigating the frequent droughts in the northern grains region. The long coleoptile lines showed a trend for improved emergence from deep sowing, DM production and grain yield in this experiment, but statistical significance could not be demonstrated, most likely due to excellent soil moisture at all depths. It is highly likely that these results could be very different if the experiment was conducted under drought conditions, where germination and emergence from the various sowing depths is likely to be quite different. The results do demonstrate the contribution of the longer coleoptile trait in improving crop emergence and establishment from deep sown crops is most likely modest. Further work is being planned to assess the long coleoptile trait more closely, and the ability of the current durum varieties to emerge from deep sowing under dry sowing conditions.

Acknowledgement

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Genotype × environment effects on durum wheat quality and yield implications for breeding

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Key findings

- Using multi-environment data allows durum breeders to better estimate the overall performance and stability of durum lines and trait heritability. This approach allows for more effective comparisons in breeding for quality and breeding for yield, allowing better productivity for the durum industry by having new, more productive and stable varieties.

Introduction

The objectives were to:

- understand genotypes (G), environment (E) and G × E interactions in the northern Australian environment for durum yield and quality
- to use that knowledge as a platform for future selection of quality traits and design more effective selection strategies in developing better varieties for breeding programs.

Site details

Location	Seven experiment sites (Table 1).
Paddock history	In each year the experiments were on long fallow paddocks planted to sorghum the previous year.
Soil type and nutrition	Soil characteristics for each experiment site are presented in Table 2.
Rainfall	Rainfall (data presented in Table 2) was average to below average at all sites except for North Star.
Experiment design	Randomised as row column designs using DiGGer, three replicates. Total environments = 16.
Sowing date	Trials were sown in mid–late May (Table 2).
Fertiliser	40 kg/ha Granulock (N:P:S; 11:21.8:4) placed 50 mm below the seed together with nitrogen fertiliser (urea) as specified in Table 2.
Plant population	Target 100 plants/m^2.
Weed management	Starane™ (fluroxypyr) or Tordon 242™ (MCPA + picloram), both Group I herbicides, were applied to control broadleaf weeds before growth stage 30.
Insect management	None.
Disease management	None.

Harvest date Trials were harvested upon ripening in mid–late November.

Table 1 Site location of the seven experiment sites, including year.

Location	Experiment sites						
	Breeza	Edgeroi	Narrabri	Moree	Tulloona	North Star	Tamworth
Year	2012, 2013, 2015	2012, 2013, 2015	2015	2012, 2013, 2015	2015	2012, 2013, 2015	2012, 2013, 2015
Latitude	31° 25'S	30° 11'S	30° 34'S	29° 46'S	30° 33'S	28° 93'S	31° 09'S
Longitude	150° 46'E	149° 79'E	149° 76'E	149° 8'E	149° 78'E	150° 39'E	150° 93'E

Table 2 Soil characteristics, nitrogen applied, sowing date and growing season rainfall at each site and year of the experiment.

Characteristic	Year	Experiment site location						
		Breeza	Edgeroi	Narrabri	Moree	Tulloona	North Star	Tamworth
Soil type		Grey cracking clay	Grey cracking clay	Grey cracking clay	Grey cracking clay	Grey cracking clay	Variable	Variable
pH_{Ca}	2012	nd	nd	nd	nd	nd	nd	nd
	2013	8.1	7.4	nd	7.0	nd	7.6	7.7
	2015	8.0	8.0	7.1	7.8	7.8	7.4	7.2
Total applied N (kg/ha)	2012	47.25	47.25	0	47.25	0	47.25	47.25
	2013	241.00	52.00	0	60.00	0	56.00	67.00
	2015	33.00	5.50	5.50	5.50	106.00	16.00	9.00
Sowing date	2012	23 May	17 May	Not sown	16 May	Not sown	15 May	25 May
	2013	21 May	10 May	Not sown	9 May	Not sown	7 May	27 May
	2015	8 May	29 June	21 May	Not sown	23 May	13 May	8 May
Growing season rainfall	2012	226.6	229.4	Not sown	186.0	Not sown	1004.6	235.0
	2013	274.2	248.8	Not sown	173.0	Not sown	1081.6	309.0
	2015	264.0	249.1	290.1	–	222.4	894.2	330.0

nd = not determined.

Treatments

Genotypes (12) Durum varieties: Caparoi$^{\phi}$, EGA Bellaroi$^{\phi}$, Jandaroi$^{\phi}$, DBA Aurora$^{\phi}$, DBA Lillaroi$^{\phi}$, DBA Vittaroi$^{\phi}$, Hyperno$^{\phi}$ and breeding lines: 240578, 280012, 280115, 290491, 290564.

Methods

Traits measured

Grain yield (GY), grain protein (GP), 1000 kernel weight (TGW), semolina yellowness (b*) and dough strength by gluten index (GI) were measured according to previously published methods (Sissons et al., 2014). Note that only a small subset of the results is reported here. Please refer to full details in Sissons et al., 2020.

Statistical analysis

Each of the above traits was analysed using a multi-environment linear mixed model (ME-LMM) that partitioned and accounted for all sources of genetic and non-genetic variation. The best linear unbiased estimates (BLUEs) of the year × location by genotype effects were extracted from the ME-LMM and summarised for relative performance across the environments by subtracting the environment mean from the within environment genotype BLUEs (Smith and Cullis 2018). All statistical models were computationally conducted using the flexible linear mixed modelling R package ASReml-R V4.

Results

The effect of G × E and their interaction on grain yield, grain and semolina quality traits.

This study used location (L) and year (Y) as the environments. For grain yield and quality traits, the analysis showed that G, environment (L and Y) and G by environment (Y × G, L × G, Y × L × G) were significant for most traits. Compared with Y and L, the statistics indicate there were strong G effects for TGW, GP*b**, and GI. Whereas, environmental effects (Y and L) were greater for GY. These traits, which had highly significant Y × L × G effects, indicates that multi environments are needed to evaluate these traits.

Expressing the best linear unbiased estimates (BLUEs) for each trait as deviations around the environment means (site x year) for all genotypes, showed which varieties had a better than average performance versus those which were worse. Selected key traits are plotted in Figure 1. Positive values (blue bars) represent better results than the environment means, while orange bars represent a lower performance than the environmental mean. The consistently highest yielding genotypes across the 16 environments were DBA Aurora$^{\phi}$ and Hyperno$^{\phi}$, and the lowest were EGA Bellaroi$^{\phi}$ and Jandaroi$^{\phi}$. Other genotypes showed variable yield responses or had yields close to the mean (bar with little height). Hence these varieties are not outstanding for yield, but whether they are retained or not depends on other grain quality attributes.

The GP responses by genotypes are inverse to the yields. The consistently highest GP performers were EGA Bellaroi$^{\phi}$, Jandaroi$^{\phi}$, DBA Vittaroi$^{\phi}$ and DBA Lillaroi$^{\phi}$ and the lowest, DBA Aurora$^{\phi}$, Hyperno$^{\phi}$, Caparoi$^{\phi}$, 290491 and 280012. This is related to high protein grain having less starch (see discussion) and other factors that have a role that is not well understood.

Jandaroi$^{\phi}$ consistently performed below the site average with the lowest *b**. Other low performing genotypes included DBA Aurora$^{\phi}$ and Caparoi$^{\phi}$, and to a lesser extent EGA Bellaroi$^{\phi}$. All the other genotypes are more recent in the breeding program than the commercial varieties (EGA Bellaroi$^{\phi}$, Caparoi$^{\phi}$, DB$^{\phi}$ Aurora$^{\phi}$, Hyperno$^{\phi}$ and Jandaroi$^{\phi}$) and would be expected to have superior *b** due to continuous selection for higher semolina *b** The best performers were 280012 and DBA Vittaroi$^{\phi}$.

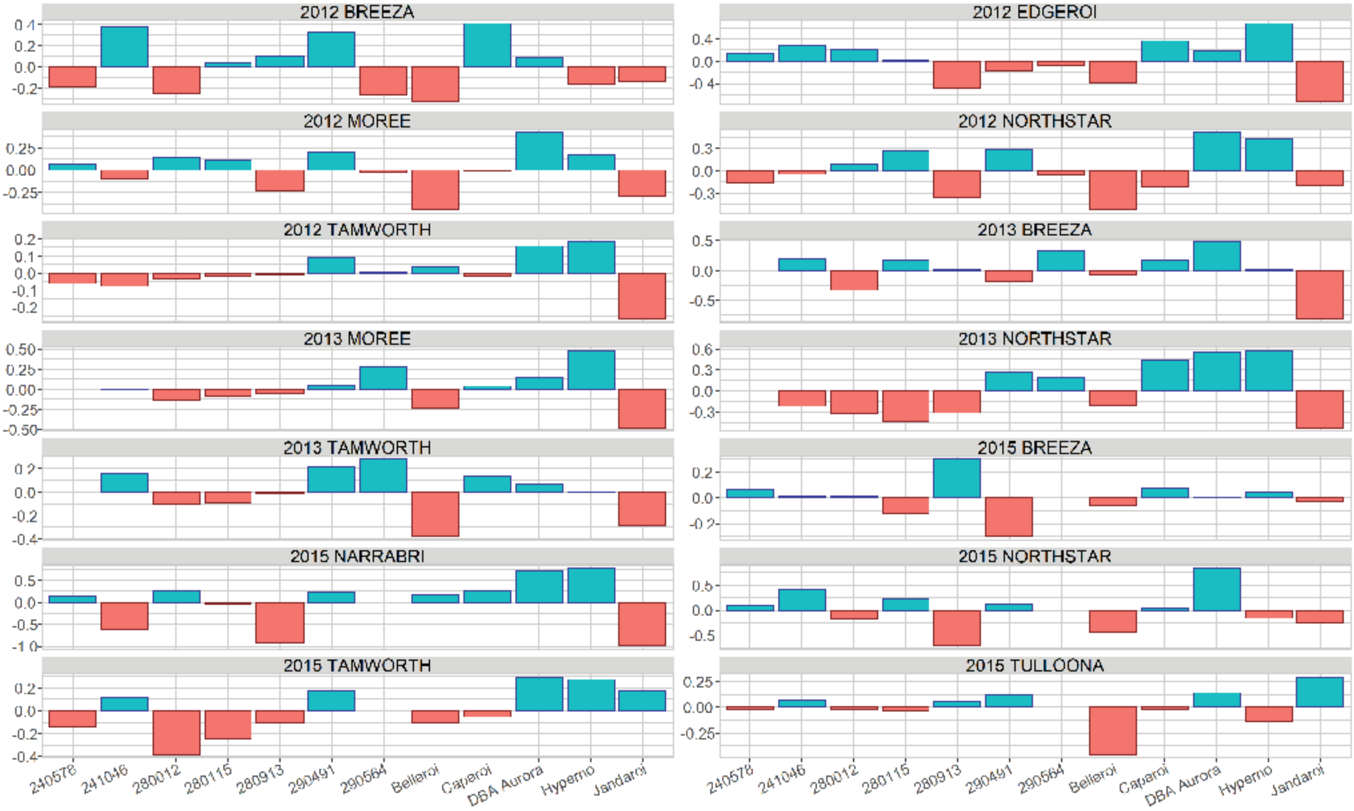


Figure 1 The BLUEs expressed as deviations around the environment (site × year) mean grain yield of 12 durum wheat genotypes across 14 environments (blue = better than average performance, orange = worse than average performance).

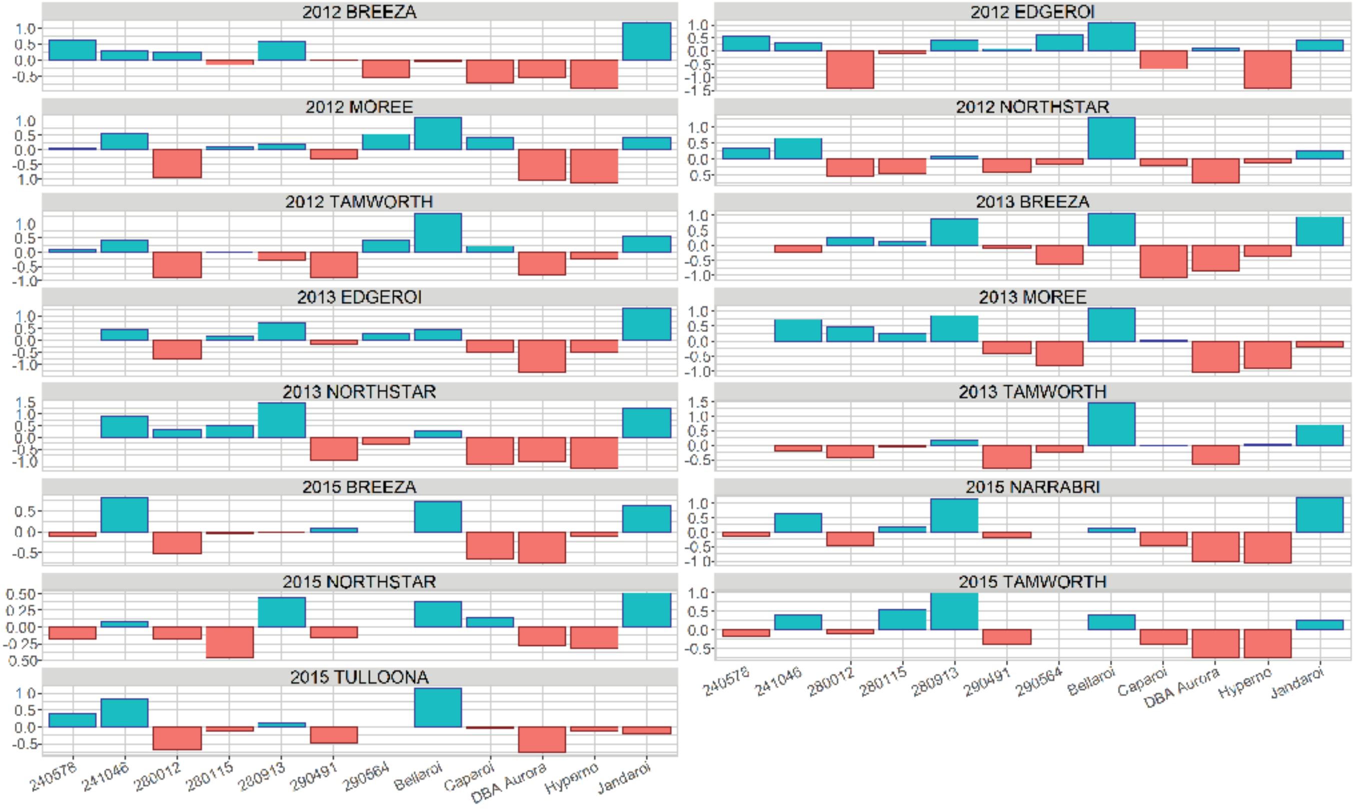


Figure 2 The BLUEs expressed as deviations around the environment (site × year) mean grain protein of 12 durum wheat genotypes across 15 environments (blue = better than average performance, orange = worse than average performance).

Figure 3 The BLUEs expressed as deviations around the environment (site × year) mean semolina yellowness (*b**) of 12 durum wheat genotypes across 15 environments (blue = better than average performance, orange = worse than average performance).

Overall performance and stability for traits

The genotype overall performance (OP) and stability (ST) are displayed in Figures 4 to 7. For any given trait, the plots provide a useful summary of the relative OP across all the Es (the further to the right on the x axis equals higher OP) and stability (the closer to the origin on the y axis means more stable trait performance).

The most important criterion for a breeder and grower is yield, with both DBA Aurora⍉ and Hyperno⍉ the standout varieties for yield across the Es (Figure 4).

Quality comparison for the varieties show:

- DBA Aurora⍉ is superior to Hyperno⍉ for TGW (Figure 6), Semo *b** and GI (Figure 5), so would be preferred over Hyperno⍉.
- DBA Lillaroi⍉ performed well for GP (Figure 7), *b** and well above average for TGW (Figure 6) with acceptable, but not outstanding grain yield and dough strength.

For these reasons, DBA Lillaroi⍉ was preferred for release. This variety has been widely adopted by NSW growers since 2016 with excellent results.

While DBA Aurora⍉ is a top yielder across these environments in NSW, it has a poor OP for grain protein (Figure 7). It is important to balance grain and pasta-making quality against yield performance requirements when developing durum varieties for northern NSW. This is because a significant portion of the grain produced is exported as DR1, a grade that requires >13% protein and attracts a price premium.

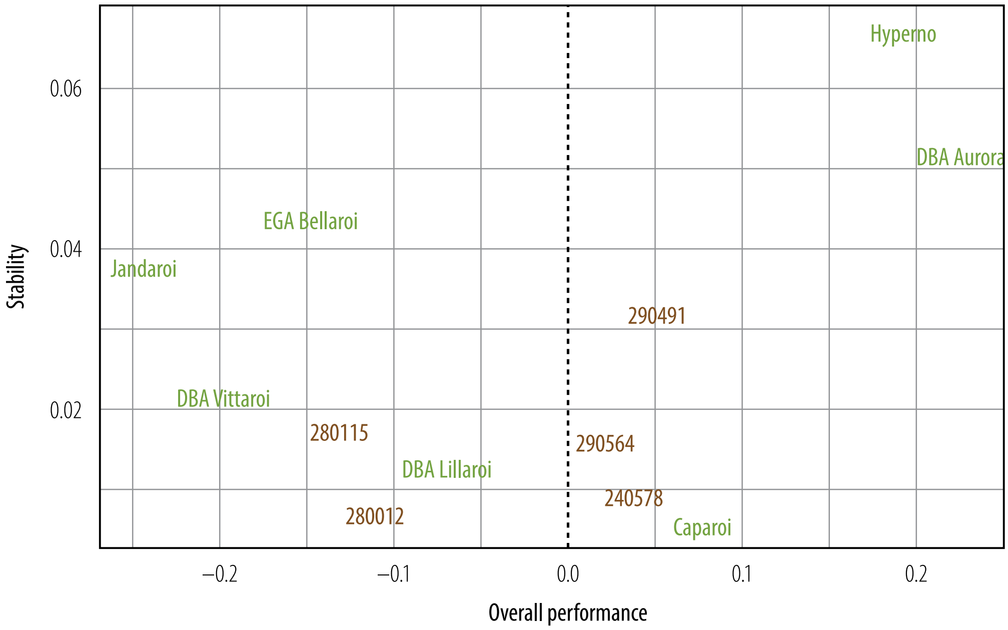


Figure 4 Stability plotted against overall performance for grain yield.

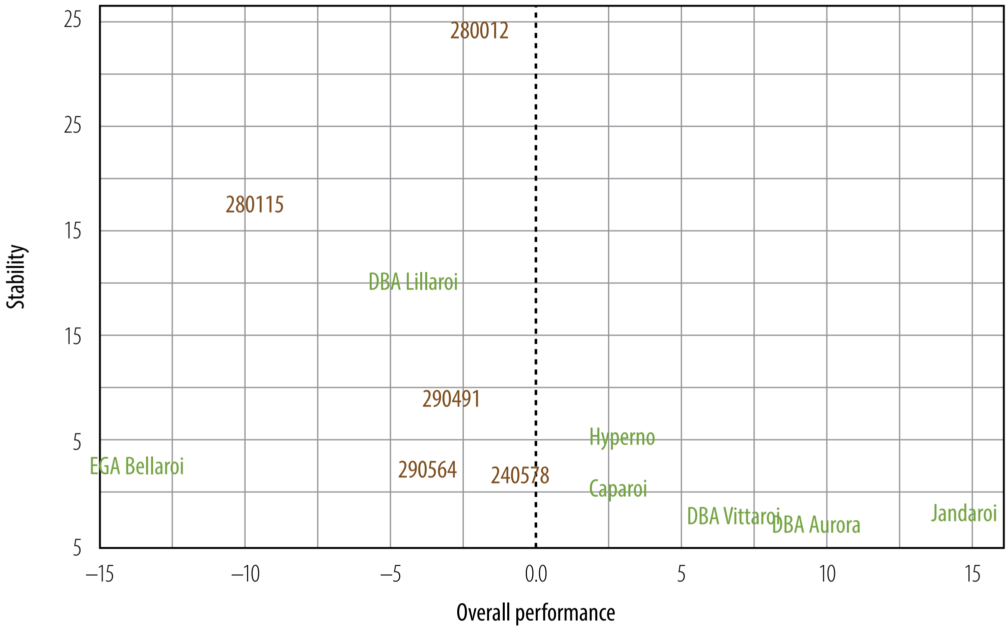
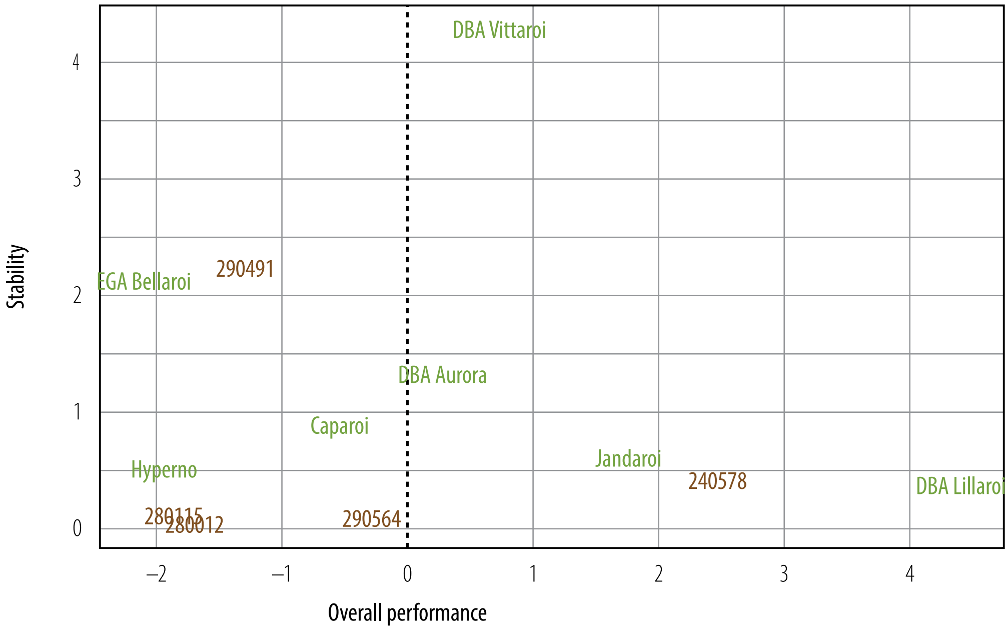
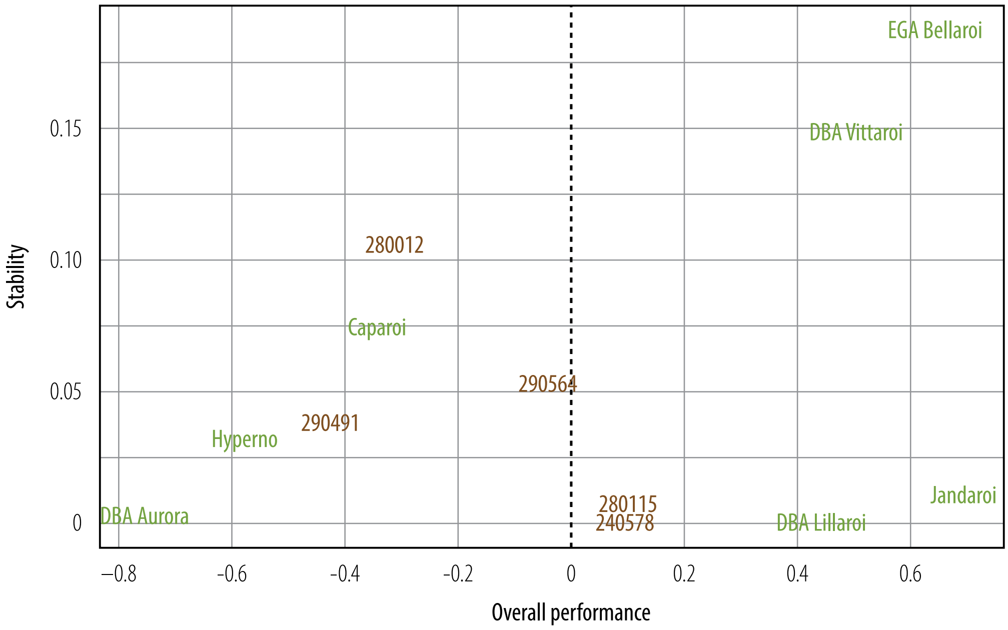


Figure 5 Stability plotted against overall performance for traits gluten index.



Varieties on the far right of the plot are the best performers across environments and varieties approaching zero on the y-axis have increased stability across environments.

Figure 6 Stability plotted against overall performance for traits 1000 grain weight.



Varieties on the far right of the plot are the best performers across environments and varieties approaching zero on the y-axis have increased stability across environments.

Figure 7 Stability plotted against overall performance for traits grain protein.

Conclusions

This G × E study presents a comprehensive analysis of durum varieties and breeder's advanced genotypes for grain yield, grain, semolina, and dough quality in the Australian dryland environment. The summary of the overall performance and stability of the genotypes will help to identify best genotypes for each trait. A breeder needs to ideally combine several commercially important traits into one genotype with the trait emphasis dependent on the end use. The focus of the DBA program is on high yield and grain quality meeting the requirements of the value chain users (millers, pasta makers, marketers and consumers).

Nearly all grain and semolina traits showed significant G × E interactions. Good heritability was observed for traits such as semolina *b**, and gluten index. Selection for these traits will enable genetic improvements. The value of the overall performance versus stability plots is that they allow superior genotypes to be easily identified at a glance. Having both a high OP and ST for as many traits as possible is desired, but usually a compromise is needed.

This is the first detailed G × E study conducted on durum wheat in Australia. Multi-environment data allows the heritability of traits to be determined and the genotypes' overall performance and stability to be compared. Such data will ensure better decision making about which genotypes to develop to achieve better productivity for the Australian durum industry.

The variety DBA Lillaroi$^{\Phi}$ is recommended for industry based on this study. It combines high performance and stability for both yield and quality traits suited to the dryland durum growing regions of northern NSW. DBA Lillaroi$^{\Phi}$ possesses a bright semolina and pasta colour, which is attractive to the durum milling and pasta making industry. A new variety, DBA Bindaroi$^{\Phi}$ (not included in this study) has been released recently and it contains many of the quality features of DBA Lillaroi$^{\Phi}$ but with higher yield.

Further information

For further details see recently published Sissons et al 2020 Crop Breed Genet Genom. 2020;2(4): e200018. https://doi.org/10.20900/cbgg20200018.

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Evaluating dual-purpose winter cereal varieties, Glen Innes 2020

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Summary of results

- Varieties that demonstrated the greatest flexibility to achieve both grazing at GS30 and the opportunity to harvest high quality grain in this environment included the wheat varieties Manning$^{\phi}$, Einstein, Sunlamb$^{\phi}$ and Illabo$^{\phi}$ and the triticale variety Cartwheel$^{\phi}$.
- Grazing at the beginning of stem elongation (GS30) improved the yield of wheat varieties Manning$^{\phi}$, Sunlamb$^{\phi}$ and Illabo$^{\phi}$ compared with non-grazed treatments.
- The highest grain yield in the non-grazed treatments in this experiment was produced from SD3 (sowing date) (14 April 2020) by wheat varieties Einstein (6.95 t/ha), RGT Calabro (6.89 t/ha) and Manning$^{\phi}$ (6.60 t/ha,) and triticale varieties Cartwheel$^{\phi}$ (6.67 t/ha) and Endeavour$^{\phi}$ (6.04 t/ha).
- The highest grain yield in the non-grazed treatments from SD1 and SD2 was produced by wheat variety Manning$^{\phi}$ (3.47 t/ha and 5.55 t/ha respectively) followed by Einstein (SD2; 5.02 t/ha) and Illabo$^{\phi}$ (SD1; 2.68 t/ha).
- The highest grain yield from treatments that received simulated grazing at GS30 was from SD3 by wheat varieties Manning$^{\phi}$ (6.85 t/ha), Einstein (6.38 t/ha), RGT Calabro (6.19 t/ha) and RGT Accroc (6.14 t/ha), and triticale variety Cartwheel$^{\phi}$ (6.65 t/ha).
- Of the grazed treatments from SD1 and SD2, the wheat variety Manning$^{\phi}$ was also the highest yielding line (4.60 t/ha and 5.68 t/ha respectively) followed by wheat varieties Sunlamb$^{\phi}$ (SD2; 4.99 t/ha) and Illabo$^{\phi}$ (SD1; 3.2 t/ha).
- The wheat varieties Manning$^{\phi}$, Sunlamb$^{\phi}$ and Illabo$^{\phi}$ produced a higher grain yield from the grazed treatments compared with their corresponding non-grazed treatments for all sowing dates.
- Only ~78% of the treatment combinations for the Australian Prime Hard (APH)/Australian Hard (AH) classified wheats achieved grain protein concentrations >13%. All feed classified wheat varieties achieved the minimum test weight (>62 kg/hL). Screenings for all varieties were within receival specifications (<15%).
- The slow-growing winter wheat varieties RGT Calabro TOS 1 (4.87 t/ha,) and RGT Accroc TOS 1 (4.43 t/ha,) produced the greatest amount of shoot biomass (t/ha dry matter (DM) at GS30. The variety RGT Accroc produced 4.0 t/ha (SD2) and required 127 days to reach GS30. By comparison, the wheat variety Einstein produced 4.03 t/ha DM at GS30 and took only 103 days to reach this stage.
- In relation to feed quality at GS30, the metabolisable energy (ME) ranged from 12.1 MJ/kg to 13.8 MJ/kg, which meets the recommended dietary requirements of most sheep and cattle. Crude protein (CP) levels AT GS30 ranged from 22.2% to 33.6% of DM. The neutral detergent fibre (NDF) values ranged from 40% for Manning$^{\phi}$ up to 47% for RGT Calabro, which is within the recommended range of 30% to 60%.

Introduction

Dual-purpose cereal crops (graze and grain recovery) offer flexibility in providing winter forage for livestock in addition to income from the grain harvested. This forms an important component of the perennial pasture and cropping systems of northern NSW. This experiment evaluated 14 varieties (nine wheat, three barley and two triticale) for grazing and grain recovery potential in the Northern Tablelands of NSW.

This experiment is a component of the NSW DPI–GRDC Grains Agronomy and Plant Pathology (GAPP) project BLG116 'Northern High Rainfall Zone dual purpose winter crop evaluation 2019–22' that is evaluating oat, wheat, barley, triticale, canola and perennial cereal varieties for their potential to produce grain following simulated grazing treatments. The project aims to support the expansion of grain production in the high rainfall zones of north-eastern NSW.

Site details

Location	Glen Innes Agricultural Institute, 444 Strathbogie Road, Glen Innes, NSW, 2370. Latitude 29°70'18.2"S, Longitude 151°70'02.3"E
Paddock history	2019 perennial pasture.
Soil type and nutrition	Light brown–grey clay loam. Chemical analysis is presented in Table 1.
Rainfall and temperature	Bureau of Meteorology rainfall and temperature data for 2020 is summarised in Figure 1.
Experiment design	• Split plot design, three replicates. • Treatments on main plot: sowing date. • Treatments on sub plot: 14 varieties (nine wheat, three barley and two triticale) combined with two grazing treatments (grazed and non-grazed).
Sowing dates	Three sowing dates: 5 March, 24 March and 14 April 2020.
Fertiliser	• 160 kg/ha of urea (N:47%) was incorporated via shallow cultivation one month prior to sowing. • 40 kg/ha of Granulock® Z (N:11%, P:21.8%, S:4%, Zn:1%) and 141 kg/ha of urea (N:47%) applied at sowing (P–phosphorus; N–nitrogen; S–sulfur; Zn–zinc).
Target plant population	100 plants/m^2
Weed management	Glyphosate 450® (450 g/L glyphosate) @ 2 L/ha and LVE MCPA 570® (MCPA 570g/L) @ 1.2 L/ha were applied before sowing.
Insect management	Gaucho® 600 (imidacloprid 600 g/L) seed treatment @ 120 mL/100 kg of seed
Disease management	Vibrance® seed treatment 180 mL/100 kg seed (difenoconazole 66.2 g/L, metalaxyl-M 16.5 g/L, sedaxane 13.8 g/L)
Harvest maturity	Harvest maturity ranged from early November to mid-December. Varieties from SD1 took 286 days (40.8 weeks) to reach maturity, with the exception of the barley variety Urambie$^{\Phi}$ (265 days, 37.8 weeks). Varieties in SD2 two took 267 days (38.1 weeks) to reach maturity. Varieties from SD3 took 246 days (35.1 weeks) to reach harvest maturity. Prolonged wet weather at the end of the season could have delayed maturity in this experiment.

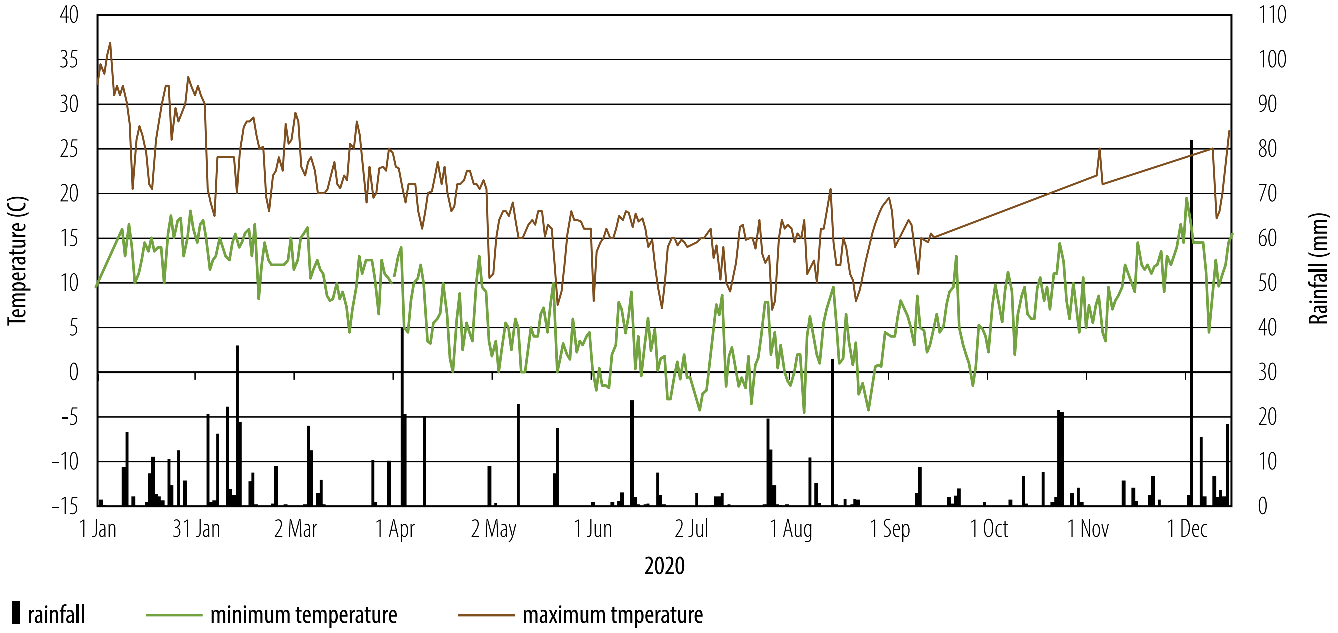

Figure 1 Rainfall and temperature data for NSW DPI Glen Innes Research Station, 2020 (Source: Bureau of Meterology).

Table 1 Soil chemical analysis of the experiment site at Glen Innes, NSW, 2020.

Characteristic	**Depth (cm)**				
	0–10	**10–30**	**30–60**	**60–90**	**90–120**
Ammonium nitrogen (mg/kg)	56	12	5	3	3
Nitrate nitrogen (mg/kg)	50	8	2	<1	<1
Phosphorus (mg/kg) [Colwell test]	82	9	4	3	2
Potassium (mg/kg) [Colwell test]	138	32	46	53	72
Sulfur (mg/kg)	25.4	11.4	18.5	12.8	9.6
Organic carbon (%)	2.0	0.75	0.48	0.36	0.3
Conductivity (dS/m)	0.18	0.05	0.04	0.04	0.04
pH$_{\text{Ca}}$	5.1	4.5	5	5.3	5.9
pH level (1:5 water)	5.9	5.7	6.2	6.6	7.3
BSES phosphorus (mg/kg)	58.2	4.0	–	–	–

Treatments Varieties (14)

Table 2 Description of winter cereal varieties in the experiment.

Variety	Type	Variety traits and reason for inclusion in trial
Cassiopee	Barley	European (French) winter, malt quality barley. Very long season (strong vernalisation and photoperiod responses).
Oxford	Barley	Slow spring type, high yield potential with wide adaptation. Feed quality with good straw strength and lodging resistance.
Urambie	Barley	Fast winter dual-purpose feed quality barley, early maturity combined with a cold requirement to initiate heading.
Cartwheel	Triticale	Mid–late maturing long-season dual-purpose triticale suitable for early March to early April sowing. A stripe rust resistant replacement for Tobruk.
Endeavour	Triticale	Semi-awnless, late maturing long season dual-purpose benchmark variety. Excellent DM production and grain recovery after grazing. Suited to early sowing opportunities.
DS Bennett	Wheat	Tall awnless high yielding winter wheat with photoperiod sensitivity, suited to early March–late April sowing. Since the detection of the new pathotype of stripe rust (198 E16 A+ J+ 17+ '198 pathotype') this variety was lowered to an S (susceptible) rating. Suited to dual-purpose grazing and grain, or grain-only production.
EGA Wedgetail	Wheat	AH quality benchmark, mid maturity winter type.
Einstein	Wheat	An awnless high-yielding, long season winter red grain feed quality wheat.
Illabo	Wheat	Mid maturing winter wheat classified as AH in the north. Similar maturity to EGA Wedgetail, higher yielding with improved black point tolerance and stripe rust resistance.
LonReach Kittyhawk	Wheat	APH quality winter wheat released in 2016, with a similar maturity and planting window to EGA Wedgetail, but with higher yield potential and grain quality package with stripe rust resistance.
Manning	Wheat	Awnless feed winter wheat. Long season, dual-purpose graze and grain variety. High yield potential in high rainfall/irrigation production. Resistance to Barley yellow dwarf virus (BYDV).
RGT Accroc	Wheat	Feed grain quality red winter wheat of suited to higher rainfall zones. High yielding, long season winter type. Suitable for sowing late from February to early April for early grazing. Good standability. Flowering time and maturity later than EGA Wedgetail.
RGT Calabro	Wheat	High yielding winter red grain feed quality wheat with excellent standability and good resistance to stripe rust.
Sunlamb	Wheat	Awnless, long season spring wheat suited to early April plantings, with strong photoperiod sensitivity. Suited to grazing and grain recovery across NSW. Similar flowering time to EGA Wedgetail

Grazing treatments (2)

- Grazed and non-grazed treatments were applied to each variety in each replicate of the experiment.
- Grazing treatments were simulated by mowing at 3 cm above ground height when plots reached GS30.
- All cut plant matter was removed from the grazed plots (Figure 2).

Figure 2 Grazing treatment

Results

Establishment

The target population of 100 plants/m^2 average was achieved across all sowing dates with an average of 96 plants/m^2 established and even establishment across the plots (Figure 3).

Figure 3 Even plant establishment is evident in this photo of Nguyen Nguyen (left) and Rick Graham (right) collecting samples for GS30 maturity and biomass data.

Statistical analysis

Variation in the traits was described by fitting a linear mixed-effects model that considered sowing date, variety and grazing treatment plus all interactions as fixed effects. Random effects were assigned to replication, main plot, range, and row of the experiment. An analysis of variance was derived from the model to test the null hypothesis with respect to each fixed term. Graphical methods were used to check model assumptions of normal and homogeneous residuals.

The analysis of variance was used to infer a statistically important effect when the relevant F-ratio statistic exceeded the expected F-ratio under the null hypothesis at 5% critical value. Specific pairwise contrasts were made by comparison of the estimated effect with a calculated least significant difference at 5% critical value. The models were also used to estimate the mean and standard error of the trait under all combinations of variety, grazing and sowing date. These were presented graphically in figures 4, 5 and 6. The estimates of grain yield, biomass and maturity are provided in more detail in Table 3. Grain quality data is presented in Table 4 and feed value analyses are presented in Table 5.

The data analysis was conducted in the R environment (R Core Team, 2021) with particular use of the lme4 package (Bates et al., 2015).

Plant shoot biomass at growth stage 30

Figure 4 shows the analysed data for plant shoot biomass at stem elongation GS30. As the grazing treatments were applied directly after the GS30 biomass data was collected, no significant difference was expected between the grazed (G; orange line) and non-grazed (NG;blue line) treatments.

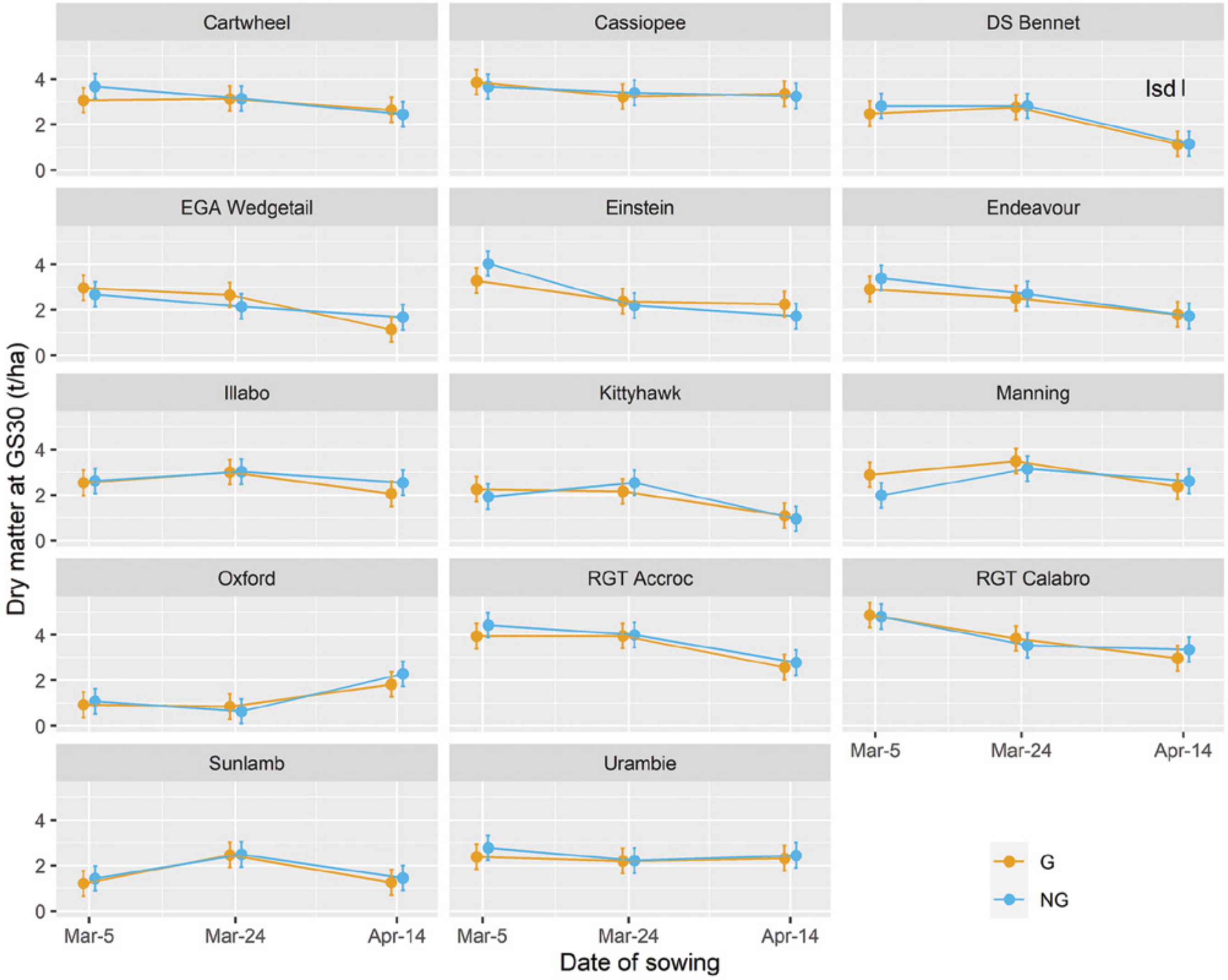

Figure 4 Dry matter (t/ha) at GS30 for 14 winter cereal varieties for three sowing dates, with grazed (orange line) and non-grazed (blue line) treatments.

SD1 and SD2 generated the highest DM at GS30, which was produced by the slow-maturing winter wheat varieties, RGT Accroc and RGT Calabro (3.5–4.8 t DM/ha). These varieties took longer to reach GS30 (118 and 127 days from SD1 and SD2 respectively) than most of the other varieties (Table 3).

The barley variety Cassiopee produced 3.2–3.6 t DM/ha and required 132 and 141 days from SD1 and SD2 respectively to reach GS30.

Other varieties required between 41 and 103 days to reach the same stage of maturity, but produced less DM ranging from 0.64 t/ha DM (Oxford; SD2) to 3.40 t/ha DM (Endeavour⁽ᴾ⁾; SD1) (Figure 4).

For SD3, the wheat varieties RGT Calabro (3.35 t/ha), RGT Accroc (2.78 t/ha), Manning⁽ᴾ⁾ (2.61 t/ha) and the long-season French barley variety Cassiopee (3.25 t/ha) produced, the greatest DM GS30.

Plant shoot biomass at GS65

Figure 5 shows the analysed data summary for plant shoot biomass at anthesis, GS65.

Most varieties in the experiment demonstrated the ability to recover from the grazing treatment applied at GS30, with little to no significant reduction in DM accumulation at GS65 compared with the non-grazed treatments (Figure 5). Biomass production and sampling was undertaken at GS65 as this crop stage represents a decision point for growers to graze the crop, bale for hay or take through to grain harvest. It is generally accepted that feed quality largely declines for most species following anthesis

The wheat varieties Manning$^{\Phi}$ (13.78 t/ha, TOS 1), DS Bennett$^{\Phi}$ (13.52 t/ha, TOS 1), RGT Calabro (12.84 t/ha, TOS 2) and RGT Accroc (12.34 t/ha, TOS 2) produced the greatest amount of DM at GS65 after a grazing treatment at GS30.

A delayed sowing date reduced biomass. The varieties that produced the least amount of DM at GS65 after a grazing treatment at GS30, were Cassiopee (4.89 t/ha; SD3), RGT Calabro (7.13 t/ha; SD3), Illabo$^{\Phi}$ (7.66 t/ha; SD3) and Oxford (7.68 t/ha; SD3).

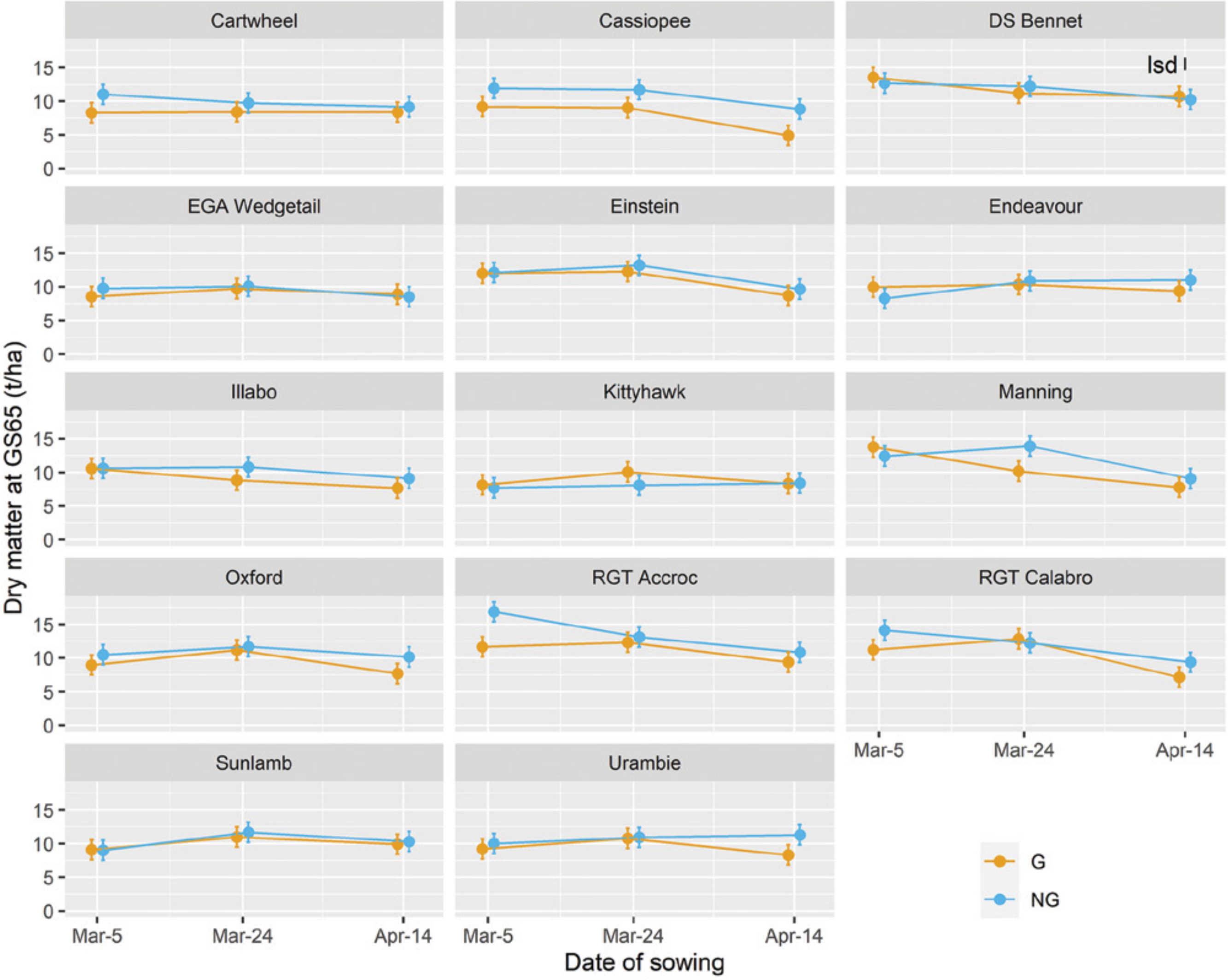

Figure 5 Dry matter (t/ha) at GS65for 14 winter cereal varieties for three sowing dates, with grazed (orange line) and non-grazed (blue line) treatments.

Grain yield

Figure 6 and Table 3 illustrate the analysed grain yield data summary for this experiment.

Grain yield varied widely between the varieties and treatments. In summary:

- The highest grain yield in the non-grazed treatments was produced from SD3 by wheat varieties Einstein (6.95 t/ha), RGT Calabro (6.89 t/ha) and Manning$^{\phi}$ (6.60 t/ha) and triticale varieties Cartwheel$^{\phi}$ (6.67 t/ha) and Endeavour$^{\phi}$ (6.04 t/ha).
- Of the non-grazed treatments from SD1and SD2, the variety Manning$^{\phi}$ was the highest yielding line (3.47 t/ha and 5.55 t/ha respectively).
- The highest amount of grain produced in the grazed treatments was also from SD3 by Manning$^{\phi}$ (6.85 t/ha) and Einstein (6.38 t/ha) and triticale Cartwheel$^{\phi}$ (6.65 t/ha).
- Of the grazed treatments from SD1 and SD2, Manning$^{\phi}$ was also the highest yielding line (4.60 t/ha and 5.68 t/ha respectively).

For some varieties in this experiment, the grazing treatment resulted in higher grain yield than the non-grazed treatments. Manning$^{\phi}$, Sunlamb$^{\phi}$ and DS Bennett$^{\phi}$ produced higher grain yields in the grazed treatments compared with the non-grazed treatments for all sowing dates. This effect might be due to the grazing treatment reducing the amount of lodging in some varieties at earlier sowing dates.

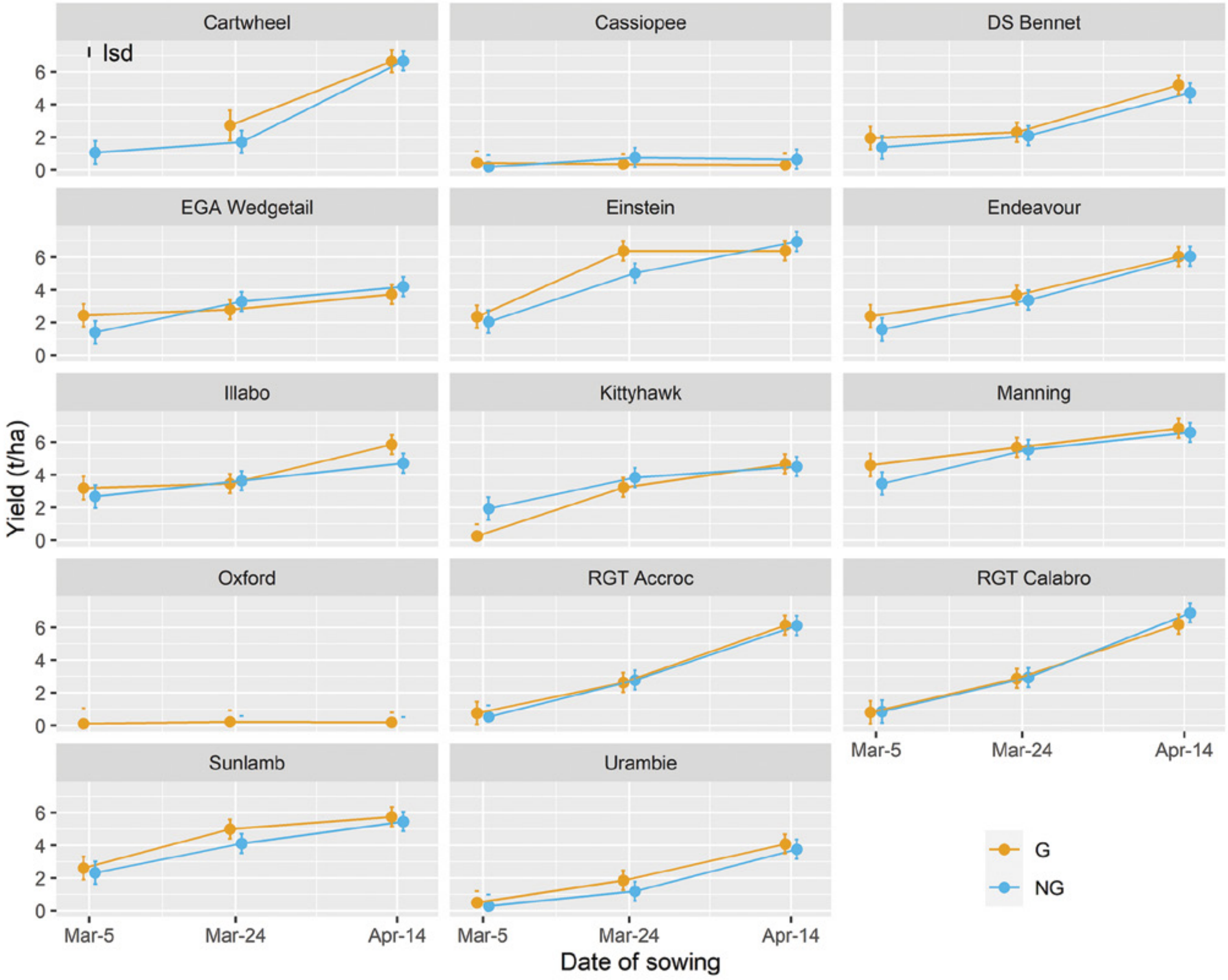

Figure 6 Grain yield (t/ha) for 14 winter cereal varieties for three sowing dates, with grazed (orange line) and non-grazed (blue line) treatments.

The triticale variety Endeavour$^{\phi}$ yielded significantly higher in the grazed treatments compared with the non-grazed treatments for SD1 (2.38 t/ha compared with 1.57 t/ha respectively) and SD2 (3.67 t/ha compared with 3.37 t/ha respectively). However, the difference between the treatments for this variety for SD3 was not significant (6.02 t/ha compared with 6.04 t/ha). Conversely, the failure of the triticale variety Cartwheel$^{Ⓐ}$ to yield following grazing for SD1, could have been due to the grazing timing and heavy frosts.

Table 3 details yield, biomass at GS30 and GS65 and the days to reach GS30 and GS65.

Table 3 Grain yield, biomass and maturity data summary for non-grazed (NG) and grazed (G) treatments of 14 winter cereal varieties for three sowing dates (SD1: 5 March, SD2: 24 March, SD3: 14 April) at Glen Innes, 2020.

Variety	**SD**	**Yield (t/ha)^{a}**		**DM at GS30 (t/ha)**		**DM at GS65 (t/ha)**		**Days to reach GS30**		**Days to reach GS65**	
Trait benchmark:		**>5.5 t/ha**		**>4 t/ha**		**>11.5 t/ha after grazing**					
Grazing treatment:		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Barley											
Cassiopee	1	0.20	0.43	3.66	3.86	11.94	9.20	132	132	209	209
	2	0.76	0.35	3.40	3.22	11.71	9.04	141	141	210	210
	3	0.65	0.31	3.25	3.35	8.84	4.89	149	149	189	189
Oxford	1	nd	0.12	1.07	0.93	10.48	8.97	41	41	174	174
	2	nd	0.23	0.64	0.84	11.71	11.19	64	64	210	210
	3	nd	0.20	2.28	1.82	10.16	7.68	120	120	189	189
Urambie	1	0.28	0.49	2.78	2.39	10.00	9.21	83	83	209	209
	2	1.18	1.85	2.22	2.20	10.93	10.77	84	84	190	190
	3	3.75	4.08	2.45	2.32	11.30	8.33	120	106	189	189
Triticale											
Cartwheel	1	1.07	nd	3.68	3.06	11.01	8.27	118	118	209	209
	2	1.71	2.72	3.14	3.13	9.73	8.41	113	113	190	190
	3	6.67	6.65	2.45	2.64	9.14	8.38	120	120	183	183
Endeavour	1	1.57	2.38	3.40	2.91	8.26	9.96	69	69	223	223
	2	3.37	3.67	2.69	2.51	10.88	10.35	84	84	204	204
	3	6.04	6.02	1.72	1.79	11.03	9.35	92	92	183	183
Wheat											
DS Bennett	1	1.38	1.94	2.82	2.47	12.68	13.52	83	83	229	229
	2	2.09	2.31	2.81	2.76	12.22	11.19	99	99	210	210
	3	4.72	5.20	1.14	1.14	10.24	10.72	106	106	189	189
EGA Wedgetail	1	1.39	2.43	2.68	2.96	9.77	8.53	83	83	223	223
	2	3.28	2.78	2.14	2.65	10.07	9.73	84	84	204	204
	3	4.19	3.72	1.67	1.13	8.52	8.90	92	92	183	183
Einstein	1	2.04	2.35	4.03	3.28	12.13	11.98	103	103	229	229
	2	5.02	6.36	2.18	2.37	13.20	12.26	99	99	210	210
	3	6.95	6.38	1.72	2.25	9.65	8.72	120	120	189	189
Illabo	1	2.68	3.20	2.62	2.54	10.63	10.58	83	83	229	229
	2	3.64	3.46	3.02	3.00	10.80	8.84	99	99	210	210
	3	4.71	5.85	2.54	2.05	9.12	7.66	120	120	189	189

Note: ^{a} Yield is expressed at 11% moisture content.
nd – grain data not possible for these plots due to inability for the plants to recover from frost damage.
ns – not significant.

Variety	SD	Yield (t/ha)[a]		DM at GS30 (t/ha)		DM at GS65 (t/ha)		Days to reach GS30		Days to reach GS65	
Trait benchmark:		>5.5 t/ha		>4 t/ha		>11.5 t/ha after grazing					
Grazing treatment:		NG	G	NG	G	NG	G	NG	G	NG	G
Kittyhawk	1	1.94	0.27	1.93	2.26	7.72	8.16	83	83	229	229
	2	3.84	3.24	2.54	2.16	8.08	10.06	84	84	210	210
	3	4.51	4.67	0.95	1.09	8.43	8.32	92	92	189	189
Manning	1	3.47	4.60	1.99	2.89	12.43	13.78	83	83	229	229
	2	5.55	5.68	3.15	3.50	13.91	10.18	113	108	210	210
	3	6.60	6.85	2.61	2.36	9.08	7.80	120	120	189	189
RGT Accroc	1	0.53	0.75	4.43	3.94	16.86	11.67	118	118	229	229
	2	2.78	2.62	4.00	3.95	13.12	12.34	127	127	210	210
	3	6.12	6.14	2.78	2.57	10.85	9.37	120	120	189	189
RGT Calabro	1	0.86	0.80	4.80	4.87	14.13	11.22	118	118	229	229
	2	2.93	2.88	3.54	3.84	12.26	12.84	127	127	210	210
	3	6.89	6.19	3.35	2.97	9.36	7.13	129	134	189	189
Sunlamb	1	2.32	2.60	1.43	1.21	9.02	9.08	55	55	229	229
	2	4.11	4.99	2.49	2.46	11.70	10.97	84	84	210	210
	3	5.45	5.74	1.45	1.26	10.33	9.90	92	92	189	189
P-value (variety)		<0.001		<0.001		<0.001		-		-	
P-value (graze)		0.001		ns		<0.001		-		-	
P-value (TOS)		<0.001		0.002		0.005		-		-	
P-value (variety:Graze)		0.002		ns		<0.001		-		-	
P-value (Variety:TOS)		<0.001		<0.001		<0.001		-		-	
P-value (graze:TOS)		ns		ns		ns		-		-	
P-value (variety:graze:TOS)		0.003		ns		<0.001		-		-	

Note: [a] Yield is expressed at 11% moisture content.
nd – grain data not possible for these plots due to inability for the plants to recover from frost damage.
ns – not significant.

Grain quality

Table 4 summarises the grain quality traits measured in this experiment.

Grain quality classifications and/or receival standards, can limit the marketing options of a variety. A wheat variety, for example, cannot be marketed above its maximum grain quality classification. The decreasing order of grain quality classifications is APH>H> Australian Premium White (APW)> Australian Standard White (ASW)>Feed. Wheat varieties evaluated in this experiment included APH, AH, ASW and Feed classified wheats. The milling quality or non-feed varieties were Kittyhawk$^{\phi}$ (APH), Illabo$^{\phi}$ (AH), EGA Wedgetail$^{\phi}$ (AH) and Sunlamb$^{\phi}$ (ASW).

The GTA trading standard (GTA, 2020) Grain quality parameters and classifications were used. Test weight is a measure of grain density. Low test weight <76 kg/hL (GTA, 2020) was the major quality parameter responsible for downgrading the milling-quality wheats in this study, with test weights ranging from 75.7 kg/hL for Kittyhawk$^{\phi}$ non-grazed from SD3 to 68.1 kg/hL for Illabo$^{\phi}$ non-grazed from SD2 (Table 4). Low test weights were most likely the result of multiple high rainfall events during December, which delayed harvest (Figure 1). Test weight decreases following rain events due to kernels swelling. The grain weight does not change, but test weight is reduced because kernels are larger, taking up greater volume.

The milling quality wheats' grain protein concentration (%) ranged from 14.9% for EGA Wedgetail$^{\Phi}$ non-grazed from SD1, to 11.2% for the Illabo$^{\Phi}$ grazed treatment from SD3. These differences in protein concentration can, in part, be related to a yield dilution effect, with the EGA Wedgetail$^{\Phi}$ non-grazed SD1 treatment yielding 1.39 t/ha compared with 5.85 t/ha for SD3 Illabo$^{\Phi}$ grazed. It should, however, be noted, that ~78% of the treatment combinations for the APH/AH classified wheats achieved grain proteins of >13%. All the wheat varieties, apart from Sunlamb$^{\Phi}$ (SD1 and SD2 non grazed and SD1 grazed), achieved <5%screenings.

All feed classified wheat varieties achieved a test weight of >62 kg/hL, the minimum test weight required for feed grade, and were below the maximum 15% allowed screenings.

Test weights of <65.0 kg/hL was also the principle factor for quality downgrading in the triticale varieties. Apart from Cartwheel$^{\Phi}$ from SD3, both triticale varieties in the grazed and non-grazed treatment combinations failed to achieve a test weight of >65.0 kg/hL. Screenings were all <10%.

Table 4 Grain quality data summary for grazed (G) and non-grazed (NG) treatments of 14 winter cereal varieties at three sowing dates (SD: 5 March, SD2: 24 March, SD3: 14 April) at Glen Innes, 2020.

Variety	**SD**	**Protein content (%)**		**Test weight (kg/hL)**		**Seed weight (g/1000 grains)**		**Screenings**	
Trait high benchmark:		**>13%**		**>76 kg/hL**				**<5%**	
Grazing treatment:		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Barley									
Cassiopee	1	17.91	16.26	59.98	58.68	49.62	48.44	1.32	0.90
	2	17.21	16.50	59.27	60.64	49.66	48.06	1.12	1.67
	3	16.15	nd	55.13	nd	44.61	nd	3.03	nd
Oxford	1	nd	nd	nd	nd	nd	nd	Nd	nd
	2	nd	nd	nd	nd	46.88	nd	3.76	nd
	3	15.24	14.01	49.93	61.03	36.21	32.97	6.91	8.68
Urambie	1	15.77	14.82	58.11	57.08	45.11	49.59	3.20	1.69
	2	15.74	15.28	58.50	59.63	48.22	48.84	1.68	2.54
	3	15.44	14.90	60.03	59.43	44.96	44.66	1.08	1.79
Triticale									
Cartwheel	1	13.23	nd	63.63	nd	34.25	nd	2.07	nd
	2	12.23	12.30	60.20	58.04	38.53	37.17	1.14	1.84
	3	11.38	10.61	67.57	70.04	39.56	37.80	1.32	1.79
Endeavour	1	12.07	11.85	62.53	60.98	29.53	25.91	4.99	7.55
	2	13.40	11.56	58.20	59.80	26.56	32.66	6.86	4.16
	3	12.27	11.55	63.97	62.97	37.62	33.91	1.90	3.04
Wheat									
DS Bennett	1	13.66	13.04	71.48	72.98	36.50	37.66	3.83	3.09
	2	13.17	12.01	72.83	73.80	38.82	41.08	3.06	1.78
	3	11.58	11.40	71.27	72.77	37.21	37.64	3.91	3.25
EGA Wedgetail	1	14.92	13.62	72.63	73.28	34.99	32.51	1.43	1.73
	2	14.75	14.49	71.50	71.17	35.95	40.50	1.43	0.96
	3	14.70	14.28	69.17	69.83	39.67	40.37	1.07	0.72

nd – grain data not possible for these plots due to inability for the plants to recover from frost damage
ns – not significant

Variety	SD	Protein content (%)		Test weight (kg/hL)		Seed weight (g/1000 grains)		Screenings	
Trait high benchmark:		**>13%**		**>76 kg/hL**				**<5%**	
Grazing treatment:		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Einstein	1	13.66	12.15	68.53	69.43	36.56	39.79	3.98	1.35
	2	12.83	11.44	71.23	71.53	38.42	36.52	1.76	2.09
	3	12.61	11.86	70.47	70.53	33.82	32.14	2.96	2.28
Illabo	1	13.94	13.89	69.38	71.58	30.77	30.71	3.87	3.01
	2	14.33	13.15	68.13	70.40	32.34	37.50	3.43	3.32
	3	13.01	11.17	71.23	71.60	38.72	37.14	1.95	1.52
Kittyhawk	1	13.19	12.94	73.98	74.38	31.36	32.65	3.54	3.33
	2	13.43	13.46	74.77	74.00	34.70	39.71	3.42	1.58
	3	12.79	12.44	75.70	74.80	40.27	39.59	1.40	1.32
Manning	1	13.07	12.36	68.78	69.58	38.01	37.18	1.87	1.83
	2	12.86	10.88	70.03	70.83	38.45	35.72	1.37	1.82
	3	12.56	11.59	69.03	68.93	31.04	29.27	4.10	3.99
RGT Accroc	1	14.19	13.22	72.38	74.18	37.78	46.38	3.14	0.98
	2	12.92	13.08	75.70	76.33	47.25	45.18	0.74	0.84
	3	12.73	12.05	74.73	73.37	42.52	41.04	1.70	1.88
RGT Calabro	1	14.88	14.78	69.98	73.23	44.30	46.57	1.39	1.44
	2	14.49	14.26	71.83	73.50	48.67	50.85	1.18	0.92
	3	12.94	11.51	73.73	71.90	45.62	41.68	1.13	1.54
Sunlamb	1	14.17	14.12	71.88	72.53	28.85	28.97	6.58	6.56
	2	13.85	12.61	74.17	74.90	29.50	32.08	5.14	3.04
	3	13.65	12.83	74.40	74.50	31.65	32.23	3.86	3.60
P-value (Variety)		<0.001		<0.001		<0.001		<0.001	
P-value (Graze)		<0.001		<0.001		ns		ns	
P-value (TOS)		0.005		ns		0.02		ns	
P-value (Variety:Graze)		0.02		0.014		ns		ns	
P-value (Variety:SD)		<0.001		<0.001		<0.001		<0.001	
P-value (Graze:SDS)		ns		ns		0.002		ns	
P-value (Variety:Graze:SD)		<0.001		ns		0.016		0.004	

nd – grain data not possible for these plots due to inability for the plants to recover from frost damage
ns – not significant

Feed value analysis

The DM cuts from SD1 at GS30 and GS65 were retained for feed value analysis. A bulked sample was prepared for each variety from the three field replicates for analysis by the NSW DPI Feed Testing Laboratories at Wagga Wagga (Table 5).

Important feed quality traits include NDF, ME and CP. NDF is a measure of the structural, slowly digested cell wall components of a plant and includes hemicellulose, cellulose, and lignin or 'indigestible fibre'. As the percentage of NDF increases, animal intake tends to decline due to the increasing fibre content, which takes longer to digest in the rumen. It is also important that NDF values are not too low (i.e. <30%) to avoid stomach upsets such as acidosis. Conversely, high NDF values (i.e. >60%) can affect digestibility, limiting intake.

Feed quality results for the simulated grazing samples taken at GS30 indicated that they were within the recommended NDF values of 30% and below the upper cut-off limit of 60% (Table 5), with NDF values ranging from 40% for Manning$^{\phi}$ up to 47% for RGT Calabro.

The ME of samples taken at GS30, ranged from 12.1 MJ/kg to 13.8 MJ/kg meeting the dietary requirements of most sheep and cattle. Levels of CP for the early simulated grazing samples, ranged from 22.2% of DM to 33.6% of DM. It is important to note that CP includes both true protein and non-protein nitrogen (NPN) and does not differentiate between nitrates and proteins in plants, with nitrate concentrations usually higher in younger plants, declining as plants mature. High nitrate levels can be an issue when grazing young cereal crops and producers should exercise caution and contact their veterinarian or Local Land Services livestock officer before grazing to discuss any potential animal health and/or management issues.

Feed analysis for DM cuts taken at anthesis (GS65), showed that NDF values increased and DM digestibility (%) decreased as crops matured, with NDF values ranging from 51% for Einstein up to 65% for Kittyhawk (Table 5). Metabolisable energy (MJ/kg) ranged from 5.5 MJ/kg for Kittyhawk up to 9.4 MJ/kg for Oxford barley satisfying the dietary requirements of most sheep and cattle. Crude protein concentration of DM ranged from 9% up to 13%, which is low to within an acceptable range.

Table 5 Feed quality analysis of 14 winter cereal varieties at Zadoks GS 30 and 65, sown on 5 March, 2020 at Glen Innes, NSW.

Variety	Growth Stage	Near infrared (NIR) spectrophotometry analysis									Cereal haygrade (GS65 only)		
		ADF (%)	ASH (%)	CP (%)	DMD (%)	DOMD (%)	ME (MJ/kg DM)	NDF (%)	OM (%)	WSC (%)	AFIA Grade	DM (%)	Moisture (%)
Barley													
Cassiopee	GS30	22	10	26.3	85	79	13.1	43	90	12.7			
	GS65	31	4	13	61	59	8.9	56	96	9.1	B1–C1	94.7	5.3
Oxford	GS30	25	10	33.6	86	80	13.2	47	90	9.0			
	GS65	30	6	12	64	61	9.4	53	94	16.4	A1–B1	95.1	4.9
Urambie	GS30	22	12	29.2	89	82	13.6	44	88	11.6			
	GS65	32	7	10	56	55	8.1	59	93	11.7	C1–C2	94.4	5.6
Triticale													
Cartwheel	GS30	22	9	23.6	86	79	13.1	44	91	18.6			
	GS65	37	4	9	53	51	7.5	62	96	9.0	C2–D2	94.6	5.4
Endeavour	GS30	22	11	26.3	88	82	13.6	44	89	15.0			
	GS65	35	6	13	54	53	7.7	60	94	9.0	C1–D1	95.3	4.7

ADF – acid detergent fibre
DMD – dry matter digestibility
NDF – neutral detergent fibre
ASH – ash
DOMD – digestibility of the organic matter contained in the dry matter
OM – organic matter
CP – crude protein
ME – metabolisable energy
WSC – water soluble carbohydrates

Variety	Growth Stage	Near infrared (NIR) spectrophotometry analysis									Cereal haygrade (GS65 only)		
		ADF (%)	ASH (%)	CP (%)	DMD (%)	DOMD (%)	ME (MJ/kg DM)	NDF (%)	OM (%)	WSC (%)	AFIA Grade	DM (%)	Moisture (%)
Wheat													
DS Bennett	GS30	24	10	25.5	86	79	13.1	43	90	14.6			
	GS65	32	11	11	56	54	7.9	55	89	10.5	C1	95.3	4.7
EGA Wedgetail	GS30	21	11	26.5	85	78	12.9	42	89	14.3			
	GS65	32	11	13	53	52	7.5	57	89	6.3	C1–D1	95.0	5.0
Einstein	GS30	23	11	27.2	86	80	13.2	45	89	11.8			
	GS65	28	8	10	63	60	9.2	51	92	21.1	B1–B2	95.7	4.3
Illabo	GS30	21	11	25.8	86	80	13.2	41	89	17.9			
	GS65	34	11	11	53	52	7.5	57	89	8.4	C1–D1	95.6	4.4
Kittyhawk	GS30	21	10	26.4	86	79	13.1	41	90	13.0			
	GS65	41	11	9	41	42	5.5	65	89	<4.0	D1–D2	93.5	6.5
Manning	GS30	21	11	25.1	89	83	13.8	40	89	20.0			
	GS65	31	8	10	59	56	8.5	57	92	11.6	B1–C2	95.5	4.5
RGT Accroc	GS30	21	9	23.4	87	80	13.3	43	91	18.3			
	GS65	33	9	10	53	52	7.5	57	91	10.2	C1–D2	95.1	4.9
RGT Calabro	GS30	24	9	22.2	80	74	12.1	47	91	14.4			
	GS65	34	9	10	54	53	7.7	57	91	12.6	C1–D2	95.9	4.1
Sunlamb	GS30	24	11	25.8	87	81	13.4	44	89	16.9			
	GS65	38	12	9	45	45	6.1	61	88	<4.0	D2	94.6	5.4

ADF – acid detergent fibre
DMD – dry matter digestibility
NDF – neutral detergent fibre
ASH – ash
DOMD – digestibility of the organic matter contained in the dry matter
OM – organic matter
CP – crude protein
ME – metabolisable energy
WSC – water soluble carbohydrates

Cereal hay grades

Australian Fodder Industry Association (AFIA) grades for cereal hay specify the highest grade A1, where A refers to ME >9.5 and 1 = CP >10%. Conversely, the lowest grade of D3 specifies an ME of <7.4 and a CP of <7%. Later letters (i.e., D) indicate lower ME and higher numbers (i.e., 3) indicate lower CP.

Oxford variety barley with an ME of 9.4 MJ/kg, CP 12% and DMD 64% was the best performing cereal for forage hay quality at GS65. In contrast, wheat variety Kittyhawk$^{\phi}$ (ME 5.5 MJ/kg; CP 9%; DMD 41%) produced the lowest quality forage hay at GS65.

Conclusions

This experiment, completed in the winter of 2020, provides growers and agronomists with a comprehensive data set to help identify winter cereal varieties with the greatest potential to produce high quality grain and the opportunity for grazing and grain recovery, in the NSW Northern Tablelands environment.

For grain-only production, the later sowing date (SD3; 14 April) produced higher grain yields than earlier sowing dates in this experiment. The greatest grain yield in non-grazed treatments was produced from SD3 by wheat varieties Einstein (6.95 t/ha) and RGT Calabro (6.89 t/ha), and the triticale variety Cartwheel$^{\phi}$ (6.67 t/ha), with several other varieties also yielding above 6 t/ha.

The greatest amount of grain produced in the grazed treatments was from SD3 by wheat variety Sunlamb$^{\phi}$.(6.85 t/ha), triticale variety Cartwheel$^{\phi}$ (6.65 t/ha) and the wheat variety Einstein (6.38 t/ha).

The simulated grazing treatment applied at GS30 resulted in a higher grain yield for some varieties such as wheat varieties Manningⴵ, Sunlambⴵ and DS Bennettⴵ across all sowing dates. This could be due to the simulated grazing treatment reducing lodging in these varieties, indicating that early grazing might be a useful management tactic for these varieties in this environment, particularly during wet seasons.

In terms of achieving grain quality specifications, ~78% of the treatment combinations for the APH/AH classified wheats achieved grain protein concentrations >13%. All the wheat varieties apart from Sunlambⴵ (SD1 and SD2 non grazed and SD1 grazed) achieved <5% screenings.

All feed classified wheat varieties achieved a test weight of >62 kg/hL, the minimum test weight required for feed grade and were also below the maximum allowed screenings of 15%.

For biomass production, the greatest amount of DM at GS30 was produced by the slow-growing winter wheat varieties RGT Calabro SD1 (4.87 t/ha; 118 days to reach GS30) and RGT Accroc SD1 (4.43 t/ha; 118 days). For SD2, the variety RGT Accroc produced 4.0 t/ha and required 127 days to reach GS30. By comparison, wheat variety Einstein produced 4.03 t/ha DM at GS30 and took only 103 days to reach this stage.

Feed quality analysis of the GS30 cuts indicated that feed values were within the recommended levels for all varieties at all sowing dates. For example, the ME of simulated grazing samples taken at GS30 ranged from 12.1 MJ/kg to 13.8 MJ/kg, which meets the dietary requirements of most sheep and cattle. Crude protein levels for these samples ranged from 22.2% to 33.6% of DM and the NDF values ranged from 40% for Manningⴵ up to 47% for RGT Calabro, which were within the recommended range of 30% to 60%.

Varieties that offer the greatest flexibility for growers to achieve both timely grazing at GS30 and the opportunity to harvest high quality grain in this high rainfall environment included the wheat varieties Manningⴵ, Einstein, Sunlambⴵ and Illaboⴵ and the triticale variety Cartwheelⴵ.

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Evaluation of dual-purpose oat varieties, Glen Innes 2020

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Summary of results

- Oat varieties Nile, Eurabbie and Dynasty demonstrated the greatest flexibility as 'graze and grain' options for growers. These varieties can achieve grazing at growth stage 30 (GS30) and grain at harvest in this environment.
- For grain production sowing date 3 (SD3) in mid-April produced significantly higher yields than SD1 (5 March) for all varieties in both the grazed and ungrazed treatments.
- Nile and Eurabbie, from the SD3 grazing treatments, produced the highest grain yields of 2.87 t/ha and 2.85 t/ha respectively.
- Yiddah$^{\text{⍉}}$ and Bimbil had the lowest grain yield from SD1.
- Grain quality was low for all varieties and treatment combinations due to frequent rainfall before harvest.
- Simulated grazing at GS30, the optimal time for first grazing, resulted in a higher grain yield than most of the ungrazed treatments of the corresponding varieties. Early grazing is a useful management option to improve grain production from dual-purpose oat varieties in this environment as it reduces lodging in the crop, particularly in a high growth potential season such as 2020.
- Varieties differed widely in the time taken to reach GS30 and the amount of biomass that they produced at this stage.
- Dynasty, Nile and Bimbil were the fastest varieties (55 days) to reach GS30 for SD1, producing biomasses of 3.06 t/ha dry matter (DM), 2.52 t/ha DM and 2.44 t/ha DM respectively.
- From SD1, Eurabbie produced the greatest amount of early biomass at GS30 of 4.1 t/ha DM, taking 69 days to reach this stage.
- From SD2, Yiddah$^{\text{⍉}}$ and Nile produced the greatest amount of biomass at GS30, with 4.75 t/ha DM and 4.73 t/ha DM produced respectively in 99 days.
- From SD3 Eurabbie and Nile produced the greatest amount of biomass at GS30 with 4.06 t/ha DM and 3.51 t/ha DM produced respectively, taking 106 days.
- Dynasty had the greatest response to sowing date, scoring the lowest DM production at GS30 in the experiment from the later sowing dates: SD2 (1.52 t/ha DM) and SD3 (1.71 t/ha DM) and respectively, compared with DM production from SD1 of 3.06 t/ha.
- A strong sowing date effect was also observed for Dynasty in relation to grain yield, which ranged from 0.42 t/ha (SD1 non-grazed) to 2.58 t/ha (SD3 grazed).
- Dynasty produced the most biomass at GS65 from the SD3 ungrazed treatment (11.71 t/ha DM), however, it took two weeks longer to reach GS65 than all other varieties. Yiddah$^{\text{⍉}}$ (10.93 t/ha, SD2), Nile (10.81 t/ha DM, SD3), and Bimbil (10.80 t/ha

DM, SD3) produced comparable DM at GS65, but required less time to achieve it than Dynasty.

- Feed values at GS30 were within the recommended dietary ranges for most sheep and cattle.
- Dynasty and Nile produced the highest forage quality at GS65 with Australian Fodder Industry Association (AFIA) Grades A1-B2 and A2-B2 respectively.

Introduction

Dual-purpose cereal crops (graze and grain recovery) offer flexibility in producing winter forage for livestock and additional income from the grain harvested. The ability to exploit early sowing windows with suitable dual-purpose varieties improves both profitability and options for the perennial pasture and cropping systems of the Northern Tablelands of NSW. Oat crops are particularly important in the region for early sowing, grazing, silage, hay and grain production. In 2020, early season soil moisture conditions were ideal for this experiment, which evaluated six varieties of oat for grazing and grain recovery potential at the NSW DPI research station at Glen Innes.

This experiment is a component of the NSW DPI–GRDC Grains Agronomy and Plant Pathology (GAPP) project BLG116 'Northern high rainfall zone dual purpose winter crop evaluation 2019–22' that is evaluating oat, wheat, barley, triticale, canola and perennial cereal varieties for their potential to produce grain following simulated grazing treatments. The project aims to support the expansion of grain production in the high rainfall zones of north eastern NSW.

Site details

Location	NSW DPI Glen Innes Agricultural Institute, 444 Strathbogie Road, Glen Innes NSW 2370 Latitude 29° 70› 18.2” S, Longitude 151° 70’ 02.3” E
Paddock history	2019 perennial grazing pasture
Soil type and nutrition	• NSW DPI Glen Innes research station • Light brown-grey clay loam soil type. • Chemical analysis of the site is presented in Table 1.
Rainfall and temperature	Figure 1 summarises the Bureau of Meteorology rainfall and temperature data for 2020.
Experiment design	• Split plot design with three replicates. • Treatments on main plot: three sowing dates (SD). • Treatments on split plot: six varieties combined with two grazing treatments (grazed and non-grazed).
Fertiliser	• 160 kg/ha of urea (N:47%) was incorporated via shallow cultivation one month before sowing. • 40 kg/ha of Granulock® Z (N:11%, phosphorus:21.8%, sulfur:4%, zinc:1%) and 141 kg/ha of urea (N:47%) applied at sowing.
Target plant population	100 plants/m^2
Weed management	2 L/ha Roundup 450® (glyphosate 450 g/L) and 1.2 L/ha LVE MCPA 570 (MCPA 570 g/L) applied before sowing.

Insect management	120 mL/100 kg Gaucho® 600 seed treatment (imidacloprid 600 g/L)
Disease management	180 mL/100 kg Vibrance® seed treatment (difenoconazole 66.2 g/L, metalaxyl-M 16.5 g/L, sedaxane 13.8 g/L)
Harvest	Harvest ranged from early November to mid December 2020.

Table 1 Soil chemical analysis of the experiment site at Glen Innes, NSW, 2020.

Characteristic	Depth (cm)				
	0–10	10–30	30–60	60–90	90–120
Ammonium nitrogen (mg/kg)	56	12	5	3	3
Nitrate nitrogen (mg/kg)	50	8	2	<1	<1
Phosphorus (mg/kg) [Colwell test]	82	9	4	3	2
Potassium (mg/kg) [Colwell test]	138	32	46	53	72
Sulfur (mg/kg)	25.4	11.4	18.5	12.8	9.6
Organic carbon (%)	2.0	0.75	0.48	0.36	0.3
Conductivity (dS/m)	0.18	0.05	0.04	0.04	0.04
pH_{Ca}	5.1	4.5	5.0	5.3	5.9
pH level (1:5 water)	5.9	5.7	6.2	6.6	7.3
BSES phosphorus (mg/kg)	58.2	4.0	–	–	–

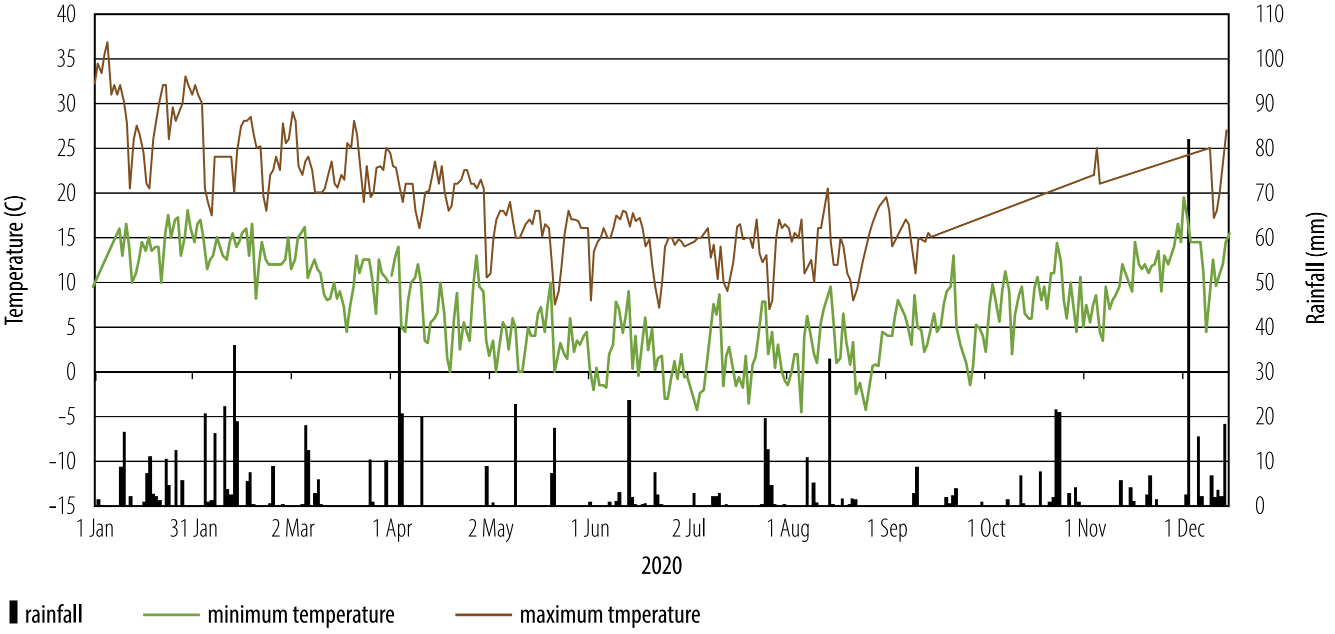


Figure 1 Rainfall and temperature data for NSW DPI Glen Innes Agricultural Research Station, 2020. (Source: Bureau of Meteorology).

Treatments

Varieties (6)

Table 2 Description of dual-purpose oat varieties in the experiment.

Variety	Traits and reason for inclusion
Bimbil	Dual-purpose type suitable for early to mid-season sowing in NSW.
SF Dynasty	A late-maturing forage oat released in Australia in 2020. As a later maturing variety, it produces most feed later into the season. It has good crown rust resistance and has good 'warm start' tolerance for early sowings.
Eurabbie	Late-maturing, semi-dwarf winter habit variety considered to have outstanding grain recovery potential. Grazing management is important as can be very short following a heavy late grazing leading to harvesting difficulties. Susceptible to *Barley yellow dwarf virus* (BYDV).
Mannus$^{(l)}$	Mid maturing, tall, strong-strawed, dual-purpose feed grain quality variety. Moderately susceptible to BYDV.
Nile	Late-maturing, medium height benchmark dual-purpose variety on the Northern Tablelands of NSW. It has good BYDV tolerance.
Yiddah$^{(l)}$	Tall, strong-strawed, early maturing variety. Moderate tolerance to BYDV with effective resistance to stem rust, and some resistance to crown rust.

Sowing dates

Three sowing dates: SD1 – 5 March; SD2 – 24 March; and SD3 – 14 April 2020.

Grazing treatments (2)

- Grazed and non-grazed treatments were applied to each variety, in each replicate of the experiment.
- Grazing treatments were simulated by mowing at 3 cm above ground height when plots reached the start of the stem elongation phase, or GS30, (GRDC Cereal growth stages guide, 2005). https://www.daf.qld.gov.au/__data/assets/pdf_file/0009/1373436/12-518-DL-File-C-Documents-RELEASE.pdf for crops intended for grain harvest, GS30 marks the end of grazing to prevent the removal of the developing grain heads and tiller death.
- All cut plant matter was removed from the grazed plots (Figure 2).

Figure 2 Application of a simulated grazing treatment to oat plots at GS30 by NSW DPI Ashley Moss, 13 May 2020.

Results

Establishment

The target population of 100 plants/m^2 was achieved across all sowing dates averaging 96 plants/m^2 established with an even establishment across the plots (Figure 3).

Figure 3 Uniform plant establishment is evident in this photo of SD1 (right) and SD2 (left) of the dual-purpose oat experiment at Glen Innes, 4 April 2020.

Statistical analysis

Variation in the traits was described by fitting a linear mixed-effects model considering the sowing date, variety and grazing treatment plus all interactions as fixed effects. Random effects were assigned to replication, main plot, range, and row of the experiment. An analysis of variance was derived from the model to test the null hypothesis with respect to each fixed term. Model assumptions of normal and homogeneous residuals were checked by graphical methods.

The analysis of variance was used to infer a statistically important effect when the relevant F-ratio statistic exceeded the expected F-ratio under the null hypothesis at 5% critical value. Specific pairwise contrasts were made by comparing the estimated effect with a calculated least significant difference at 5% critical value. The models were also used to estimate the mean and standard error of the trait under all combinations of variety, grazing and sowing date.

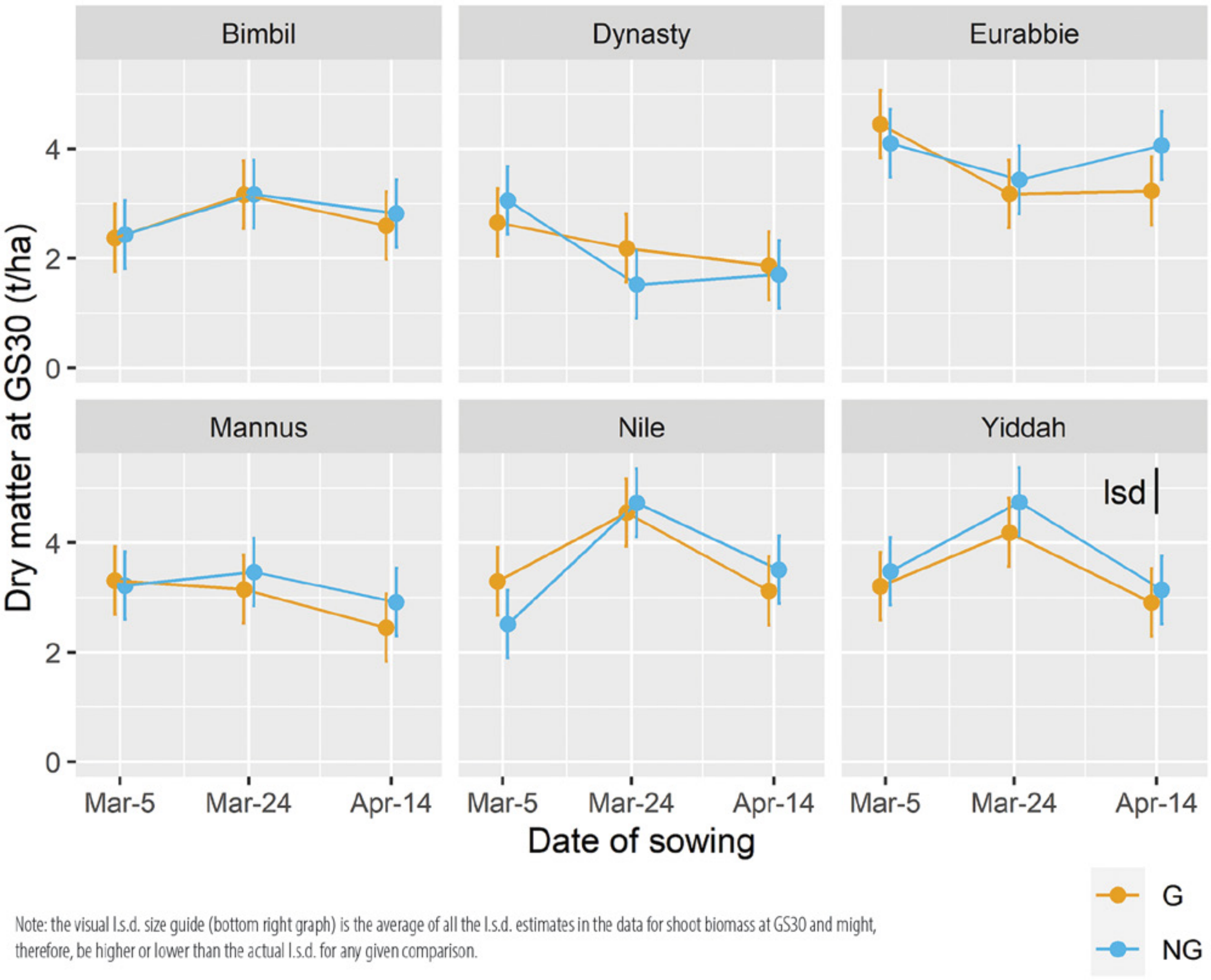
Data summaries are presented graphically in figures 4, 5 and 6. The estimates of grain yield, biomass and maturity are provided in more detail in Table 3.

Grain quality data is presented in Table 4 and feed value analyses in Table 5.

The data analysis was conducted in the R environment (R Core Team, 2021) with particular use of the lme4 package (Bates et al. 2015).

Plant shoot biomass at growth stage 30

Analysed data for plant shoot biomass at GS30 is presented in Figure 4. As the grazing treatments were applied directly after the GS30 biomass data was collected, there was no significant difference between the grazed (G, orange line) and non-grazed (NG, blue line) treatments (Figure 4).



Note: the visual l.s.d. size guide (bottom right graph) is the average of all the l.s.d. estimates in the data for shoot biomass at GS30 and might, therefore, be higher or lower than the actual l.s.d. for any given comparison.

Figure 4 Plant shoot biomass (tonnes dry matter/ha) at GS30 for six oat varieties from three sowing dates, with grazed (G, orange line) and non-grazed (NG, blue line) treatments.

The greatest amount of shoot biomass at GS30 in this experiment was produced from SD2 by Yiddah$^{\Phi}$ and Nile (4.75 t/ha DM and 4.73 t/ha DM respectively).

Eurabbie produced the highest biomass from SD1 (4.10 t/ha DM) and SD3 (4.06 t/ha DM). For SD1 the next highest biomass production was Yiddah$^{\Phi}$ (3.48 t/ha DM) and Nile from SD3 (3.51 t/ha DM).

Dynasty showed the greatest response to sowing date, scoring the lowest DM production in the experiment for SD2 and SD3 (1.52 t/ha DM and 1.71 t/ha DM respectively) and the highest DM production at GS30 for SD3 at 4.06 t/ha DM.

The days taken to reach GS30 varied widely with variety (Table 3). For SD1 Nile, Dynasty and Bimbil reached GS30 in 55 days while the remaining varieties Eurabbie, Mannus$^{\Phi}$ and Yiddah$^{\Phi}$, required 69 days to reach this stage.

For SD2, the days to reach GS30 ranged from 64 days (Dynasty) to 99 days (Mannus$^{\Phi}$ and Yiddah$^{\Phi}$). For SD3, the days to reach GS30 ranged from 78 days (Dynasty) to 106 days (all remaining varieties).

Plant shoot biomass at GS65

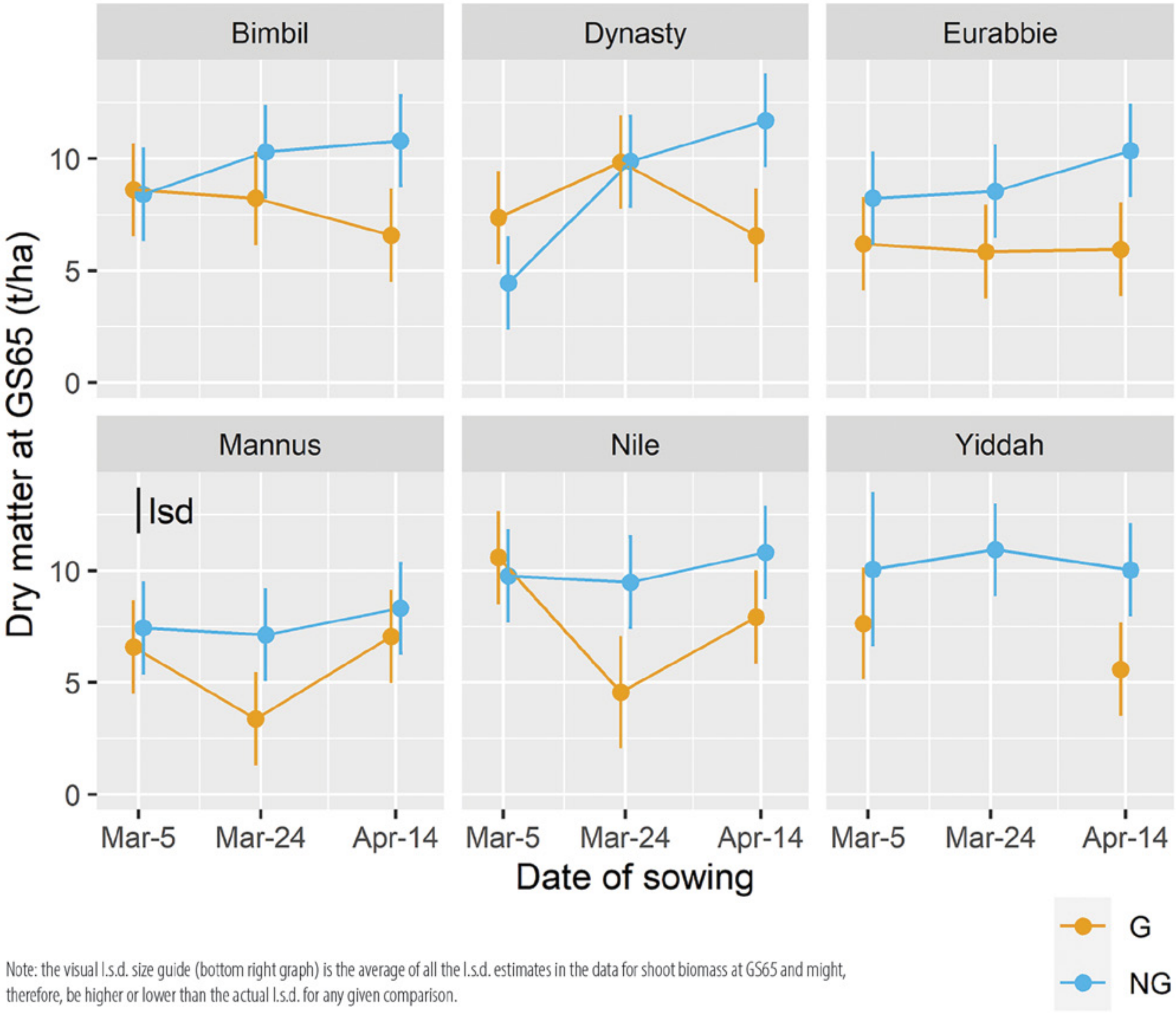
Feed values generally decline from anthesis (GS65) (GRDC. 2018), representing the decision point for growers regarding the options to graze, cut and bale for hay or silage, or take the crop through to grain harvest.

Figure 5 and Table 3 presents a summary of the analysed data for plant shoot biomass at GS65.

Of the non-grazed treatments, the greatest amount of shoot biomass at GS65 was produced from SD2 and SD3 by Dynasty (11.71 t/ha DM; SD3), Yiddah$^{\Phi}$ (10.93 t/ha DM; SD2) and Nile (10.81 t/ha DM, SD3) (Figure 5).

Most treatment combinations that received a simulated grazing treatment at GS30 produced less biomass at GS65 than the corresponding non-grazed treatments. The most notable exception was Nile from SD1 with a biomass of 10.59 t/ha DM, (0.83 t/ha higher than the non-grazed treatment of 9.76 t/ha DM at GS65). None of the other varieties from SD1 showed this capacity to recover from the GS30 grazing treatment.

The time required to reach GS65 decreased as sowing time was delayed, irrespective of grazing treatment (Table 3).



Note: the visual l.s.d. size guide (bottom right graph) is the average of all the l.s.d. estimates in the data for shoot biomass at GS65 and might, therefore, be higher or lower than the actual l.s.d. for any given comparison.

Figure 5 Plant shoot biomass (tonnes dry matter/ha) at anthesis, GS65 for six oat varieties from three sowing dates, with grazed (G, orange line) and non-grazed (NG, blue line) treatments.

Harvest maturity

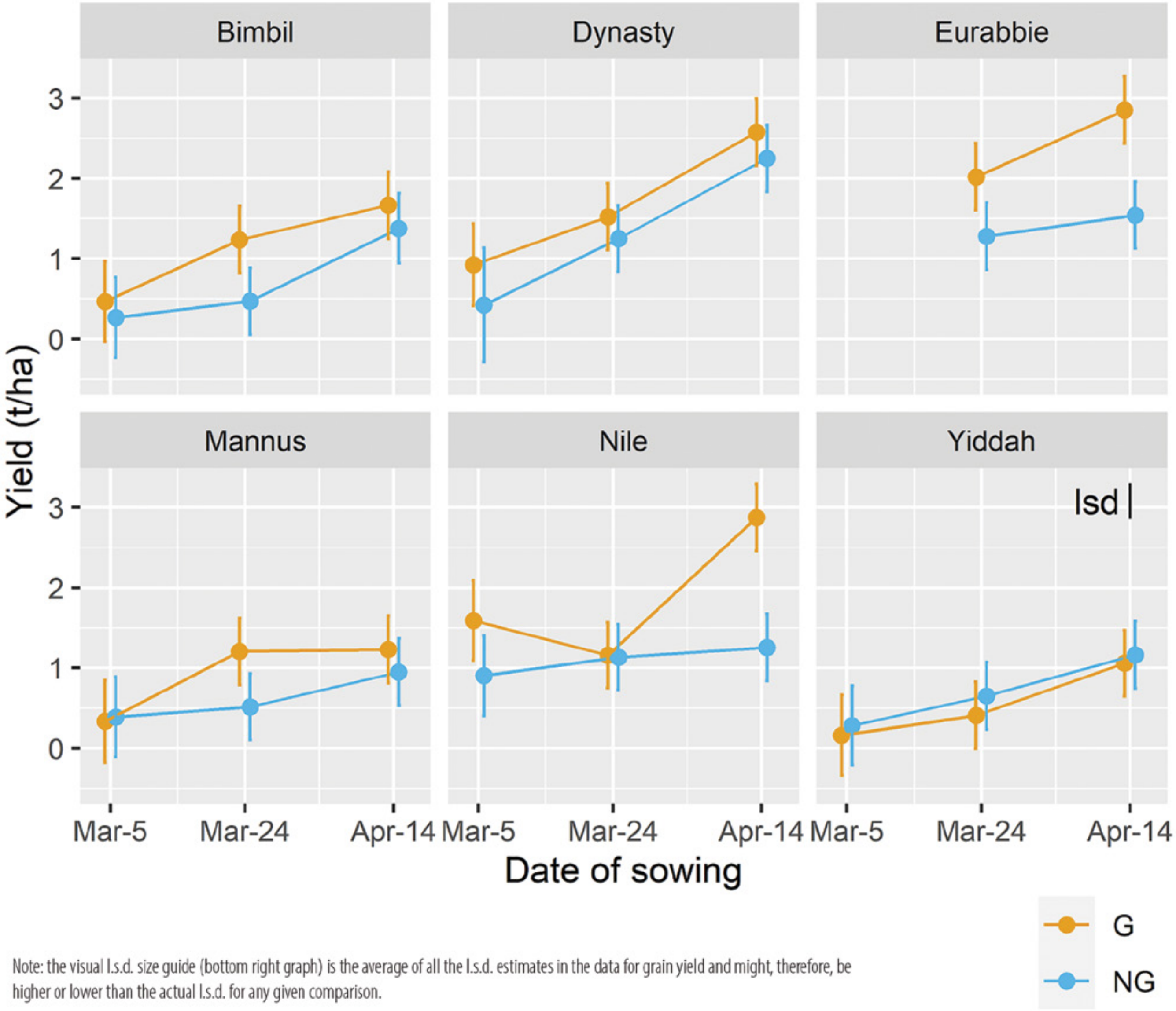
Frequent rainfall at the end of the 2020 season could have delayed maturity (Figure 1).

- For SD1, Eurabbie took 265 days (37 8 weeks) to reach maturity, which was three weeks earlier than the other varieties, which took 286 days (40.8 weeks).

- Eurabbie was also faster to mature from SD2 taking 246 days (35.1 weeks) compared with all other varieties, which took 267 days (38.1 weeks).
- For SD3 all varieties took 246 days (35.1 weeks) to reach harvest maturity.
- Grazing treatments did not affect maturity in comparison with non-grazed treatments.

Grain yield

Figure 6 and Table 3 present a summary of the analysed grain yield data for this experiment.



Note: the visual l.s.d. size guide (bottom right graph) is the average of all the l.s.d. estimates in the data for grain yield and might, therefore, be higher or lower than the actual l.s.d. for any given comparison.

Figure 6 Grain yield (t/ha) for six oat varieties at three sowing dates, with grazed (orange line) and non-grazed (blue line) treatments.

- Grain yield from all treatment combinations was highest from SD3, compared with SD1 and SD2 (Figure 6 and Table 3).
- Nile and Bimbil had the highest yield for grazed treatments from SD3 (2.87 t/ha2.85 t/ha respectively).
- Yiddah$^{\phi}$ and Bimbil had the lowest grain yield from SD1 (0.16 t/ha, grazed; 0.27 t/ha, non-grazed respectively).
- No yield data was recovered from Eurabbie from SD1 due to bird damage, however, a sample of grain was possible for quality analysis.

- For grain production in this experiment, the later sowing date (14 April) was preferable to the earlier (5 March, 24 March) sowing dates.
- Across all treatment combinations, grain yield was higher in the grazed treatment compared with its corresponding non-grazed treatment (Figure 6), suggesting that grazing at GS30 was beneficial for grain production in the varieties used in this experiment. This is likely to be because grazing can reduce crop lodging, particularly in a high biomass, high rainfall season such as 2020.
- For the non-grazed treatments, grain yield ranged from 2.25 t/ha (Eurabbie, SD3) to 0.27 t/ha (Bimbil, SD1).
- A strong sowing date effect on grain yield was observed for Dynasty, which ranged from 0.42 t/ha (SD1, non-grazed) to 2.58 t/ha (SD3, grazed) (Figure 6).

Table 3 shows yield and biomass at GS30 and GS65 and the days to reach GS30 and GS65.

Table 3 Grain yield, biomass and maturity data summary for grazed (G) and non-grazed (NG) treatments of six oat varieties at three sowing dates (5 March, 24 March, 14 April), Glen Innes, 2020.

Variety	**SD**	**Yield (t/ha)**[a]		**Dry matter at GS30 (t/ha)**		**Dry matter at GS65 (t/ha)**		**Days to reach GS30**		**Days to reach GS65**	
Grazing treatment		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Bimbil	1	0.27	0.47	2.44	2.37	8.41	8.61	55	55	229	229
	2	0.47	1.24	3.17	3.17	10.31	8.23	84	84	210	210
	3	1.38	1.66	2.82	2.60	10.80	6.57	106	106	189	189
Dynasty	1	0.42	0.92	3.06	2.66	4.44	7.37	55	55	244	244
	2	1.25	1.52	1.52	2.19	9.89	9.85	64	64	225	225
	3	2.25	2.58	1.71	1.87	11.71	6.57	78	78	204	204
Eurabbie[b]	1	–	–	4.10	4.46	8.24	6.20	69	69	229	229
	2	1.28	2.02	3.44	3.18	8.55	5.84	84	84	210	210
	3	1.54	2.85	4.06	3.23	10.37	5.95	106	106	189	189
Mannus	1	0.39	0.33	3.22	3.31	7.44	6.59	69	69	229	229
	2	0.52	1.21	3.46	3.15	7.14	3.37	99	99	210	210
	3	0.95	1.23	2.92	2.45	8.32	7.06	106	106	189	189
Nile	1	0.90	1.59	2.52	3.29	9.76	10.59	55	55	229	229
	2	1.13	1.16	4.73	4.55	9.48	4.56	99	99	210	210
	3	1.25	2.87	3.51	3.12	10.81	7.93	106	106	189	189
Yiddah[b]	1	0.28	0.16	3.48	3.21	10.07	7.64	69	69	209	209
	2	0.65	0.41	4.75	4.19	10.93	-	99	99	210	210
	3	1.16	1.06	3.14	2.91	10.03	5.59	106	106	189	189
P-value (variety)		<0.001		<0.001		<0.001		–		–	
P-value (graze)		0.001		ns		<0.001		–		–	
P-value (SD)		<0.001		ns		ns		–		–	
P-value (variety:graze)		<0.001		ns		ns		–		–	
P-value (variety:SD)		0.026		<0.001		<0.001		–		–	
P-value (graze:SD)		ns		ns		<0.001		–		–	
P-value (variety:graze:SD)		0.02		ns		ns		–		–	

[a] Yield is expressed at 11% moisture content.

[b] Data not available for Eurabbie from SD1 due to bird damage; and for variety Yiddah(b) in SD2 as it did not recover from a frost after grazing.

Grain quality

All varieties in this experiment were feed/forage classified. Grain quality parameters and classifications from the Grain Trade Australia (GTA) trading standard (GTA, 2020) were used to define quality as per the Feed Oats No.1 receival standards.

Grain quality was reduced due to frequent rainfall before harvest (figures 1 and 7). Grain quality data is summarised in Table 4.

Low test weights of <48 kg/hL (GTA, 2020) were the major quality parameter responsible for downgrading feed oats. Grain test weights decrease following rain due to the kernels swelling. Although grain weight does not change, the test weight is reduced because the kernels are larger, taking up greater volume. Only Eurabbie from SD3 (non-grazed) produced a test weight just above 48 kg/hL (Table 4).

Figure 7 NSW DPI Nguyen Nguyen inspecting oat grain quality and maturity in the dual-purpose oat experiment at Glen Innes, 2020.

In addition to low test weights, high levels of screenings (the % of material by weight below 2.0 mm screen) was another quality parameter responsible for downgrading from Feed Oats No 1, being >20%. Dynasty and Mannus$^{\Phi}$ performed the worst with screenings above 20% from most treatments (Table 4).

Grain protein responses in general were variable, although Yiddah$^{\Phi}$, at comparable grain yields, appeared to achieve a higher grain protein concentration.

Of the varieties evaluated, Eurabbie from SD2 and SD3 with its lower screenings and higher test weight performed better than the recognised benchmark variety Nile for this environment.

Table 4 Grain quality data summary for grazed (G) and non-grazed (NG) treatments of six oat varieties at three sowing dates (5 March, 24 March, 14 April), Glen Innes, 2020.

Variety	**SD**	**Protein content[a] (%)**		**Test weight (kg/hL)**		**Seed weight (g/1000 grains)**		**Screenings**	
Grazing treatment		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Bimbil	1	13.3	13.3	40.9	41.7	24.3	26.8	11.7	11.1
	2	13.8	13.2	42.6	42.2	24.6	26.2	13.5	12.5
	3	13.0	13.0	43.9	42.4	27.0	28.3	11.2	12.0
Dynasty	1	12.0	12.2	24.9	34.5	14.6	16.9	18.0	26.0
	2	12.6	12.4	33.2	36.2	17.8	19.4	20.3	23.8
	3	13.2	12.3	40.4	40.6	20.2	24.9	20.1	24.1
Eurabbie	1	11.0	11.7	29.8	34.8	18.2	21.1	14.8	13.1
	2	11.9	11.8	40.4	40.7	21.9	25.0	11.3	8.2
	3	12.5	11.7	48.4	45.1	28.9	26.0	6.7	10.3
Mannus	1	12.0	11.7	28.9	24.2	18.0	16.2	20.3	28.1
	2	11.6	11.8	29.5	32.9	18.9	25.0	24.3	15.8
	3	12.0	11.6	29.8	28.9	16.7	17.1	26.2	25.0
Nile	1	11.8	11.6	29.3	33.1	19.0	20.2	22.4	19.3
	2	11.7	11.4	29.3	31.0	21.5	30.0	17.6	13.0
	3	12.6	12.1	35.3	38.4	23.4	25.3	15.3	13.8
Yiddah	1	12.7	12.6	36.4	38.5	25.4	25.1	16.0	16.3
	2	13.4	12.7	40.2	39.8	24.9	34.3	13.2	15.4
	3	14.1	13.2	40.2	38.3	24.2	25.3	12.2	12.3
P-value (variety)		<0.001		<0.001		<0.001		<0.001	
P-value (graze)		0.008		0.04		<0.001		ns	
P-value (SD)		ns		0.012		0.03		ns	
P-value (variety:graze)		ns		ns		ns		<0.001	
P-value (variety:SD)		0.005		<0.001		<0.001		<0.001	
P-value (Graze:SD)		ns		0.04		0.002		0.002	
P-value (variety:graze:SD)		ns		ns		0.04		<0.001	

[a] Grain protein concentration is expressed as % dry matter basis

Feed value analysis

The dry matter cuts from SD1 at GS30 and GS65 were retained for feed value analysis. A bulked sample was prepared for each variety from the three field replicates and analysed by the NSW DPI Feed Testing Laboratories at Wagga Wagga (Table 5).

Table 5 Feed quality analysis of six oat varieties at GS30 and GS65, sown on 5 March, 2020 at Glen Innes, NSW.

Variety	**Growth stage**	**Near infrared (NIR) spectrophotometry analysis**									**Cereal hay grade (GS65 only)**		
		ADF (%)	**ASH (%)**	**CP (%)**	**DMD (%)**	**DOMD (%)**	**ME (MJ/kg DM)**	**NDF (%)**	**OM (%)**	**WSC (%)**	**AFIA Grade**	**DM (%)**	**Moisture (%)**
Bimbil	GS30	23	13	27.1	87	81	13.4	43	87	9.0			
	GS65	34	9	11	54	53	7.7	62	91	<4.0	C1–D2	95.1	4.9
Dynasty	GS30	24	11	25.1	84	78	12.9	49	89	7.9			
	GS65	31	7	10	64	61	9.5	57	93	13.8	A1–B2	96.2	3.8
Eurabbie	GS30	23	11	23.3	86	80	13.2	44	89	11.8			
	GS65	31	9	12	60	57	8.6	57	91	8.6	B1–C1	95.8	4.2
Mannus	GS30	25	14	21.0	87	80	13.3	46	86	14.8			
	GS65	36	5	9	54	53	7.7	64	95	9.2	C2–D2	95.0	5.0
Nile	GS30	25	11	26.4	87	81	13.4	47	89	9.3			
	GS65	30	7	9	64	61	9.4	56	93	15.6	A2–B2	96.4	3.6
Yiddah	GS30	23	11	24.9	89	82	13.7	44	89	11.4			
	GS65	31	9	13	59	56	8.5	58	91	8.3	B1–C1	93.9	6.1

ADF – acid detergent fibre
DMD – dry matter digestibility
NDF – neutral detergent fibre
ASH – ash
DOMD – digestibility of the organic matter contained in the dry matter
OM – organic matter
CP – crude protein
ME – metabolisable energy
WSC – water soluble carbohydrates

Important feed quality traits include neutral detergent fibre (NDF), metabolisable energy (ME) and crude protein (CP).

Neutral detergent fibre is a measure of the structural, slowly digested, cell wall components of a plant and includes hemicellulose, cellulose and lignin or indigestible fibre. As the percentage of NDF increases, animal intake tends to decline due to increasing fibre content, which takes longer to digest in the rumen. It is also important that NDF values are not too low (i.e. <30%) to avoid stomach upsets such as acidosis. Conversely, high NDF values (i.e. >60%) can affect digestibility, limiting intake.

Feed quality analysis of samples taken at GS30 ranged in NDF values from 43% to 49% (Table 5), which were within the recommended NDF values of above 30%, and below the upper limit of 60%.

The ME of samples taken at GS30 were very similar, ranging from 12.9 MJ/kg to 13.7 MJ/kg of DM, which is acceptable for the dietary requirements of most sheep and cattle. Forage quality of >11 MJ/kg is considered high quality.

Levels of CP for the early simulated grazing samples ranged from 21% DM to 27.1% DM. It is important to note that CP includes both true protein and non-protein nitrogen (NPN) and does not differentiate between nitrates and proteins in plants, with nitrate concentrations usually higher in younger plants, and declining as plants mature. High nitrate levels can be an issue when grazing young cereal crops. Producers should exercise caution and contact their veterinarian or Local Land Services livestock officer before grazing to discuss any potential animal health and/or management issues.

Feed analysis of the dry matter cuts taken at anthesis (GS65) showed that NDF values increased and DM digestibility (%) decreased as the crop matured. The NDF values ranged from 57% to 64%, which is borderline or over the recommended limit of 60% NDF.

The ME values in the GS65 cuts ranged from 7.7 MJ/kg to 9.5 MJ/kg of DM (Table 5).

The CP concentration % of dry matter at GS65 ranged from 9% to 13%, which is low but within the recommended range.

Cereal hay grades

Australian Fodder Industry Association (AFIA) grades for cereal hay specify the highest grade A1, where A refers to ME >9.5 and 1 = CP >10%. Conversely, the lowest grade D3 specifies an ME of <7.4 and a CP of <7%. Later letters (i.e. D) indicate lower ME and higher numbers (i.e. 3) lower CP.

Dynasty and Nile produced the highest grade of forage quality at GS65, with AFIA Grades A1-B2 and A2-B2 respectively (Table 5). In contrast, Mannus$^{\Phi}$ produced the lowest forage quality at GS65 with a grade of C2-D2.

Conclusions

This experiment completed in the winter of 2020 provides data to help growers and agronomists identify oat varieties with the potential to produce grain along with the option of grazing with grain recovery, in the NSW Northern Tablelands. Nile was included for comparison as it is popular with local graziers.

Grain yield

- Grain yield from all treatment combinations was higher from SD3 (mid April) than in SD1 and SD2 (5 March and 24 March respectively).
- The highest grain yield in the experiment was produced by Nile (2.87 t/ha) and Eurabbie (2.85 t/ha) in the SD3 **grazed** treatments.
- Dynasty produced the highest grain yield in the **ungrazed** treatments from SD3 at.2.5 t/ha. Dynasty (SD3) achieved a yield increase of 15% to 2.58 t/ha when grazed compared with the ungrazed treatment.

The simulated grazing treatment applied at GS30 resulted in a higher grain yield for most of the treatment combinations suggesting that early grazing is a useful management option for recovering grain from dual-purpose oat varieties in this environment. This is likely to be due to the positive effect of early grazing to reduce lodging in the crop, particularly in a season with high growth potential as experienced in 2020.

Biomass at GS30

- In contrast to grain yield, biomass production at GS30 was generally higher for SD1 and SD2.
- Yiddah$^{\Phi}$ and Nile produced the greatest amount of DM for SD2 (4.75 t/ha DM and 4.73 t/ha DM, respectively).
- For SD1, Eurabbie, Yiddah$^{\Phi}$, Mannus$^{\Phi}$ and Dynasty produced more biomass at GS30 (4.10 MJ/kg to 3.06 t/ha DM) than the local benchmark variety Nile (2.52 t/ha DM).
- Feed values at GS30 for all varieties were high and within recommended ranges for sheep and cattle diets.

Biomass at GS65

- Biomass and feed value analysis was conducted at GS65 (anthesis) as it is a critical decision point for most dual-purpose crops to either graze, cut for hay or silage, or to 'lock up' the crop for grain harvest.
- The biomass at GS65 was higher in the non-grazed treatments compared with the grazed treatments in almost all the variety × sowing date combinations. Nile from SD1 was the exception with the highest biomass at GS65 of 10.59 t/ha DM, demonstrating the ability of this variety to recovery from grazing at GS30 in this environment.
- At GS65, Dynasty (SD3) produced the greatest amount of biomass (11.71 t/ha DM).
- Yiddah$^{\Phi}$, Nile, and Bimbil produced comparable dry matter production at GS65 to Dynasty but required less time to achieve it.

- In most treatment combinations, varieties that received a simulated grazing treatment at GS30 produced less biomass at GS65 than their corresponding non-grazed treatment. However, the local benchmark variety Nile showed the greatest capacity to recover from the grazing treatment applied at GS30 to produce higher biomass at GS65 than the corresponding ungrazed treatment.

Feed quality at GS65

Feed value analysis of all varieties at GS65 indicated border line to above the recommended levels for NDF, which can affect digestibility, limiting intake.

Response to sowing date

Varieties showed a wide variety in the time required to reach critical growth stages. For example, from SD3 Nile and Eurabbie required 106 days to reach GS30 while Dynasty took only 78 days. Whilst it was faster to reach GS30 from SD3, Dynasty then took longer to reach GS65 (204 days) compared with Nile and Eurabbie (both 189 days).

The relatively new variety Dynasty, (released in Australia in 2020) showed the greatest response to sowing date. This variety was the fastest to reach GS30 taking 55 days, 64 days and 78 days for SD1, SD2 and SD3 respectively – at least two weeks faster than most other treatment combinations. This data suggests that a later sowing date and grazing at GS30 are critical to reach the genetic potential of this variety in this environment. A strong sowing date effect was also observed for this variety in relation to grain yield, which was very low from SD1 and highest from SD3.

Grain quality

The grain quality in the experiment was low due to frequent rainfall before harvest, with most treatment combinations scoring test weights below the 48 kg/hL standard specification (GTA, 2020).

Screenings were also high in many treatments. The inability to achieve grain receival standards, limited the marketability of the grain produced.

Eurabbie, from a mid-April sowing, was the best performing variety in terms of physical grain quality.

This experiment suggests that the oat varieties that offer the greatest flexibility for growers to achieve both grazing at GS30 and the opportunity to harvest grain in this high rainfall environment, included Nile, Eurabbie and Dynasty. Both Eurabbie and Dynasty produced biomass at GS30 and grain yield comparable with Nile at the late sowing date (14 April). Like Nile, at all sowing dates, Eurabbie and Dynasty produced higher grain yield from the grazed treatments compared with the corresponding ungrazed treatments.

The NSW DPI 2021 *Winter crop variety sowing guide* (Matthews et al. 2021) provides additional multi-season biomass and yield data and disease ratings for oat varieties in the Northern Tablelands and northern slopes regions of NSW. It also includes information on varietal differences in terms of feed values in oat grain.

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Dual-purpose canola evaluation, Tamworth 2020

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Summary of results

- All varieties evaluated showed a trend for yield decline with a delayed sowing date and grazing.
- The highest yielding variety following grazing was the mid–late spring type 45Y91 CL, which yielded 3.09 t/ha for the first sowing date (2 April; SD1), with comparable yields for non-grazed treatments for SD1 and SD2 (23 April).
- The variety 45Y91 CL was adversely affected when sowing date was delayed, with a 57% decrease in grain yield; 3.14 t/ha non-grazed versus 1.34 t/ha grazed from SD3 (7 May).
- The overall highest yielding variety was 45Y91 CL, with a grain yield of 3.14 t/ha non-grazed from SD3.
- Hyola® 970 CL was the best performed winter variety for both grazed and non-grazed treatments with a grain yield of 2.13 t/ha grazed from SD1and 2.29 t/ha non-grazed from SD2.
- Grain oil content (%DM) ranged from 39.8% for 45Y91 CL from SD2 down to 29.7% for Phoenix CL from SD3. The variety 45Y91 CL achieved the highest oil concentrations for all treatments, apart for SD3 grazed.
- The varieties 45Y91 CL, Hyola® 970 CL and Nizza CL produced comparable biomass (DM t/ha) at full ground cover: ~2.5–2.6 t DM/ha (SD2) and ~2.8 t DM/ha (SD3).
- Varieties suitable for hay/silage making include 45Y91 CL and Hyola® 970 CL, which produced >11 t DM/ha and >9.0 t DM/ha for the non-grazed treatments at the end of flowering.
- Feed quality analysis of samples taken at mid flower showed that varieties had the potential to produce good quality hay with adequate metabolisable energy (ME) and protein (CP) levels.

Introduction

Dual-purpose (graze and grain) canola (*Brassica napus*) offers growers the opportunity to exploit early sowing options, potentially providing valuable winter forage without necessarily incurring substantial grain yield penalties. In southern NSW, the adoption of dual-purpose slow spring and winter canola varieties into mixed farming systems is well established. In contrast, in the medium to high rainfall zones of northern NSW, there has been limited research into dual-purpose canola.

In 2020, six canola varieties, five winter and one spring type, were evaluated at Tamworth on the north-west slopes, for their dual-purpose potential (graze and grain). This research is a component of the NSW DPI–GRDC Grains Agronomy and Plant Pathology partnership (GAPP) project BLG116.

The BLG116 project has been set up to evaluate oat, wheat, barley, triticale, canola and perennial cereal varieties for their potential grain yield following simulated grazing treatments. The aim is to identify winter cereal and canola varieties that are suitable for grain production in grazing systems, and to potentially increase grain production and options for producers with mixed farming systems in northern NSW. Experiments are being conducted at Tamworth on the north west slopes and Glen Innes on the NSW northern tablelands. Following a preliminary experiment at Glen Innes in 2019 where canola varieties were severely affected by frost, it was decided to only evaluate canola at the Tamworth site in 2020.

This paper presents results from the 2020 canola experiment at Tamworth. Results include biomass production, phenology responses, grain recovery and yield and grain quality parameters from non-grazed and simulated grazing treatments.

Site details

Location	NSW DPI Tamworth Agricultural Institute (TAI), Tamworth, NSW (31° 15' 263" S, 150° 98' 525" E)
Soil type	Grey vertosol
Paddock history	Sorghum 2018, long fallowed 2019.
Starting soil nitrogen (N)	~300 kg N/ha (0–120 cm).
Starting soil phosphorus (P)	Colwell: 31 mg P/kg (0–10 cm), 7 mg/kg (10–30 cm).
Starting water	~181 mm plant available water capacity (PAWC) to 120 cm.
Rainfall and temperature	High starting soil water levels meant sowing dates did not the need supplementary irrigation. Figure 1 shows the rainfall and temperature data for the Tamworth site in 2020. Total rainfall for 1 April to 30 November was 338 mm, which was below the long-term mean of 363 mm.
Fertiliser	• 60 kg/ha of starter fertiliser Granulock® Z applied at sowing; (12% nitrogen (N), 21.8% phosphorus (P), 4% sulfur (S), 1.0% zinc (Z)). • 141 kg/ha urea (47% N) side banded at sowing.
Plant population	Target: 40 plants/m^2.
Weed management	• Glyphosate® 450 (450 g/L glyphosate) 2 L/ha and LVE MCPA® (570 g/L MCPA) 1.2 L/ha applied pre-planting. • Intervix® 500 mL/ha (33 g/L imazamox, 15 g/L imazapyr) in-crop.
Insect management	Aphidex® 1 kg/ha (500 g/kg pirimicarb) applied 14 October 2020.
Disease management	Jubilee® 500 (500 g/L flutriafol) 0.2 L/ha applied in-furrow as a fertiliser treatment.
Harvest date	Harvest/maturity ranged between 7 October for SD1 (non-grazed 45Y91 CL) and 4 December for SD3 (grazed Hyola® 970 CL).

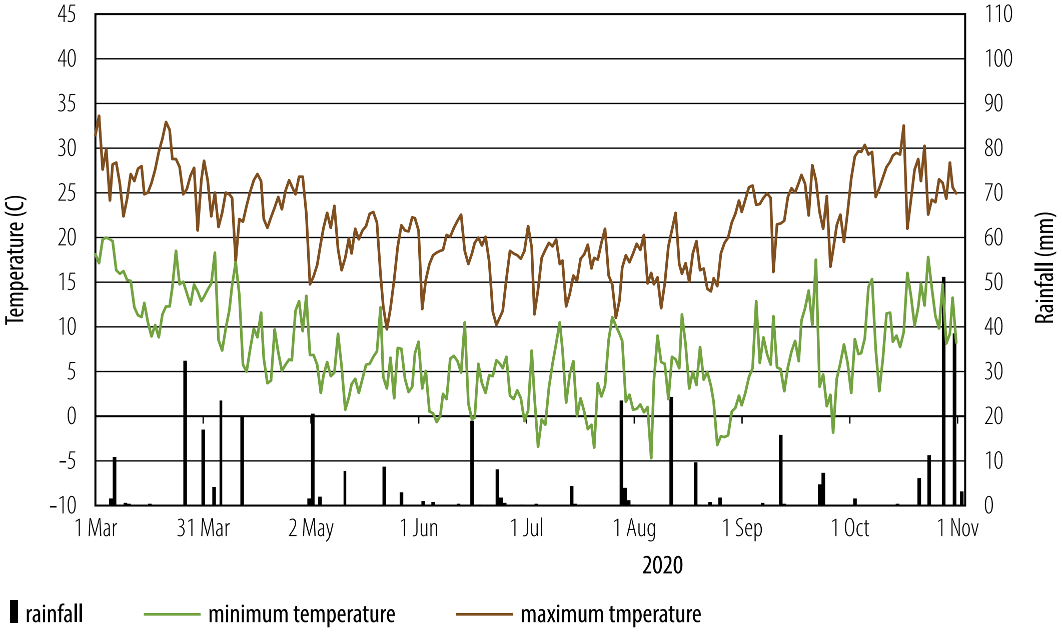


Figure 1 Rainfall and temperature data for the canola site at Tamworth, NSW, winter 2020.

Treatments

Variety (6)

- Six varieties were selected to test their grazing potential and grain recovery following grazing (Table 1).
- Five varieties were winter types, requiring a period of cold temperature (vernalisation) before transitioning to their reproductive phase and initiating flowering.
- One variety was a mid–late maturing spring type, 45Y91 CL, with photoperiod sensitivity (flowering in response to the combination of increasing length of daylight and temperature).

Vernalisation and photoperiod sensitivity traits enable these varieties to be sown earlier, making them potential dual-purpose options for the medium to high rainfall zones of northern NSW.

Table 1 Description of canola varieties and seed source, Tamworth 2020.

Variety	Variety description and seed source
Hyola 970 CL	Benchmark graze and grain winter Clearfield (CL) canola hybrid. Late maturing suited to February–April sowings. Advanta seeds.
Phoenix CL	Late-maturing hybrid winter CL canola. Slightly quicker to flower than other winter types. AGF seeds.
Nizza CL	A hybrid, winter CL canola released by Seed Force Australia as a replacement for Edimax CL.
Pioneer 45Y91 CL	Mid–late maturing spring hybrid CL canola, with excellent early growth. Pioneer seeds.
H210003 CL	Advanced hybrid winter CL canola line undergoing evaluation.
H82005 CL	Advanced hybrid winter CL canola line undergoing evaluation.

Sowing date (3)

SD1: 2 April, SD2: 23 April and SD3: 7 May 2020.

Grazing (2)

- Non grazed.
- Grazed. Simulated grazing was achieved by mowing to ~3 cm height at full ground cover (~8–10 leaf stage and before stem elongation).

Experiment design

- Randomised complete block design.
- Twelve treatments (six varieties, grazed and non-grazed) and three sowing dates, three replicates.
- Plot size: 1.65 m wide and 9.5 m long, 5 rows per plot at 0.33 m row spacing.

Statistical analysis

Statistical analysis was completed using the R environment package. A linear mixed-effects model using the lmer package was fitted to the data considering main plot (sowing date) and subplot (variety × grazing treatment) as fixed effects. Random effects were assigned to replication, range, and row of the experiment. Analysis of variance (ANOVA) with Kenward–Roger's method was used to obtain the p-value of fixed effect factors. The Q–Q normal plot and plots against the residual of the fitted model were checked for normality and homogeneity.

In this type of analysis, *P* values are generated for each fixed effect and the effect can be interpreted as having significance where the *P* values are ≤0.05. The l.s.d. guide provided in the figures is the average of all the l.s.d. estimates in the data and will, therefore, be higher or lower than the actual l.s.d. for any given comparison.

The analysed data summaries are presented in figures 3, 4, 5 and 6 and in tables 3, 4 and 5. To assist interpretation, each variety is presented separately in the figures, with sowing dates across the x axis and the traits e.g. yield (Figure 4), on the y axis.

Results

Plant establishment

The plant population, averaged across treatments, was 46 plants/m^2, greater than the target of 40 plants/m^2. Populations ranged from 40 plants/m^2 to 49 plants/m^2.

Figure 2a shows the uniformity of canola plots for SD1.

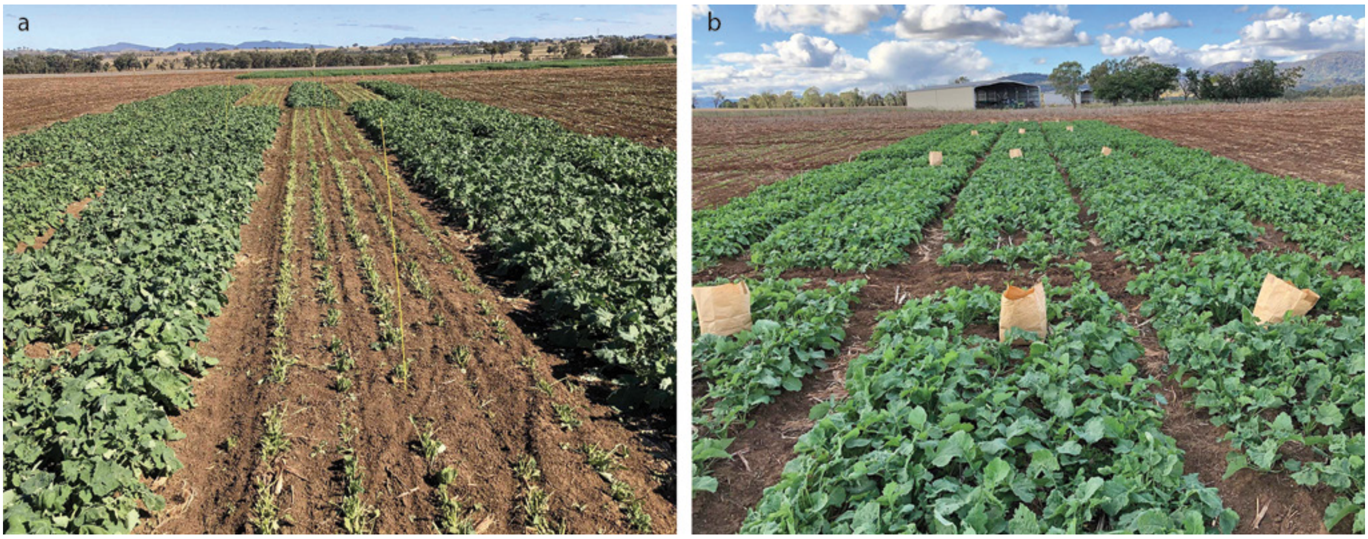


Figure 2 (a) Simulated grazing treatment (mowing to ~3 cm height), on canola plots at full ground cover ~8–10 leaf stage before stem elongation; (b) shows the biomass cuts.

Biomass at full ground cover ~8–10 leaf stage before stem elongation

Grazing treatments were simulated by mowing at ~3 cm height (Figure 2a) when plots reached full ground cover, defined as '~8–10 leaf stage and before stem elongation'. Biomass cuts (0.5 m^2) were also taken from plots, both grazed and non-grazed, at full ground cover (Figure 2b).

Results showed that DM produced from plots ranged from 1.45 t/ha for H210003 CL to >2.8 t/ha for 45Y91 CL and Hyola® 970 CL from SD3 (Table 2). Most varieties showed a trend towards producing greater DM, with delayed sowing dates. This could be a consequence of the longer time taken to reach full ground cover and hence accumulate DM (Figure 3). The amount of DM produced, and the grazing treatments timing corresponded to when producers typically introduce livestock, that is, when 1.5 t DM/ha to 2.6 t DM/ha is present, about 8–10 weeks after sowing (Fisher and Jones, 2018).

Grazing (orange points) and non-grazed treatments (blue points); G = grazed, NG = non-grazed.

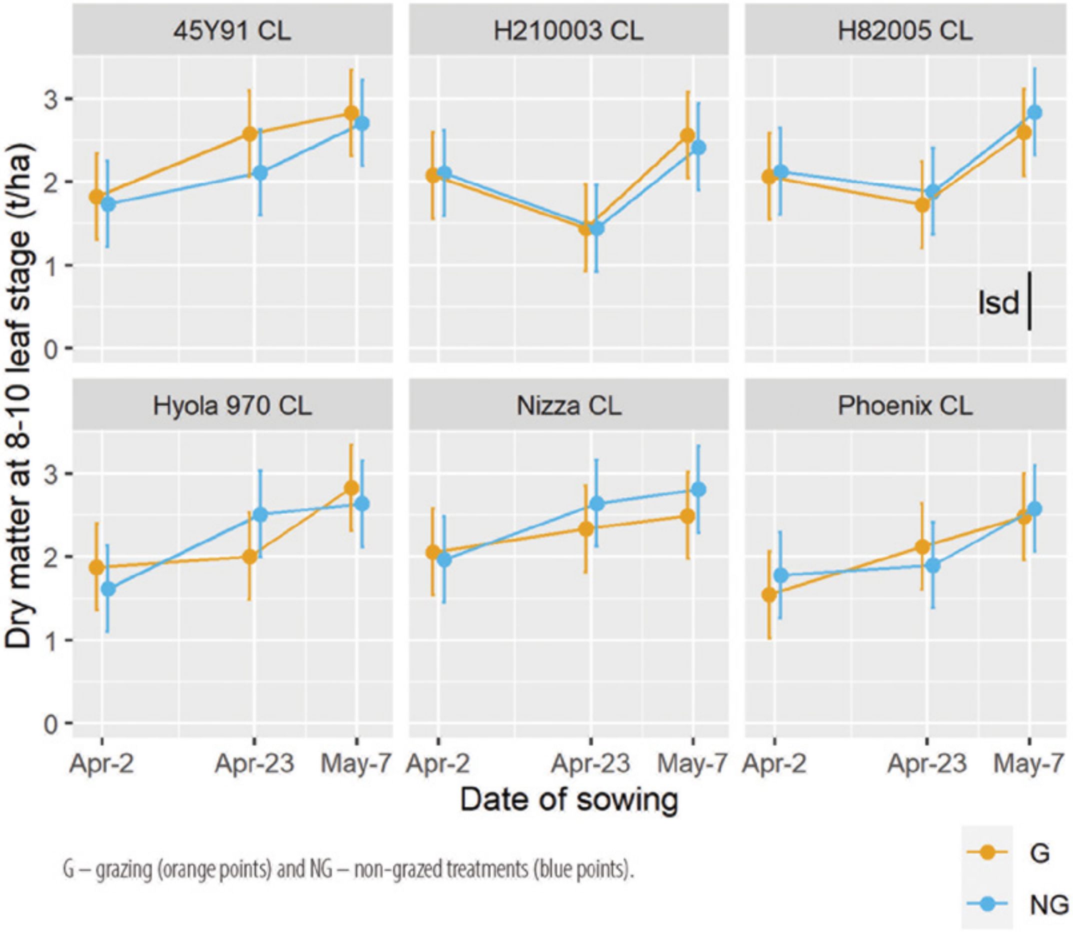


Figure 3 Dry matter at full ground cover ~8-10 leaf stage before stem elongation of six canola varieties for three sowing dates at Tamworth 2020.

Biomass at end of flowering/early pod fill

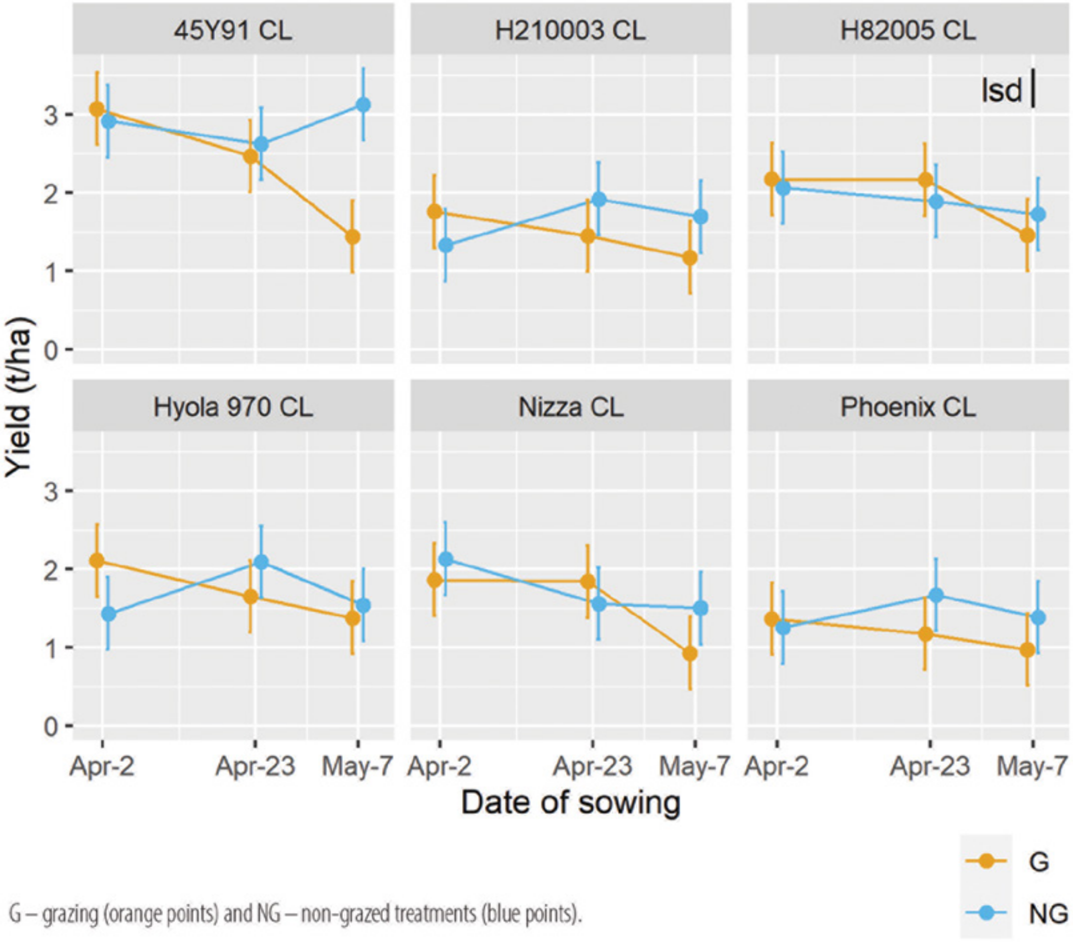
The amount of biomass, (DM t/ha) produced at the end of flowering/early pod fill, ranged from 13.0 t/ha for 45Y91 CL non-grazed, to 4.5 t/ha for H210003 CL grazed (Table 2). Results highlighted the effect of the grazing treatments at full ground cover on subsequent biomass produced by 45Y91 CL from delayed sowings. DM declined by 60% from 11.4 t/ha non-grazed to 4.6 t/ha grazed from SD3. These findings highlight the inability of 45Y91 CL to recover from grazing, affecting both yield and biomass accumulation, from late sowing dates in northern NSW.

The overall effect of the grazing treatment on biomass accumulation for the winter varieties varied, averaging a ~12% decline in biomass production. It should be noted that some varieties such as Nizza CL from SD1 were able to recover from the early grazing and achieved comparable biomass by the end of flowering/early pod fill (e.g. 8.1 t/ha grazed, non-grazed 7.8 t/ha). In contrast, Hyola® 970 CL from SD2, produced 9.5 t/ha biomass for the non-grazed compared with only 6.2 t/ha for the grazed treatment (Table 2).

Yield

The variety, 45Y91 CL (mid–late spring type) was the highest yielding across all sowing dates in non-grazed treatments (Figure 4). It was able to maintain its yield potential (non-grazed vs grazed) following grazing treatments for SD1 and SD2. However, 45Y91 CL suffered the largest yield penalty (grazed versus non-grazed) from an SD3 delayed sowing. This might be due to the shorter flowering period in response to grazing. It was observed that the grazing treatment both delayed and shortened the flowering period (i.e., from 50% flower to the end of flowering). In the grazed treatment, 45Y91 CL flowered over ~30 days compared with ~43 days in the non-grazed plots (Table 2).

These results highlight that grain recovery following grazing for varieties such as 45Y91 CL are best achieved from an earlier sowing date. There is a greater likelihood of a grain yield penalty when later sown crops are grazed. Similarly, all varieties evaluated in this experiment showed a trend for yield to decline in response to both grazing and delayed sowing. (Figure 4). For example, grain yield for the winter type Hyola® 970 CL declined from 2.13 t/ha (SD1) to 1.40 t/ha (SD3) (Table 2). The winter varieties evaluated, however, did not show any significant yield penalties in response to grazing for any sowing dates



G – grazing (orange points) and NG – non-grazed treatments (blue points).

Figure 4 Grain yield of six canola varieties for three sowing dates at Tamworth 2020.

Table 2 Analysed data for yield, dry matter (DM) production and phenology at Tamworth 2020.

Variety	SD	Yield (t/ha)		DM at full ground cover[a] (~8–10 leaf stage) (t/ha)		DM at end of flower/early pod fill (t/ha)		Days to reach full ground cover[ab]	Days to 50% flower[b]		Days to end of flower[b]	
Grazing treatment		NG	G	NG	G	NG	G		NG	G	NG	G
Pioneer 45Y91 CL	1	2.87	3.09	1.7	1.8	12.7	10.9	46.0	102.0	123.0	162.0	165.7
	2	2.69	2.48	2.1	2.6	13.0	6.5	71.3	116.0	121.0	150.0	154.0
	3	3.14	1.34	2.7	2.8	11.4	4.6	72.3	111.0	122.3	153.7	152.0
H210003 CL	1	1.34	1.96	2.1	2.1	4.9	4.5	46.0	171.3	172.3	195.0	196.3
	2	2.06	1.34	1.4	1.4	6.1	5.9	65.3	160.7	162.0	189.0	186.0
	3	1.59	1.20	2.4	2.6	6.2	5.5	73.7	149.3	151.0	167.0	157.0
H82005 CL	1	2.08	2.06	2.1	2.1	7.0	7.9	46.0	160.7	163.0	186.7	187.3
	2	1.84	2.18	1.9	1.7	8.0	7.7	70.3	149.0	152.3	172.7	176.0
	3	1.74	1.54	2.8	2.6	9.1	6.9	71.0	138.0	142.7	162.3	167.0
Hyola 970 CL	1	1.27	2.13	1.6	1.9	9.5	7.0	46.0	169.3	171.0	192.3	193.7
	2	2.29	1.54	2.5	2.0	9.5	6.2	66.7	156.0	171.0	184.0	184.0
	3	1.61	1.40	2.6	2.8	7.9	7.2	72.3	146.7	149.7	170.3	176.7
Nizza CL	1	2.08	2.01	2.0	2.1	7.8	8.1	46.0	162.3	167.3	186.7	187.0
	2	1.46	1.68	2.6	2.3	8.9	7.5	65.3	151.0	153.7	173.3	175.7
	3	1.45	1.07	2.8	2.5	8.6	6.1	72.3	139.7	146.0	161.7	167.0
Phoenix CL	1	1.21	1.38	1.8	1.5	6.5	6.6	46.0	146.3	168.7	188.7	193.7
	2	1.69	1.25	1.9	2.1	7.9	7.3	72.7	152.7	156.7	176.3	178.0
	3	1.41	0.87	2.6	2.5	7.9	5.5	75.0	142.7	147.7	170.0	173.0
P-value (SD)		0.017		0.015		ns			0.001			
P-value (variety)		<0.001		ns		<0.001			<0.001			
P-value (graze)		0.003		ns		<0.001			<0.001			
P-value (variety:graze)		ns		ns		<0.001			ns			
P-value (variety:SD)		ns		0.026		0.002			<0.001			
P-value (graze:SD)		<0.001		ns		0.002			ns			
P-value (variety:graze:SD)		0.006		ns		ns			ns			

[a] (~8–10 leaf stage)
[b] Days after sowing

Seed quality parameters (protein and oil concentration)

All varieties were below the Australian Oilseed Federation (AOF) commodity receival standards base oil level of 42%, therefore could be expected to attract a 1.5% price deduction for each 1% below the base level. In non-grazed treatments, oil concentrations ranged from a high of 39.8% for 45Y91 CL, from SD2 to 29.7% for Phoenix CL from SD3 (Table 3). Based on current receival standards, this indicates an equivalent price penalty of between 3.0% for 45Y91 CL up to 18% for Phoenix CL.

Compared with the non-grazed 45Y91 CL, all winter varieties had lower oil concentration levels. The lowest oil concentration for grazed 45Y91 CL was 35.8% from SD3.This was equivalent to the best winter variety in terms of oil concentration; grazed Nizza CL with 35.80% from SD3.

The lower oil concentration for the winter varieties is most likely related to their later flowering dates compared with 45Y91 CL. This is seen when comparing the number of days taken to reach 50% flowering and the subsequent days to reach the end of flowering: a measure of the start and duration of the flowering window (Table 3). The non-grazed Hyola® 970 CL treatment for SD2 reached

50% flowering 156 days after sowing (DAS), on 26 September and finished flowering 184 DAS on 24 October. In contrast, 45Y91 CL from the same SD and non-grazed treatment reached 50% flowering 116 DAS on 17 August, finishing flowering 150 DAS (20 September). The consequence of delayed flowering for Hyola® 970 CL in 2020 meant that seed development occurred during less favourable conditions compared with 45Y91 CL, i.e. increasing temperatures, greater evapotranspiration and declining plant available moisture (Figure 1).

Canola seed protein results exhibit an inverse relationship to oil content. Low oil content is generally associated with higher protein concentrations (Table 3). Although canola seed does not attract a premium for protein concentration, this low protein would have implications for the canola by-product, canola meal.

Table 3 Grain oil and protein concentration for six canola varieties for three sowing dates at Tamworth 2020.

Variety	**SD**	**Oil concentration (% DM)**		**Protein concentration (% DM)**	
		Non grazed	**Grazed**	**Non grazed**	**Grazed**
Pioneer 45Y91 CL	1	38.87	39.17	24.93	23.77
	2	39.83	38.90	24.60	23.17
	3	39.60	35.77	25.13	23.73
H210003 CL	1	31.73	32.93	28.07	27.10
	2	32.27	32.63	28.33	27.97
	3	31.60	33.37	28.77	27.77
H82005 CL	1	31.30	32.13	28.57	27.97
	2	29.97	31.60	29.73	27.80
	3	32.17	32.23	28.37	26.77
Hyola 970 CL	1	30.43	32.13	29.60	27.63
	2	30.40	31.33	29.87	29.20
	3	30.67	32.07	29.73	28.97
Nizza CL	1	34.40	35.60	27.87	24.93
	2	31.97	33.67	28.77	27.13
	3	33.13	35.80	28.33	25.73
Phoenix CL	1	31.80	31.40	27.60	25.57
	2	30.27	31.80	28.57	27.73
	3	29.70	31.40	28.50	27.80
P-value (SD)		ns		0.04	
P-value (variety)		<0.001		<0.001	
P-value (grazing)		0.01		<0.001	

Feed analysis

Important feed quality traits include NDF, ME and CP. Feed quality analysis results for grazing samples taken at full ground cover show they were above the recommended level for NDF of 30% and below the upper cut-off limit of 60% (Table 4). It is important that NDF levels are not too low to avoid stomach upsets such as acidosis. Conversely, high NDF values (i.e. >60%) can affect digestibility, thereby reducing nutrient intake.

The ME of samples at full ground cover ranged from 9.9 MJ/kg–11.5 MJ/kg, satisfying the dietary requirements of most sheep and cattle diets.

The CP levels of early grazing ranged from 26.8% to 28.7% of DM. It is important to note that CP includes both true protein and non-protein nitrogen (NPN). CP does not differentiate between nitrates and proteins in plants. Nitrate concentrations are usually higher in younger plants, declining as plants mature. High nitrate levels can be an issue for livestock. It is advised that grain samples have a nitrate test done as well, particularly if CP is above 24% (Ferrier, 2018).

Feed analysis for DM cuts taken at mid flower showed that all samples were within the acceptable levels for NDF at 43.3% to 51.2% (Table 4). ME levels at 9.1–10.7 MJ/kg would satisfy dietary requirements for most ruminant diets. Likewise, CP concentration (%DM) at 16.7–22.6% would satisfy most dietary requirements. Producers should exercise caution and contact their veterinarian or Local Land Services Livestock officer before grazing to discuss any potential animal health and/or management issues.

Table 4 Feed value analysis (DM basis) per variety at full ground cover and mid flowering for six canola varieties at Tamworth 2020.

Variety	NDF	ADF	CP	ASH	OM	DMD	DOMD	ME	WSC
Full ground cover									
Pioneer 45Y91 CL	43.1	26.9	28.7	19.4	80.6	67.1	63.7	9.9	5.3
H210003 CL	38.2	22.4	27.9	16.9	83.1	74.0	69.5	11.1	8.1
H82005 CL	42.1	26.4	27.8	17.8	82.2	68.5	64.8	10.2	5.4
Hyola 970 CL	40.6	24.2	28.3	18.0	82.0	70.1	66.2	10.4	6.7
Nizza CL	39.8	23.7	26.8	17.3	82.7	72.5	68.3	10.9	7.3
Phoenix CL	40.5	24.6	27.2	16.9	83.1	76.2	71.4	11.5	8.2
Mid flower									
45Y91 CL	51.2	32.3	18.6	9.1	90.9	65.9	62.7	9.7	7.6
H210003 CL	46.4	30.8	16.7	8.7	91.3	62.3	59.6	9.1	10.4
H82005 CL	47.4	31.8	17.1	9.1	90.9	63.3	60.4	9.3	8.6
Hyola 970 CL	43.3	28.3	20.3	9.1	90.9	65.8	62.6	9.7	8.7
Nizza CL	45.0	26.8	22.6	9.8	90.2	71.6	67.4	10.7	11.0
Phoenix CL	45.9	30.5	18.6	9.0	91.0	66.0	62.7	9.7	11.3

ADF – acid detergent fibre (%)
DMD – dry matter digestibility (%)
NDF – neutral detergent fibre (%)
ASH – ash (%)
DOMD – digestibility of the organic matter contained in the dry matter (%)
OM – organic matter (%)
CP – crude protein (%)
ME – metabolisable energy (MJ/kg DM)
WSC – water soluble carbohydrates (%)

Conclusions

Winter and long spring type canola varieties, are early planting options that have the potential to provide valuable winter forage for livestock and/or grain in mixed farming systems. The issues confronting growers is that there has been limited research conducted in northern NSW that has looked at variety response to sowing date, forage production, grain recovery after grazing, grain yield potential and grain quality. These, along with crop use, are important factors that growers need to consider when selecting varieties and sowing date options.

Biomass at full ground cover ~8–10 leaf stage

- All varieties evaluated showed a trend for biomass to increase at full ground cover (~8–10 leaf). when sowing date was delayed.
- Differences in responses to DM production to sowing date were possibly associated with the longer time taken to reach full ground cover from delayed sowing dates (i.e. SD1 versus SD3), and time to accumulate biomass.
- The varieties 45Y91 CL, Hyola® 970 CL and Nizza CL achieved comparable levels of DM production across sowing dates (2.5 t DM/ha to 2.6 t DM/ha from SD2 and ~2.8 t DM/ha from SD3).

- As a dual-purpose selection based on DM production at full ground cover and subsequent effect of grazing on grain yield, 45Y91 CL from SD2 would be a preferred option.

Biomass at end of flowering/early pod fill

- The amount of biomass produced at the end of flowering/early pod fill is an indication of potential as forage hay/silage options.
- The mid–late spring type 45Y91 CL produced the greatest amount of DM at the end of flowering/early pod fill (>11 t DM/ha, non-grazed treatment) and the highest amount of DM from SD2 (13.0 t DM/ha).
- The best performed winter variety was Hyola® 970 CL, which produced >9.0 t DM/ha for the non-grazed treatments for all sowing dates.
- Feed quality samples taken at mid-flower for all varieties met the parameters to produce high quality hay (ME 9.1 MJ/kg–10.7 MJ/kg and CP concentrations of 16.7–22.6%).
- These results indicate that 45Y91 CL and Hyola® 970 CL can produce high biomass and good quality hay.

Response to grazing

- Varieties demonstrated variable responses to grazing at full ground cover and DM production at the end of flowering/early pod fill and in response to sowing date. These treatments simulate the potential for hay/silage production following opportunistic grazing.
- The variety 45Y91 CL for SD1, following grazing, was the best performed variety, with 10.9 t DM/ha at the end of flowering/early pod fill.
- The best performed winter variety was Nizza CL, which produced 8.1 t DM/ha from SD1.
- With delays in sowing date, 45Y91 CL was adversely affected by grazing at full ground cover, experiencing declines of 50% and 60% for SD2 and SD3 respectively. This shows that 45Y91 CL has an inability to recover biomass after grazing from late sowing dates (e.g. SD3; 11.4 t DM/ha non-grazed versus 4.6 t DM/ha grazed).
- All the winter varieties produced more biomass than 45Y91CL from SD3 and were comparable to it from SD2

Grain yield

- All varieties had grain yield declines from grazing and delayed sowing dates.
- The variety 45Y91 CL was the highest yielding variety across all three sowing dates for non-grazed treatments, yielding 3.14 t/ha from SD3.
- The highest yielding winter types were Hyola® 970 CL (SD2, 2.3 t/ha) and Nizza CL (SD1, 2 1 t/ha) from non-grazed treatments.
- The variety 45Y91 CL suffered a 57% decrease in yield in response to grazing from SD3 (3.14 t/ha non-grazed versus 1.34 t/ha grazed), indicating a significant yield penalty associated with grazing and delayed sowing date. Grazing was shown to both delay and shorten the flowering period for 45Y91 CL for SD3, meaning that pod fill and seed development occurred under less favourable conditions (increasing temperature and declining PAW).
- Grazing also affected both grain yield and oil concentration, with oil concentration decreasing from 39.6% non-grazed versus 35.8% grazed.
- The variety 45Y91 CL had the highest grain yield (non-grazed, SD3) in the experiment.
- Although 45Y91 CL achieved a comparable yield from SD1, the increased risk of frost damage needs to be considered as its flowering window in 2020, was from ~13 July to 11 September.

Grain quality

- All varieties were below the base oil concentration level of 42% and ranged from 39.8% for 45Y91 CL from SD2, to 29.7% for Phoenix CL from SD3.
- The variety 45Y91 CL (apart from the SD3 grazed treatment) achieved the highest oil concentrations across all treatments.
- The lower oil concentration achieved by the winter varieties was most likely related to a shorter, later flowering window, resulting in less favourable conditions for seed development.
- Based on both yield and oil content, 45Y91 CL non-grazed from SD2 or SD3 was the best performed variety.

For grain yield and oil content, sowing in the early part of the sowing window is important for winter canola varieties. In contrast, 45Y91 CL, a mid–late spring type, achieved high yield potential and oil content from SD3 and was the best graze and grain option in this experiment from the SD2 planting.

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Dual-purpose oat evaluation, Tamworth 2020

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Key findings

- Varieties differed in the amount of dry matter (DM) produced at stem elongation (growth stage 30; GS30) and in response to sowing date.
- Sowing date two (SD2) sown on 2 April, produced the highest grain yield responses following grazing at GS30.
- All varieties suffered yield penalties when sown early, SD1 sown on 13 March, versus SD2.
- Some varieties had significant yield increases in response to grazing due to reduced lodging.
- Varieties differed in their ability to achieve grain receival standards. The combination of rainfall and inherently inferior grain quality resulted in downgrading due to low test weight and/or high screenings.

Introduction

Dual-purpose graze and grain cereals offer growers the potential to exploit early sowing opportunities, providing both valuable winter forage for livestock as well as income from grain. Excellent early season soil moisture profiles and planting opportunities in 2020, following on from severe droughts in 2018 and 2019, greatly increased the interest in early sowing options across the north-western slopes of NSW. In this system, oats are regarded as a versatile crop. They are commonly sown earlier than other winter cereals being suitable for forage production (grazing, hay and silage), grain production and as a dual-purpose, graze and grain crop.

In 2020, five oat varieties were evaluated at Tamworth as dual-purpose, graze and grain options. This research, a component of the NSW DPI-GRDC Grains Agronomy and Plant Pathology partnership (GAPP) project BLG116 'Northern High Rainfall Zone dual purpose winter crop evaluation 2019–22', is evaluating oat, wheat, barley, triticale, and canola for their potential to yield grain following simulated grazing treatments. The aim of the project is to compare and identify winter cereal and canola cultivars suitable for grain production in grazing systems, and to potentially increase grain production for producers in mixed farming systems in northern NSW. Experiments are being conducted at Tamworth on the north western slopes and Glen Innes on the NSW northern tablelands.

Site details

Location	NSW DPI Tamworth Agricultural Institute (TAI), Tamworth, NSW S31° 15' 263" E150° 98' 525"
Soil type	Grey vertosol
Paddock history	Sorghum 2018, long fallowed 2019
Starting soil nitrogen (N)	~300 kg N/ha (0–120 cm)

Starting soil phosphorus (P)	Colwell: 31 mg/kg (0–10 cm), 7 mg/kg (10–30 cm)
Starting water	~181 mm plant available water (PAW) to 120 cm
Rainfall and temperature	Excellent starting soil water meant sowing dates did not need supplementary water. Figure 1 shows the rainfall and temperature data for the Tamworth site, in 2020. Rainfall from 1 March to 30 November was 401 mm, which was slightly below the median of 435 mm.
Fertiliser	• 60 kg/ha of starter fertiliser Granulock® Z applied at sowing (12% nitrogen (N), 21.8% phosphorus, 4% sulfur, 1.0% zinc). • 141 kg/ha urea (47% N) side banded at sowing.
Plant population	Target population:100 plants/m^2.
Weed management	• Glyphosate 450 2 L/ha (450 g/L glyphosate) and LVE MCPA 1.2 L/ha (570 g/L) applied as a knockdown before planting. • Starane® Advanced 900 mL/ha (333 g/L fluroxypyr), Uptake® spraying oil (582 g/L paraffinic oil, 240 g/L alkoxylated alcohol non-ionic surfactants) 500 mL/100L of water in-crop.
Disease management	Jubilee® 500 200 mL/ha (500 g/L flutriafol) applied in-furrow as a fertiliser treatment. Propiconazole 285 mL/ha (250 g/L propiconazole).
Harvest date	• SD1 and SD2 were harvested on 18 November. • SD3 harvested on 3 December 2020.

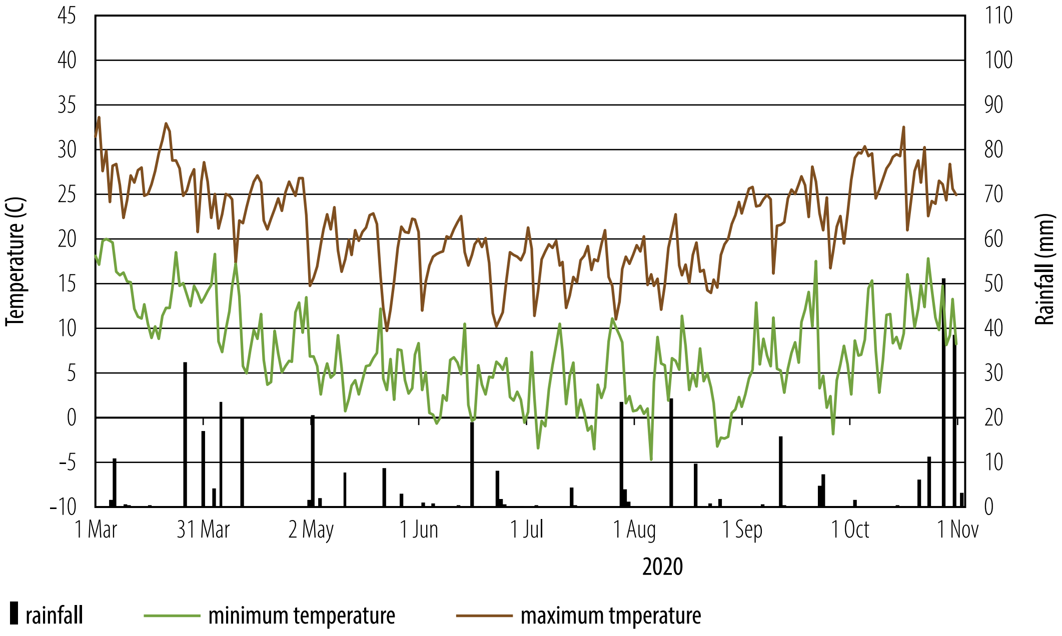


Figure 1 Rainfall and temperature data for the Tamworth site, 2020.

Treatments

Sowing date (3)

Three sowing dates: 13 March: SD1; 2 April: SD2; 23 April: SD3 2020.

Grazing (2)

Grazed and non-grazed

Variety (5)

A total of five varieties were evaluated for grain yield, grazing potential and grain yield recovery following grazing (Table 1).

Experiment design

Split plot design, three replicates.

- Treatments on main plot: three sowing dates.
- Treatments on split plot: five varieties combined with two grazing treatments (grazed and non-grazed).
- Plot size: 9.5 m long on 2 m centres, with 5 rows per plot on 0.33 m row spacings.

Table 1 Description of varieties, Tamworth 2020.

Variety	Variety description and seed source
SF Dynasty	Late-maturing forage oat producing more feed later into the season. Good crown rust resistance and has good warm start tolerance for early sowings. Released in 2020.
Eurabbie	Late maturing semi-dwarf winter habit. Industry benchmark for DM production and yield. Grain quality is generally inferior. Grazing management is important, the crop can be very short following heavy, late grazing, leading to harvesting difficulties. Susceptible to Barley yellow dwarf virus (BYDV). Bred by NSW DPI released in 1998.
Mannus	Mid maturing winter habit. Tall, strong-strawed, dual-purpose feed grain quality variety. Intended as a grazing variety, can lodge under high yield when ungrazed. Large, good quality grain. Moderately susceptible to BYDV, more resistant than Eurabbie. Bred by NSW DPI released in 2006.
Nile	Late maturing medium height benchmark dual-purpose variety, producing good winter grazing potential. Grain recovery depends on good late-finishing conditions. It has good BYDV tolerance. Released by Tasmanian Department of Agriculture in 1982.
Yiddah	Tall, strong-strawed, early maturing winter growth habit. Large grain with good grain quality. Moderate tolerance to BYDV with effective stem and some crown rust resistance. Bred by NSW DPI released in 2001.

Statistical analysis

Variation in the traits was described by fitting a linear mixed-effects model considering sowing date, variety and grazing treatment plus all interactions as fixed effects. Random effects were assigned to replication, main plot, range, and row of the experiment. An analysis of variance was derived from the model to test the null hypothesis with respect to each fixed term. Model assumptions of normal and homogeneous residuals were checked by graphical methods.

The analysis of variance was used to infer a statistically important effect when the relevant F-ratio statistic exceeded the expected F-ratio under the null hypothesis at 5% critical value. Specific pairwise contrasts were made by comparing the estimated effect with a calculated least significant difference at 5% critical value. The models were also used to estimate the mean and standard error of the trait under all combinations of variety, grazing and sowing date. These are presented graphically in figures 3, 4 and 5. The estimates of grain yield, biomass and maturity are provided in more detail in Table 2. Grain quality data is presented in Table 3 and feed value analyses are presented in Table 4.

The data analysis was conducted in the R environment (R Core Team, 2021) with particular use of the lme4 package (Bates et al. 2015).

Results

Plant establishment

Good plant establishment was achieved across all sowing dates, averaging 98 plants/m^2.

Figure 2 Simulated grazing treatment (mowing to ~3 cm height) being applied at GS30.

Biomass at GS30 – the start of stem elongation

Total above ground DM production was calculated from biomass cuts (0.5 m^2) taken from the inner three rows of plots at GS30.

Growth stage 30 is defined as 'when the tip of the developing ear/head on the main stem, was 1 cm from the base of the stem, where the lowest leaves attach to the shoot apex' (GRDC Cereal growth stages guide, 2005). Grazing is commonly terminated at GS30 to prevent the removal of developing heads, tiller death and hence potential grain yield loss.

GS30 biomass production ranged from 4.6 t DM/ha for Mannus$^{\Phi}$ from SD1, down to 0.9 t DM/ha for SF Dynasty® from SD3. Days taken to reach GS30 also varied considerably and ranged from ~78 days for both Eurabbie and Mannus$^{\Phi}$ for SD3 down to 36 days for SF Dynasty® from SD1, a reflection of the different phenology/maturity types and responses to sowing date in this experiment. Varieties that took longer to reach GS30 from SD1, (Mannus$^{\Phi}$, Nile and Yiddah$^{\Phi}$) tended to accumulate the most biomass (Table 2). In contrast, SF Dynasty®, which is considerably faster to GS30 than any other variety in this experiment, produced lower total DM yield This variety could offer a quick, early grazing option to meet a feed gap in some situations.

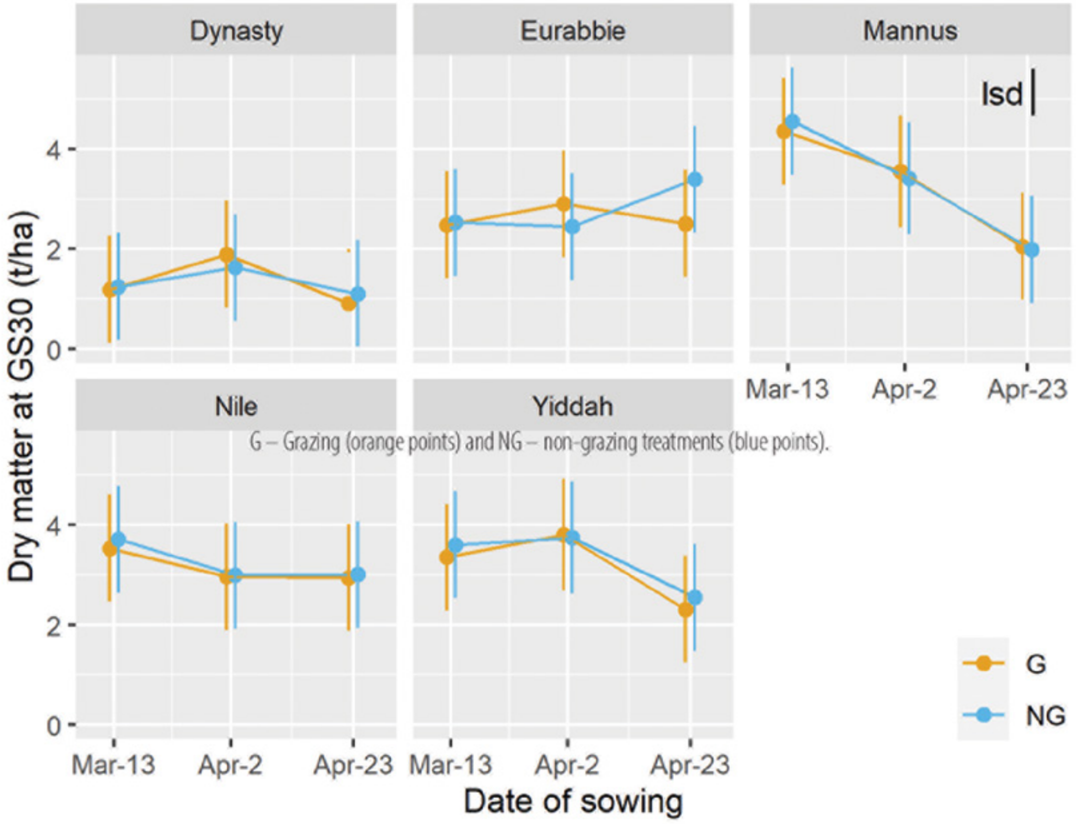
Table 2 Grain yield, biomass and maturity data summary for five oat varieties at Tamworth 2020.

Variety	SD	Yield at 11% moisture (t/ha)		GS30 dry matter (t/ha)		Days to GS30	GS65 dry matter (t/ha)		Days to GS65	
Grazing treatment		**NG**	**G**	**NG**	**G**		**NG**	**G**	**NG**	**G**
Dynasty	1	1.72	2.03	1.25	1.19	36	13.24	13.74	187	190
	2	2.56	2.96	1.63	1.89	44	15.32	13.88	173	180
	3	1.65	1.25	1.11	0.92	58	18.51	13.81	155	141
Eurabbie	1	2.92	2.68	2.53	2.48	49	17.17	17.83	200	197
	2	3.61	4.25	2.45	2.90	64	12.75	13.10	161	185
	3	4.11	3.86	3.39	2.51	78	12.74	11.08	148	156
Mannus	1	2.01	3.01	4.56	4.35	64	13.18	9.41	196	199
	2	2.53	3.82	3.41	3.55	73	14.67	11.22	177	170
	3	2.78	2.85	1.99	2.05	78	12.53	12.00	157	156
Nile	1	2.09	1.96	3.71	3.53	56	12.81	10.05	196	191
	2	2.53	3.36	2.99	2.96	60	15.73	12.78	158	171
	3	2.55	1.69	3.00	2.94	74	17.81	13.35	161	144
Yiddah	1	1.47	2.17	3.60	3.35	60	17.35	14.42	204	201
	2	2.06	3.51	3.74	3.79	71	16.96	10.27	160	171
	3	2.10	2.68	2.55	2.32	74	14.23	10.72	153	158
P-value (variety)		<0.001		<0.001		-	0.04		-	
P-value (graze)		<0.001		ns		-	<0.001		-	
P-value (SD)		0.004		ns		-	ns		-	
P-value (variety:graze)		0.003		ns		-	ns		-	
P-value (variety:SD)		0.003		<0.001		-	<0.001		-	
P-value (graze:SD)		<0.001		ns		-	ns		-	
P-value (variety:graze:SD)		ns		ns		-	ns		-	

Variety response to sowing time

- Mannus$^{(D)}$ showed significant declines in DM production at GS30 when sowing date (Figure 3), was delayed to SD2 and SD3.
- Eurabbie and Nile were able to maintain DM production across sowing dates.
- Yiddah$^{(D)}$ was able to maintain relatively high levels of DM production from SD1 and SD2, however, this declined sharply for SD3 (~3.8 t DM/ha SD2 compared with 2.4 t DM/ha SD3).

These results indicate that varieties such as Mannus$^{(D)}$, and to a lesser extent Yiddah$^{(D)}$, are best sown early, while varieties such as Eurabbie and Nile illustrated that they are capable of maintaining DM production across the sowing window.



G – Grazing (orange points) and NG – non-grazing treatments (blue points).

Figure 3 Dry matter production (t/ha) at GS30 for five oat varieties at Tamworth 2020.

Biomass at GS65 – anthesis

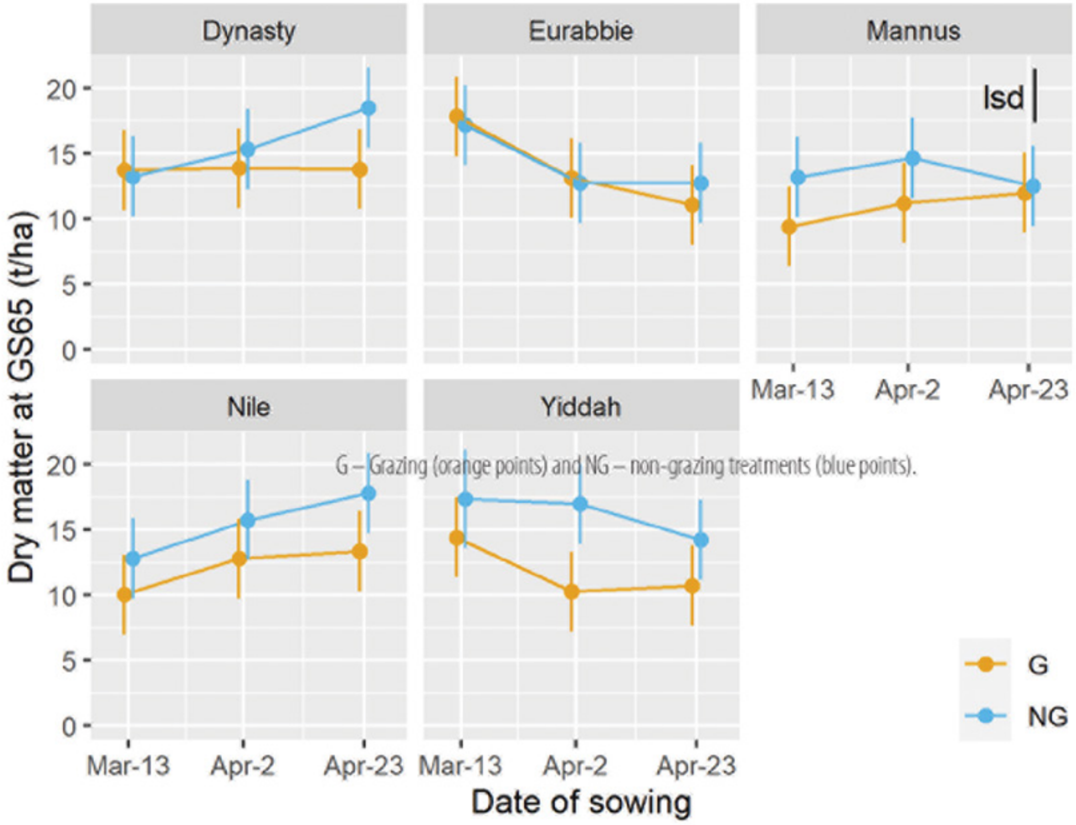
When the plants reached anthesis (GS65), DM cuts (0.5 m^2) were taken from the inner three rows of plots. Biomass production and sampling at anthesis was chosen as it is generally accepted that feed quality largely declines for most species after this time (GRDC 2018).

The amount of above ground biomass produced at GS65 for non-grazed treatments, ranged from 18.5 t DM/ha for SF Dynasty® from SD3, down to 12.5 t DM/ha for Mannus$^{\phi}$ from SD3. These results highlight SF Dynasty's® high forage and hay/silage potential due to its high DM. Eurabbie, Nile and Yiddah$^{\phi}$ also fit this profile producing >17.0 t/ha DM/ha (Figure 4).

Total DM production at GS65 after simulated grazing at GS30, ranged from 17.8 t/ha for Eurabbie , down to 9.4 t/ha for Mannus$^{\phi}$ both from SD1. The overall effect of the simulated grazing treatment at GS30 on biomass accumulation at GS65 was variable, averaging a 16% decline in biomass production, across all varieties and sowing dates.

Yiddah$^{\phi}$ had the greatest decrease in DM following simulated grazing at GS30: a 39% decrease for SD2 (~17.0 t DM/ha non-grazed versus 10.3 t DM/ha grazed). Yiddah$^{\phi}$ also had declines in DM production in response to grazing from SD1 and SD2 of ~17% and 25% respectively. Other varieties with large declines in total DM production following grazing included Nile with a 25% decrease for SD3 averaging 21% across all sowing dates; Mannus$^{\phi}$ with a 29% decrease for SD1 and 24% for SD2; and SF Dynasty® for SD3 with a 25% decrease. These results underlining the variable DM production potential of varieties in response to sowing date and also their divergent responses to grazing in terms of DM recovery.

Eurabbie was the least affected by grazing and had the highest DM production following grazing (i.e. SD1).



G – Grazing (orange points) and NG – non-grazing treatments (blue points).

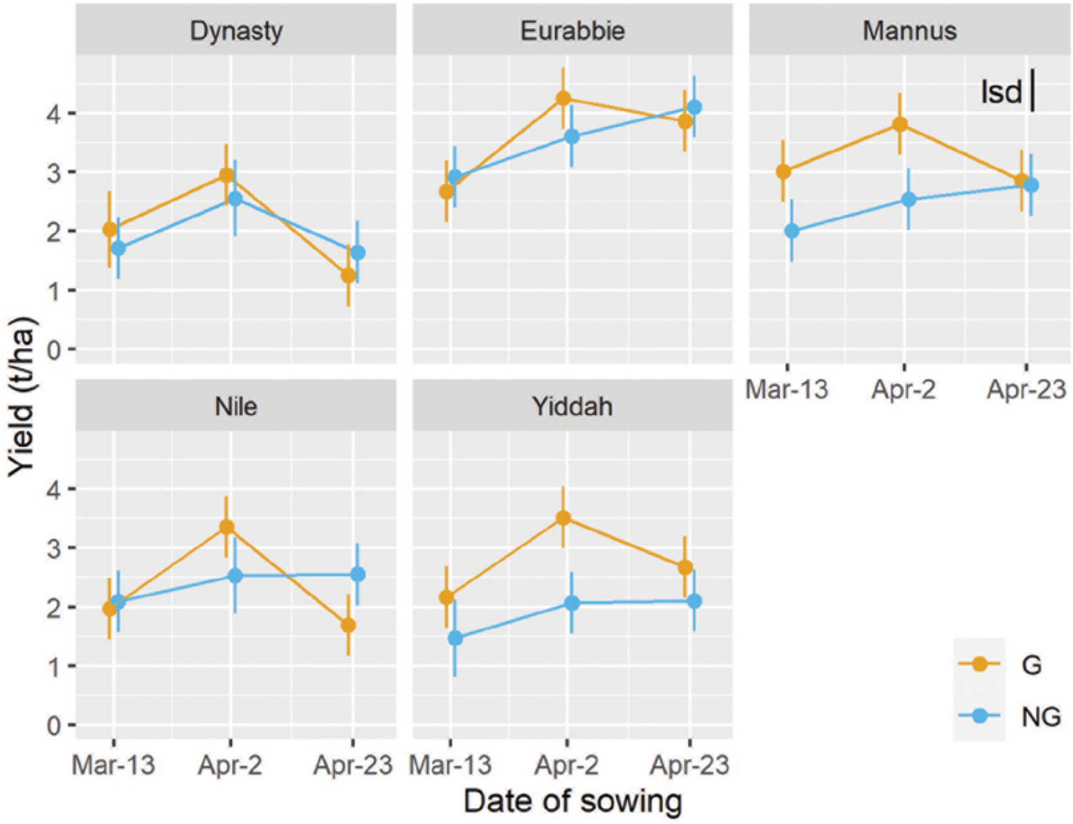
Figure 4 Dry matter production (t/ha) at GS65 for five oat varieties at Tamworth 2020.

Grain yield

- Eurabbie, which is considered the industry benchmark for DM production and yield (Matthews et al. 2021), was the highest yielding variety at 4.3 t/ha for the grazed treatment for SD2, it also maintained its yield potential for SD3 yielding 3.9 t/ha (Table 2).
- Grain yields were optimised from SD2 following grazing at GS30 (Figure 5).
- All varieties suffered yield penalties for early sowing; SD1 compared with SD2 ranged from 0.8 t/ha for Mannus$^{\text{\textphi}}$ up to 1.6 t/ha for Eurabbie.
- All varieties (apart from Eurabbie) showed yield declines of >0.8 t/ha with delayed sowing (SD3 versus SD2) ranging up to ~1.7 t/ha for both SF Dynasty® and Nile.
- Mannus$^{\text{\textphi}}$ and Yiddah$^{\text{\textphi}}$ are both tall varieties and benefited significantly from grazing (Figure 5) with yield increases of ~1.3 t/ha and 1.5 t/ha respectively from SD2 grazed versus non-grazed. This yield response is the consequence of reduced lodging following grazing.
- Nile, for SD3, was the only variety that was adversely affected by the grazing treatment, with a~0.9 t/ha decline in yield. This most likely the result of its late maturity, in combination with delayed sowing, affecting its grain recovery.

Results from the first year of this experiment, based purely on grain yield, indicated that Eurabbie would be the preferred option for a mid April sowing, and the preferred grain recovery option following grazing for a 23 April sowing.

The results also indicate that Mannus$^{\text{\textphi}}$ would be a good early sowing option, particularly given its response to grazing and GS30 DM production.



G – Grazing (orange points) and NG – non-grazing treatments (blue points).

Figure 5 Grain yield (t/ha) for five oat varieties at Tamworth 2020.

Grain quality

All varieties in this experiment were classified as feed/forage. Grain quality parameters and classifications detailed in the Grain Trade Australia (GTA) trading standards (https://www.graintrade.org.au/commodity_standards) (GTA, 2020) guidelines, were used to define grain quality as per the Feed Oats No.1 receival standards. Low test weight <48 kg/hL (GTA, 2020) was the major parameter responsible for quality downgrading in this experiment. These low test weights were possibly due to the multiple rainfall events in late October/early November (Figure 1). Test weight decreases following rain due to kernels swelling, although grain weight does not change; the test weight is reduced because kernels are now larger, taking up greater volume. Screenings (% material by weight, below 2.0 mm screen) >20% was the other grain quality parameter responsible for downgrading from Good Sound Feed oats (GSF)1.

- Eurabbie is considered the benchmark variety for DM production and yield but has inferior grain quality compared with other feed varieties, with small grain and low test weight. Low test weights in this experiment (<48 kg/hL) resulted in SD1 and SD2 grazing being downgraded and the non-grazed treatment from SD1 (Table 3).
- SF Dynasty®, which is marketed as a forage variety and not generally recognised as a feed grain variety, was only able to achieve the feed grain receival standard for the non-grazed SD2 and SD3 treatments.
- Mannus⚖ had inherently better grain quality than Eurabbie, with larger grain size (apart from the SD2 non-grazed, which had low test weight).
- Yiddah⚖ was shown to have large grain size and high test weights (apart fromSD1).
- Nile was unable to meet grain receival standards from any sowing date or treatment combination.

There was no difference in grain protein content between varieties at comparable yields. Results indicated that grain protein content tended to follow a yield dilution response, with increased grain proteins associated with declining yields.

Table 3 Grain quality parameters of five oat varieties at Tamworth 2020.

Variety	SD	Seed weight (g/1000 grains)		Screenings (%)		Protein (%)		Test weight (kg/hL)	
Grazing treatment		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Dynasty	1	26.1	23.0	17.1	24.8	13.9	14.0	42.2	-
	2	26.1	27.5	17.5	15.7	15.1	14.6	48.2	47.6
	3	27.3	25.7	16.7	19.4	14.9	15.2	48.6	45.6
Eurabbie	1	24.0	25.8	15.0	14.2	12.7	12.3	46.2	47.3
	2	26.6	25.3	15.3	20.2	12.8	12.3	48.1	46.2
	3	28.1	28.3	11.8	15.9	14.2	12.9	49.0	48.0
Mannus	1	29.4	32.5	15.8	12.5	14.1	12.5	48.3	50.0
	2	28.8	28.3	15.8	15.0	14.5	13.0	47.9	48.7
	3	31.8	34.1	12.0	12.0	14.9	14.4	49.3	50.9
Nile	1	31.3	26.3	18.6	24.0	14.0	13.1	46.4	44.1
	2	28.0	30.0	25.5	20.5	13.9	12.5	45.5	48.3
	3	28.9	26.0	29.2	32.1	12.7	12.9	45.9	43.9
Yiddah	1	26.7	34.3	22.2	8.4	13.3	14.1	41.7	47.8
	2	34.7	32.3	9.2	8.5	14.8	14.3	50.8	53.9
	3	37.9	39.7	8.5	6.0	14.6	15.8	54.6	54.7
P-value (variety)		<0.001		<0.001		<0.001		<0.001	
P-value (graze)		ns		ns		0.004		ns	
P-value (SD)		ns		ns		0.02		ns	
P-value (variety:graze)		ns		<0.001		0.005		0.02	
P-value (variety:SD)		0.002		<0.001		0.006		<0.001	
P-value (graze:SD)		ns		ns		ns		ns	
P-value (variety:graze:SD)		0.026		0.001		ns		ns	

Feed value analysis

The dry matter cuts from SD1 at GS30 and GS65 were retained for feed quality analysis. A bulked sample for each variety, from each replicate, was analysed by the NSW DPI Feed Testing Laboratories at Wagga Wagga.

Table 4 Feed quality analysis (DM basis) for bulked samples taken from three replicates per variety at GS30 and GS65 for SD1 (13 March) at Tamworth 2020.

Variety	Growth stage	Near infrared (NIR) spectrophotometry analysis									AFIA cereal hay grade* (GS65 only)
		ADF	ASH	CP	DMD	DOMD	ME	NDF	OM	WSC	
Dynasty	GS30	26.4	11.8	25.5	86.0	79.0	13.1	47	88.0	9.0	
	GS65	34.0	6.3	13.3	64.0	61.0	9.4	62	93.7	15.8	B1
Eurabbie	GS30	26.3	12.6	24.4	83.0	77.0	12.7	48	87.0	9.3	
	GS65	37.1	6.6	8.7	57.9	55.9	8.4	65	93.4	11.1	C2
Mannus	GS30	26.6	12.1	21.9	81.0	75.0	12.3	48	87.9	10.5	
	GS65	32.0	6.9	12.5	61.5	59.0	9.0	62	93.1	14.5	B1
Nile	GS30	27.4	11.4	21.1	84.0	78.0	12.8	49	88.6	11.1	
	GS65	34.3	7.5	13.6	60.6	58.1	8.8	64	92.5	9.3	B1
Yiddah	GS30	27.6	13.4	24.3	83.0	77.2	12.7	50	86.6	8.8	
	GS65	36.5	5.5	8.9	55.4	53.8	7.9	67	94.5	12.2	C2

ADF – acid detergent fibre (%)
ASH – ash (%)
CP – crude protein (%)
DMD – dry matter digestibility (%)
DOMD – digestibility of the organic matter contained in the dry matter (%)
ME – metabolisable energy (MJ/kg DM)
NDF – neutral detergent fibre (%)
OM – organic matter (%)
WSC – water soluble carbohydrates (%)

* Australian Fodder Industry Association (AFIA) standards for cereal hay (https://graintrade.org.au/sites/default/files/file/Commodity%20Standards/Section%2005%20-%20Fodder%20201112.pdf), which consider DMD, ME and CP when grading hay and silage. Under this system the highest grade A1, has an ME >9.5 MJ/kg, DMD >66% and CP% >10, whereas the lowest grade D4 has an ME <7.5 MJ/kg, CP <4% and DMD <53%. Lower letters (i.e. D) indicating lower ME and/or DMD higher numbers (i.e. 4) an indicator of lower CP% (Fodder Standards, 2011/12).

Feed analysis

Important feed quality traits include NDF, ME, CP and DMD. Neutral detergent fibre is a measure of the structural, slowly digested cell wall components of a plant and includes hemicellulose, cellulose and lignin – or indigestible fibre. As the percentage of NDF increases, animal intake tends to decline due to increasing fibre content, which takes longer to digest in the rumen. It is also important that NDF values are not too low (i.e., <30%) to avoid stomach upsets such as acidosis. Conversely, high NDF values (i.e. >60%) can affect digestibility, limiting intake.

Feed quality results for the grazing samples taken at GS30 indicated that they were within the recommended NDF values of 30% and below the upper cut-off limit of 60%, ranging from 47% for SF Dynasty® to 50% for Yiddah$^{\phi}$ (Table 4).

The ME of the forage samples taken at GS30, ranged from 12.3 MJ/kg for Mannus$^{\phi}$ to 13.1 MJ/kg for SF Dynasty®, satisfying the dietary requirements of most sheep and cattle diets, with forage with an ME >11 MJ/kg considered high quality. Again, indicating that lower fibre diets (i.e. less mature plant material) are more digestible and are higher in ME.

Crude protein (CP) levels for these early simulated grazing samples, ranged from 21.1% to 25.5% of DM. It is important to note, that CP includes both true protein and non-protein nitrogen (NPN) and doesn't differentiate between nitrates and proteins in plants, with nitrate concentrations usually higher in younger plants, declining as plants mature. High nitrate levels can be an issue when grazing young cereal crops and producers should exercise caution and contact their veterinarian or Local Land Services livestock officer prior to grazing to discuss any potential animal health and/or management issues.

Feed analysis for DM cuts taken at GS65, showed that NDF values increased and DM digestibility (%) decreased as crops matured, with NDF values ranging from 62% for SF Dynasty® and Mannus$^{\phi}$, up to 67% for Yiddah$^{\phi}$ (Table 4).

The ME ranged from 7.9 MJ/kg for Yiddah⌽ up to 9.4 MJ/kg for SF Dynasty®, with CP ranging from 8.7% for Eurabbie up to 13.3% CP for SF Dynasty®. Based on this grading system, SF Dynasty®, Mannus⌽ and Nile all achieved a 'B1' grade whereas, both Eurabbie and Yiddah received the lower 'C2' grading. From these results it can be seen that the forage variety SF Dynasty® produced the best quality hay (Table 4), with feed analysis results from the GS30 sample also indicating its higher feed quality.

Conclusions

In mixed farming systems, oats are seen as a versatile crop that has number of uses. Oats can be sown as a dual-purpose, graze and grain option, providing early grazing (up until GS30) and then can either be retained for grain or cut at ~GS65 for hay or silage production. Alternatively, oats can be grown purely as a grain or forage crop.

The issue confronting growers is which variety is the best option. This needs to take into account the purpose of the crop (grain versus graze versus grain and graze), sowing dates and marketing opportunities.

Biomass at GS30

- Results from this experiment show that varieties differ in the time taken reach GS30, the amount of DM produced at GS30 and response to sowing date.
- Varieties such as Mannus⌽ and Nile, and to a lesser extent Yiddah⌽, were best sown early – SD1 or SD2.
- Varieties such as Eurabbie produced less DM at GS30 but maintained its DM across the sowing dates.
- If growers were aiming to fill a feed gap (DM at GS30) then varieties such as Mannus⌽, Nile and Yiddah⌽ would be preferred options for an early sowing date.

Biomass at GS65

- Several varieties evaluated accumulated >17 t DM/ha at GS65 for non-grazed treatments including SF Dynasty®, Eurabbie, Nile and Yiddah⌽. These results indicate their potential as forage hay/silage options.
- This experiment also highlighted differences in feed/hay quality between varieties.
- SF Dynasty® from SD3, the highest yielding of the non-grazed treatments for DM at GS65 (18.5 t/ha), also achieved the best feed quality analysis and AFAI hay grading.
- SF Dynasty® achieved an AFIA hay grading of B2 whereas Eurabbie only received a C2 grade when both were evaluated at the same growth stage.
- These results indicate that if growers are after a superior quality forage hay variety, SF Dynasty®® should be considered.

Response to grazing

- Varieties demonstrated variable responses to grazing at GS30 and subsequent DM production at GS65.These treatments simulated the potential for hay/silage production following opportunistic grazing.
- Eurabbie from SD1, following grazing at GS30, was still capable of producing 17.8 t DM/ha at GS65.
- In contrast, Mannus⌽, although producing significantly more DM at GS30 than Eurabbie, (4.6 t DM/ha versus 2.5 t DM/ha), only managed to produce 9.4 t DM/ha at GS65.
- Eurabbie was the least affected by grazing and produced the greatest amount of DM at GS65 from SD1, following grazing.

Grain yield

- The highest grain yield responses for all varieties were achieved from grazed treatments from SD2.
- Mannus⌽ and Yiddah⌽, both tall varieties, benefited significantly from grazing, with yield increases of ~1.3 t/ha and 1.5 t/ha respectively grazed versus non-grazed treatments (SD2), due to reduced lodging.

- Nile (SD3) was the only variety where grain yield was adversely affected by grazing, due to delayed maturity affecting yield potential.
- When looking solely at grain yield potential, Eurabbie (SD2 and SD3), Mannus$^{\Phi}$ and Yiddah$^{\Phi}$ (SD2) were the best yielding varieties.

Grain quality

- Eurabbie failed to achieve GSF classification for the SD2 grazed treatment due to low test weight (<48 kg/hL) and would have received a price discount.
- Both Mannus$^{\Phi}$ and Yiddah$^{\Phi}$ both exceeded test weight requirements for GSF classification and had larger grain size than Eurabbie, increasing their marketability.

When looking at overall responses, findings from this study indicate that growers should select an oat variety based on perceived crop use(s), sowing date, inherent grain quality and marketing options.

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Dual-purpose cereal evaluation, Tamworth 2020

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Summary of results

- The cereals evaluated in this experiment had a high grain yield potential (i.e.>6 t/ha), after simulated grazing at stem elongation (GS30).
- Some varieties produced >5.0 t/ha dry matter (DM) at GS30.
- Yields varied in response to grazing and sowing date. Varieties, such as DS Bennett⦶ wheat, yielded ≥20% across all three sowing dates (e.g. SD3 4.82 t/ha non-grazed versus. 5.77 t/ha grazed).
- Other varieties, such as Cartwheel⦶ triticale, showed a decrease in grain yield with grazing. For SD2, Cartwheel⦶ had a 23% decrease from the non-grazed treatments compared to the grazed treatments (7.25 t/ha versus 5.56 t/ha respectively)
- The European feed quality wheats RGT Calabro, RGT Accroc and Einstein, achieved grain yields of between 6.90 t/ha and 6.01 t/ha for grazing treatments, for all three sowing dates (13 March, 2 April and 23 April). They produced between 5.21 t DM/ha –3.35 t DM/ha for potential winter grazing at GS30.
- Some higher quality, milling grade wheats performed well, providing high yielding, dual-purpose options for growers. Illabo⦶, an Australian Hard (AH) classified wheat, yielded 6.6 t/ha after being grazed (SD3). Likewise, EGA Wedgetail⦶ an AH and LongReach Kittyhawk⦶, (Prime Hard (APH)) were also high yielding (6.02 t/ha and 5.87 t/ha for SD3 and SD2 respectively). Biomass accumulation at GS30 [for which group of wheats?}, was significantly lower than the European wheats at between 2.37–2.14 t DM/ha, due to their faster rate of biomass accumulation and time to reach GS30.
- The two slow maturing spring wheats evaluated achieved grain yields of ≥6 t/ha following simulated grazing treatments, LongReach Nighthawk⦶ yielding 6.67 t/ha in SD3, and Sunlamb⦶ yielding 6.23 t/ha and 6.08 t/h from SD2 and SD3 respectively. Sunlamb⦶ produced the most biomass of the two varieties with ~3.0 t DM/ha at GS30 in SD2.
- The triticale Cartwheel⦶ yielded 6.35 t/ha from SD3 following grazing, which was comparable to the European wheats and produced good levels of biomass of ~3.8 t DM/ha at GS30. Cartwheel⦶ was also the second highest yielding variety yielding 7.68 t/ha in the SD3 non-grazed treatment. Cartwheel⦶ showed a yield penalty when grazed or where sowing was delayed.
- Barley was generally lower yielding than the better performing wheats and triticales. Dry matter production at anthesis (GS65), an indicator of potential hay production, ranged from 16.5 t DM/ha to 9.4 t DM/ha SD3. DM production at GS65 following grazing at GS30 tended to decline with later sowing times.

Introduction

Dual-purpose graze and grain cereals means that growers can exploit early sowing opportunities, potentially providing both valuable winter forage for livestock as well as income from grain. Excellent early season soil moisture profiles and planting opportunities in 2020, following on from severe droughts in 2018 and 2019, greatly increased the interest in early sowing options across the north-western slopes of NSW. Interest has been further heightened by the release and/or introduction of some newer high yielding winter and long spring wheat varieties, some with improved grain classifications, in addition to dual-purpose barley and triticale.

In 2020, 15 cereals varieties, (10 wheat, three barley and two triticale) were evaluated at Tamworth for their potential as dual-purpose graze and grain options. This research, a component of the NSW DPI-GRDC Grains Agronomy and Plant Pathology partnership (GAPP) project BLG116, is evaluating oat, wheat, barley, triticale, and canola for their potential for grain yield following 'simulated grazing'. Experiments were conducted at both Tamworth and Glen Innes in 2020.

Site details

Location	NSW DPI Tamworth Agricultural Institute (TAI), Tamworth, NSW (31° 15' 263" S; 150° 98' 525" E)
Soil type	Grey vertosol.
Paddock history	Sorghum 2018, long fallowed 2019
Starting soil nitrogen (N)	~300 kg N/ha (0–120 cm)
Starting soil phosphorus (P)	Colwell: 31 mg/kg (0–10 cm), 7 mg/kg (10–30 cm).
Starting water	~181 mm plant available water (PAW) to 120 cm.
Rainfall and temperature	Excellent starting soil water meant that the experiment was sown on the ideal dates, without the need for supplementary water. Rainfall and temperature data for the Tamworth site in 2020 is presented in Figure 1. Rainfall from 1 March to 30 November was 401 mm, which was slightly below the long-term median of 435 mm.

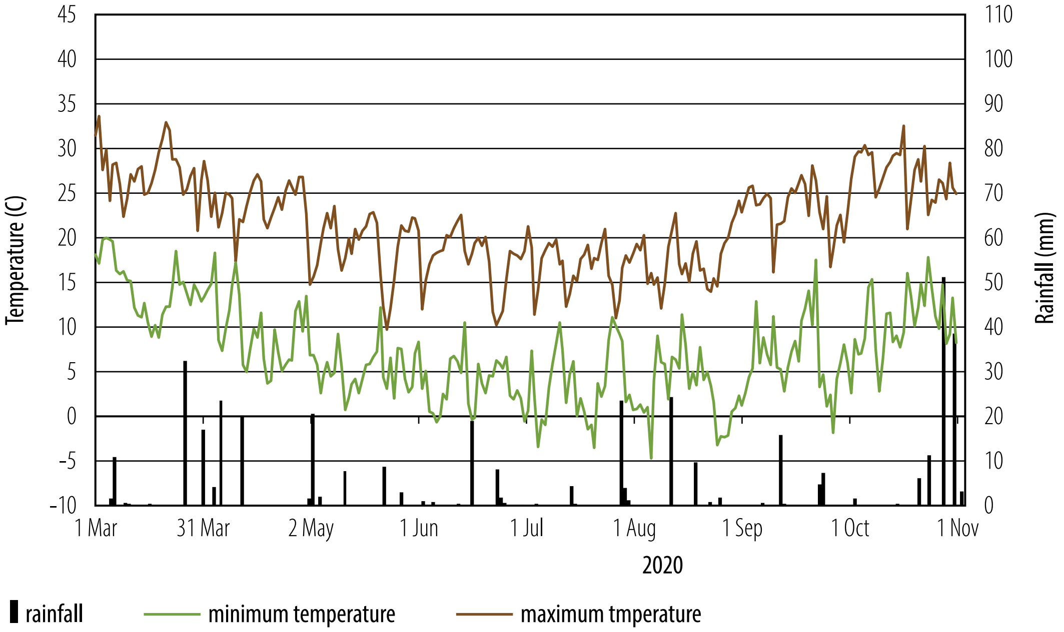


Figure 1 Rainfall and temperature data for Tamworth, 2020.

Fertiliser	• 60 kg/ha of starter fertiliser Granulock® Z applied at sowing 12% N, 21.8% P, 4% sulfur (S), 1.0% zinc (Zn). • 141 kg/ha urea (47% N) side banded at sowing.
Plant population	Target plant population: 100 plants/m^2.
Weed management	• 2 L/ha Glyphosate 450 (450 g/L glyphosate) and 1.2 L/ha LVE MCPA (570 g/L) applied as a pre-plant knockdown. • 900 mL/ha Starane® Advanced (333 g/L fluroxypyr), 500 ml/100L of water of Uptake® oil (582 g/l paraffinic oil, 240 g/L alkoxylated alcohol non-ionic surfactants) in-crop.
Disease management	• 200 mL/ha Jubilee® 500 (500 g/L flutriafol) applied in-furrow at sowing with fertiliser. • 285 mL/ha Propiconazole (250 g/L propiconazole) applied in-crop.
Harvest date	• SD1 and SD2: 18 November 2020. • SD3: 3 December 2020.

Experiment design

- Split plot design, three replicates.
- Treatments on main plot: three sowing dates.
- Treatments on split plot: 15 varieties combined with two grazing treatments (grazed and non-grazed).

Treatments

Sowing dates (3)

- SD1: 13 March
- SD2: 2 April
- SD3: 23 April.

Varieties (15)

- 15 varieties (10 wheat, three barley and two triticale).
- Evaluated for grain yield, grazing potential and grain yield recovery following grazing (Table 1).

Statistical analysis

Variation in the traits was described by fitting a linear mixed-effects model that considered sowing date, variety and grazing treatment plus all interactions as fixed effects. Random effects were assigned to replication, main plot, range, and row of the experiment. An analysis of variance was derived from the model to test the null hypothesis with respect to each fixed term. Graphical methods were used to check model assumptions of normal and homogeneous residuals.

The analysis of variance was used to infer a statistically important effect when the relevant F-ratio statistic exceeded the expected F-ratio under the null hypothesis at 5% critical value. Specific pairwise contrasts were made by comparing the estimated effect with a calculated least significant difference at 5% critical value. The models were also used to estimate the mean and standard error of the trait under all combinations of variety, grazing and sowing date. These were presented in figures 3, 4 and 5.

The estimates of grain yield, biomass and maturity are provided in more detail in Table 2. Grain quality data is presented in Table 3 and feed value analyses are presented in Table 4.

The data analysis was conducted in the R environment (R Core Team 2021) with particular use of the lme4 package (Bates et al. 2015).

Table 1 Description of varieties and seed source, Tamworth 2020.

Species/variety	Variety description
Wheat	
DS Bennett	A tall, awnless, white-grained feed quality, mid to slow winter wheat, which generally flowers 7–10 days later than EGA Wedgetail. It has a vigorous prostrate early growth habit and is suited to both grazing and grain production, or straight grain. Since the detection of the new stripe rust pathotype (198 E16 A+ J+ 17+ '198 pathotype') has lowered to a susceptible (S) rating for 2020. Bred in Australia.
EGA Wedgetail	Benchmark dual-purpose, AH quality, mid maturating awned winter wheat, released in 2002. Its popularity has been affected by changes in its stripe rust rating, which is moderately susceptible (MS). Lower grain quality compared with some newer varieties.
Einstein	A slow-maturing feed quality awnless red winter wheat. Better suited to higher rainfall zones, bred in the United Kingdom.
Illabo	A mid maturing awned winter wheat with a similar planting window and maturity (~2–3 days quicker) than EGA Wedgetail, released in 2018. It is classified as AH in the north and has improved stripe rust (moderately resistant [MR], previously resistant–moderately resistant [R–MR}) and black point resistance over EGA Wedgetail.
LongReach Kittyhawk	APH quality, mid maturing awned winter wheat with a similar maturity and planting window to EGA Wedgetail, released in 2016. Has improved stripe rust resistance (R–MR) and grain quality over EGA Wedgetail.
LongReach Nighthawk	A slow-maturing, awned spring wheat, with strong photoperiod sensitivity that allows it to be planted earlier in systems that don't suit traditional winter wheat types. Quality classification NNSW and QLD currently under review. Released in 2020.
Manning	A slow-maturing white grain feed quality awnless winter wheat, released in 2013. It has good standability and is resistant to *Barley yellow dwarf virus* (BYDV).
RGT Accroc	Slow-maturing, red feed quality awned winter wheat released in Australia in 2017. Suitable for sowing in late February to early April for early grazing. Good standability. Better suited to higher rainfall zones. Flowering time and maturity are later than EGA Wedgetail.
RGT Calabro	Slow-maturing, red feed quality awned winter wheat released in Australia in 2017. Suitable for sowing in late February to early April for early grazing, better suited to higher rainfall zones. Good standability.
Sunlamb	An awnless Australian Standard White (ASW) quality, long-season spring wheat suited to early April plantings, with strong photoperiod sensitivity, released in 2015. Suited to grazing and grain recovery across NSW.
Triticale	
Cartwheel	A long-season winter habit dual-purpose variety suitable for an early March to early April sowing. A stripe rust resistant replacement for Tobruk. Released in 2016.
Endeavour	A semi-awnless long-season winter habit dual-purpose benchmark variety. Excellent DM production and grain recovery after grazing. Suited to early sowing opportunities. Released in 2007.
Barley	
Cassiopee	French winter malt quality barley. Very long season (strong vernalisation and photoperiod responses). Bred by RAGT and released in Europe in 2012.
Oxford	A mid to late maturing spring type, with high yield potential and wide adaptation. Feed quality with good straw strength and lodging resistance. Resistant (R) to powdery mildew and moderately resistant (MR) to leaf rust. Bred in the United Kingdom and released in 2009.
Urambie	A fast, winter, dual-purpose, feed quality barley. Early maturity combined with a cold requirement to initiate heading. Bred by NSW DPI released in 2006.

Results

Plant establishment

The mean plant population was ~83 plants/m^2. This is below the targeted 100 plants/m^2, but the establishment was even across the plots (Figure 2).

Figure 2 (a) Biomass cuts and (b) simulated grazing treatment (mowing to ~3 cm height) was conducted on cereal plots at growth stage 30 (GS30).

Biomass at growth stage 30: the start of stem elongation

Total above ground (DM) production was calculated from biomass cuts (0.5 m2) taken from the inner three rows of plots at GS30 (Figure 2a). Growth stage 30 is defined as 'when the tip of the developing ear/head on the main stem, is 1 cm from the base of the stem, where the lowest leaves attach to the shoot apex' (GRDC Cereal growth stages guide 2005).

Grazing is commonly terminated at GS30, to prevent the removal of developing heads, tiller death and hence potential loss of grain yield. The grazing treatments were applied directly after GS30 biomass data was collected (Figure 2b), and no significant difference was recorded between the grazed (orange line) and non-grazed (blue line) treatments (Figure 3).

GS30 biomass production ranged from 5.5 t DM/ha for Cassiopee from SD2, down to 1.10 t DM/ha for Sunlamb$^{\Phi}$ from SD3.

The days taken to reach GS30 varied considerably between varieties and ranged from 35 days for Oxford up to 108 days for RGT Calabro, reflecting differences in phenology and maturity type and response to sowing dates.

The slower maturing winter types take longer to reach GS30, resulting in a longer grazing period and higher DM production compared with other varieties evaluated. The results do not fully capture the effective grazing period, as these varieties are initially slow to grow, and therefore accumulate more DM later in the season. In contrast, quicker maturing varieties would have a reduced length of grazing.

The slower maturing winter wheats, RGT Accroc and RGT Calabro, and the winter barley Cassiopee generally took longer to reach GS30 compared with other varieties, but accumulated more biomass (Table 2). These three varieties produced >4.0 t DM/ha across all three sowing dates. Einstein, another slow maturing winter wheat produced >4.0 t DM/ha from SD1 and SD2 (Table 2).

The long-season, winter habit triticale, Cartwheel$^{\Phi}$, also accumulated high amounts of DM (>4.0 t DM/ha for SD1 and SD2).

The AH wheat, Illabo$^{\Phi}$ was the best performed Australian bred winter wheat, producing 4.18 t DM/ha from SD1 and 3.91 t/ha from SD2 (Table 2).

Varieties such as Illabo$^{\Phi}$ underline the importance of timely sowing, to ensure enough time for DM accumulation. When sowing was delayed (SD3), there was significantly less DM produced.

Similarly, the slow spring variety, Sunlamb$^{(D)}$, highlighted the importance of sowing date on DM production. It was better suited to an early April sowing (SD2) opposed to a mid-March (SD1) sowing to optimise DM accumulation.

Table 2 Grain yield, biomass and maturity data summary for 15 cereal varieties with grazing (G) and non-grazing (NG) treatments at three sowing dates (SD1:13 March, SD2: 2 April, SD3: 23 April) at Tamworth 2020.

Variety	**SD**	**Yield at 11% (t/ha)**		**GS30 DM (t/ha)**		**GS65 DM (t/ha)**		**Days to F50**		**Days to GS30**
Grazing treatment:		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**	
Barley										
Cassiopee	1	3.72	3.69	4.67	3.82	9.84	10.61	192	192	100
	2	4.81	4.51	5.49	4.86	10.27	9.53	168	186	89
	3	4.32	3.98	4.47	5.12	10.61	9.35	153	158	96
Oxford	1	2.22	3.40	1.21	1.44	12.46	10.57	197	188	35
	2	4.59	5.72	1.76	2.02	15.92	12.94	177	183	42
	3	5.25	5.59	1.96	1.83	13.15	10.92	157	149	55
Urambie	1	4.52	5.09	2.81	3.04	12.55	11.13	186	189	59
	2	4.56	5.46	3.70	3.92	11.72	11.81	157	166	60
	3	5.31	5.54	1.69	1.55	11.82	11.22	149	158	58
Triticale										
Cartwheel	1	3.53	4.47	4.42	4.66	11.31	8.91	185	193	91
	2	7.25	5.56	4.02	4.85	10.98	8.49	169	173	91
	3	7.68	6.35	3.87	3.82	10.89	6.76	156	138	96
Endeavour	1	4.07	4.97	3.11	2.68	13.87	12.19	201	194	60
	2	5.74	5.89	2.38	2.36	12.30	12.29	186	185	52
	3	5.18	4.98	2.28	2.63	13.52	10.88	162	161	71
Wheat										
DS Bennet	1	3.36	4.67	1.51	1.80	16.49	15.16	184	310	50
	2	4.34	6.14	2.63	2.70	14.23	13.11	162	166	52
	3	4.82	5.77	2.35	1.98	11.97	10.53	163	154	71
EGA Wedgetail	1	4.39	4.97	2.00	2.38	14.50	11.89	199	199	56
	2	5.17	5.58	3.72	3.76	11.38	10.02	178	168	65
	3	5.72	6.02	2.18	2.39	9.36	10.43	157	156	73
Einstein	1	6.45	6.01	4.11	3.55	14.62	12.84	196	200	80
	2	6.81	6.06	4.11	4.85	16.39	11.95	181	180	85
	3	6.27	6.19	3.01	3.35	13.68	11.58	160	152	91
Illabo	1	3.42	4.51	3.80	4.18	14.71	10.59	188	197	75
	2	4.39	5.42	3.91	3.48	12.45	11.38	184	181	68
	3	5.91	6.59	2.05	2.14	11.81	11.30	152	167	75
LongReach Kittyhawk	1	4.43	4.77	2.49	2.41	11.19	13.84	195	192	50
	2	4.90	5.87	2.65	2.37	11.98	11.45	189	186	55
	3	5.49	5.76	1.55	1.75	12.28	9.57	162	159	65
LongReach Nighthawk	1	1.00	1.81	1.81	1.45	11.35	12.16	178	199	51
	2	3.66	4.52	2.63	2.54	14.15	12.13	171	175	50
	3	6.20	6.67	1.47	1.55	13.34	11.75	159	153	65

Variety	SD	Yield at 11% (t/ha)		GS30 DM (t/ha)		GS65 DM (t/ha)		Days to F50		Days to GS30
Grazing treatment:		NG	G	NG	G	NG	G	NG	G	
Manning	1	4.43	4.81	2.40	2.32	12.85	11.56	200	195	63
	2	5.25	5.26	3.59	3.29	13.34	12.60	170	160	64
	3	4.61	5.40	2.16	1.73	12.36	11.42	149	143	76
RGT Accroc	1	5.01	6.30	4.98	5.15	13.19	12.21	191	184	87
	2	6.21	6.40	5.28	5.18	13.31	9.96	175	183	95
	3	6.12	6.48	4.24	4.42	14.96	10.90	157	145	102
RGT Calabro	1	6.21	6.64	4.88	4.45	13.97	11.89	182	202	76
	2	7.75	6.58	5.04	5.21	12.67	10.64	154	163	89
	3	7.17	6.90	4.41	4.77	15.40	9.99	148	152	108
Sunlamb	1	3.23	4.49	1.69	1.71	12.73	12.55	193	201	48
	2	5.25	6.08	2.96	3.12	14.64	11.99	161	160	46
	3	5.71	6.23	1.33	1.10	13.38	12.19	161	157	61
P-value (variety)		<0.001		<0.001		<0.001		–		–
P-value (graze)		<0.001		ns		<0.001		–		–
P-value (SD)		<0.001		0.014		ns		–		–
P-value (variety:graze)		<0.001		ns		0.005		–		–
P-value (variety:SD)		<0.001		<0.001		<0.001		–		–
P-value (graze:SD)		0.002		ns		ns		–		–
P-value (variety:graze:SD)		ns		ns		0.029		–		–

Biomass at GS65 – anthesis

Total DM production was calculated from biomass cuts (0.5 m^2) taken from the inner three rows of plots when plants reached anthesis (GS65). Sampling at GS65 was chosen as it is generally accepted that feed quality largely declines for most species following anthesis (GRDC 2018).

The amount of above ground biomass produced at GS65 for non-grazed treatments ranged from 16.5 t DM/ha for DS Bennett$^{\phi}$ from SD1, down to 9.4 t DM/ha for EGA Wedgetail$^{\phi}$ from SD3. The results highlight the high DM yield potential of DS Bennett$^{\phi}$, the spring barley Oxford, and the European winter wheats (e.g. RGT Calabro, Einstein), which were all capable of producing >15.0 t/ha (Figure 4).

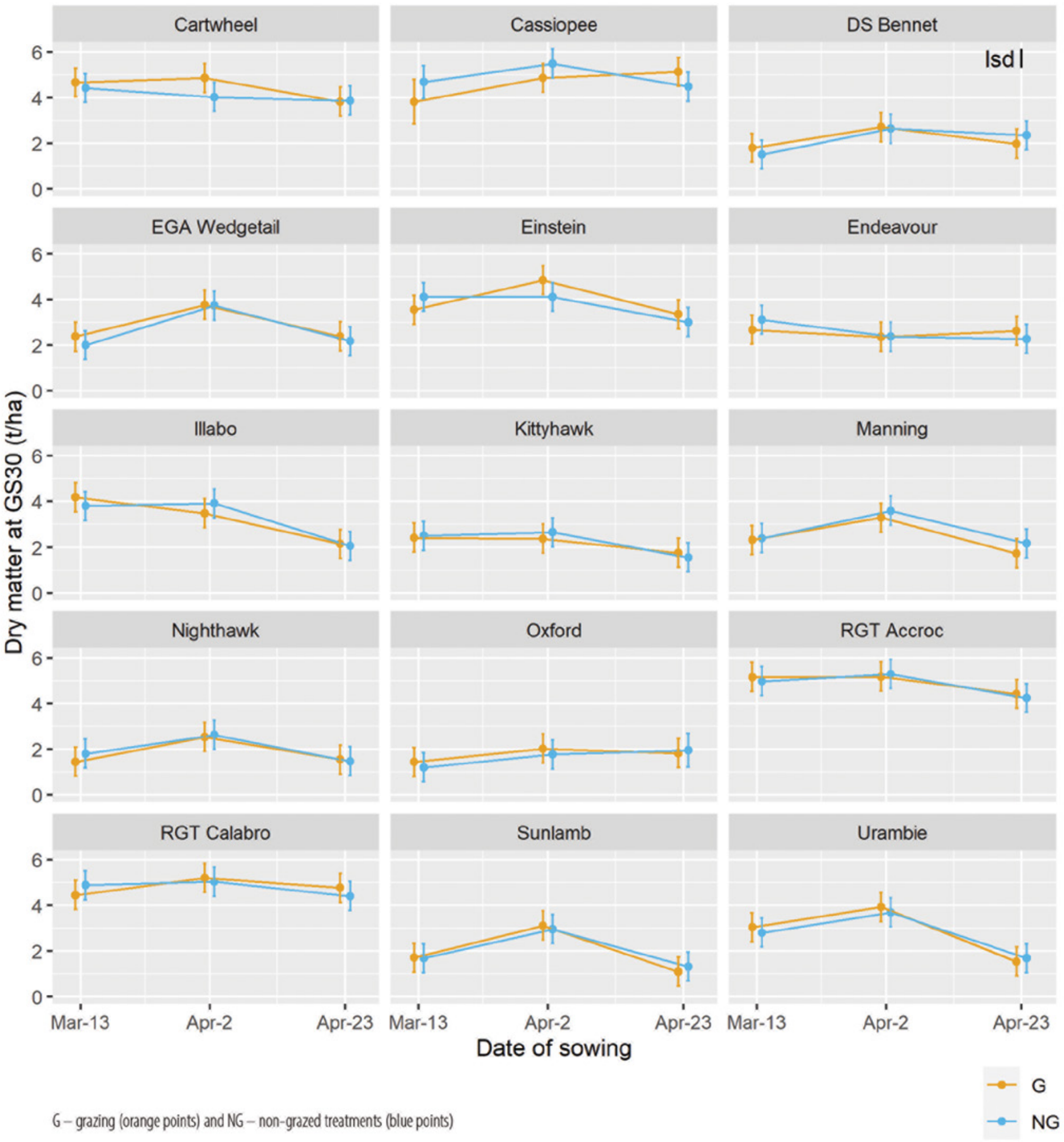
The overall effect of grazing on biomass accumulation was variable, averaging a 12% decline in DM, across all varieties and sowing dates. Dry matter production declined following grazing with delayed sowing dates averaging 8% from SD1, 12.5% from SD2, and up to ~15% from SD3 averaged across varieties.

Total DM production at GS65 (after grazing at GS30), ranged from 15.2 t/ha for DS Bennett$^{\phi}$ from SD1, down to 6.8 t/ha for Cartwheel$^{\phi}$ from SD3.

Cartwheel$^{\phi}$ triticale had the greatest decrease in DM production following grazing, (38% for SD3, 0.89 t DM/ha non-grazed versus 6.76 t DM/ha grazed). The variety's declines in DM in response to grazing were ~21% and 23% for SD1 and SD2 respectively.

Other varieties that displayed large declines in DM following grazing included RGT Calabro (35% decrease from SD3), RGT Accroc (27% from SD3), Einstein 27% (SD2) and RGT Accroc with a 25% decrease (SD2).

These results highlight differences in DM yield potential of varieties both in response to SD and recovery following grazing at GS30.



G – grazing (orange points) and NG – non-grazed treatments (blue points)

Figure 3 Dry matter production (t/ha) at GS30 for 15 cereal varieties) for three sowing dates at Tamworth 2020.

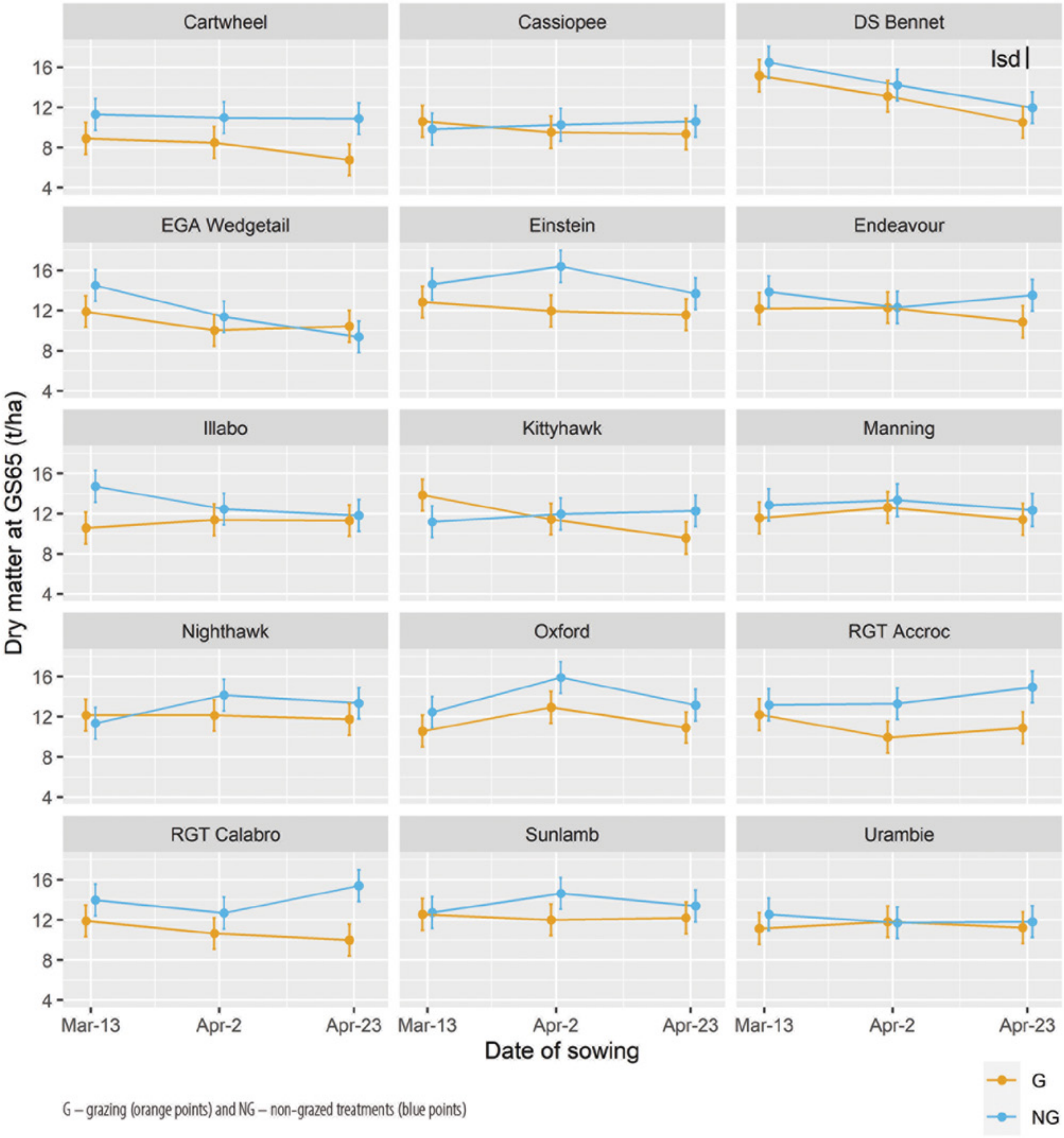
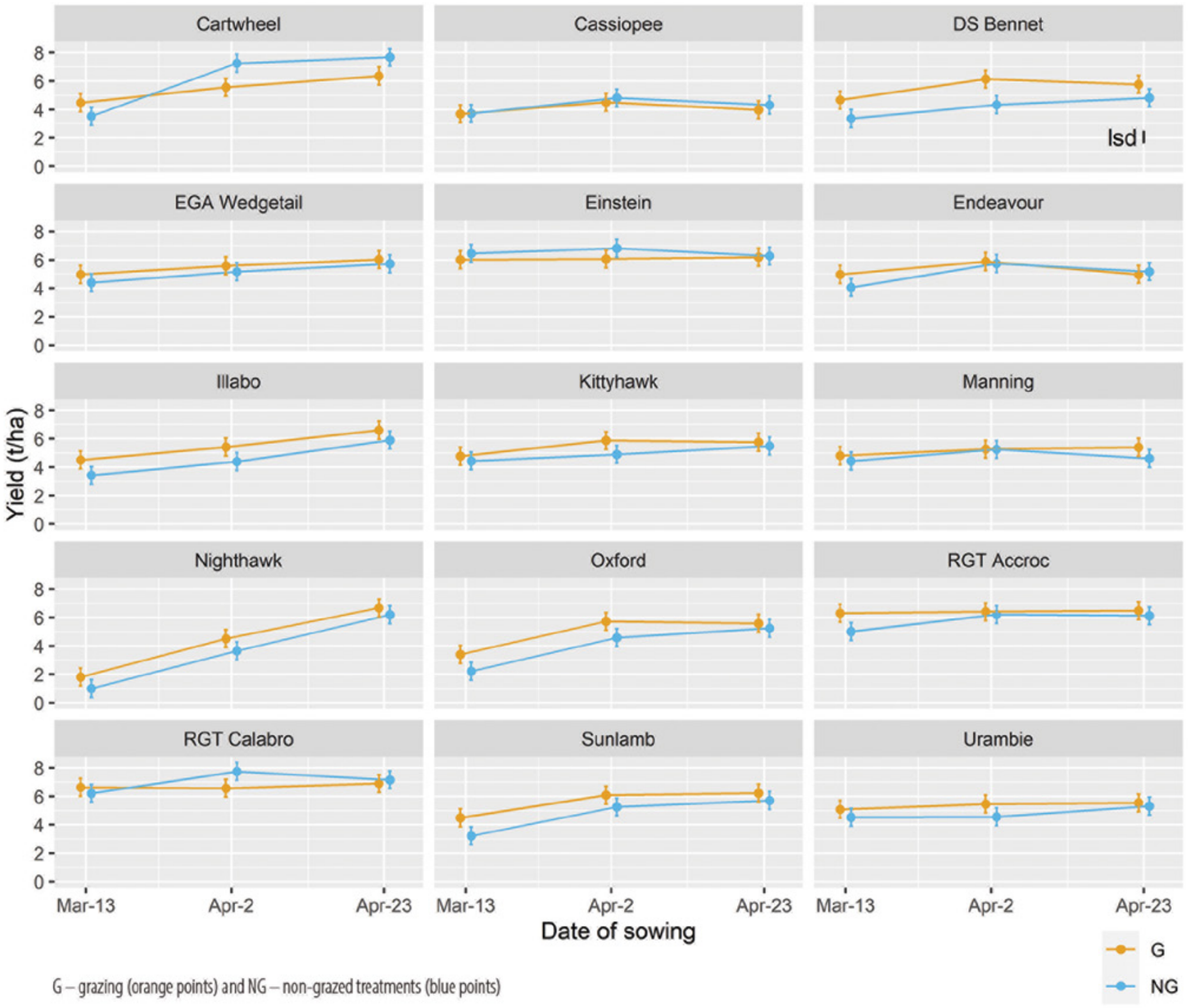


Figure 4 Dry matter production (t/ha) at GS65 for 15 cereal varieties for three sowing dates at Tamworth 2020.

Grain yield

This experiment highlighted the high yielding potential of varieties and their variable responses of yield to grazing and sowing date:

- A range of variety and sowing date combinations achieved grain yields of >6.0 t/ha, some exceeding 7.0 t/ha.
- The European varieties Einstein, RGT Accroc and RGT Calabro were all high yielding. RGT Calabro was the highest yielding variety in this experiment with >6.0 t/ha for all sowing dates for both grazed and non-grazed (Figure 5).
- RGT Calabro also had the highest individual yield in this experiment with 7.75 t/ha for the non-grazed treatment from SD2 (Table 2). Einstein achieved similar yields of >6.0 t/ha for all treatment combinations both grazed and non-grazed.
- The late-maturing varieties' ability to maintain yield from delayed sowings, particular from SD3, was probably due to good, late spring rainfall received in October.
- The triticale Cartwheel$^{\Phi}$ achieved comparable yields with the best performing wheats, yielding 7.68 t/ha and 7.25 t/ha respectively for the non-grazed treatments from SD2 and SD3 (Table 2).
- The results highlight the potential for yield decline with grazing. From SD2, there was a 23% yield decrease from grazing factors that could lead to yield declines following grazing including:
    - frost effects after grazing
    - poor leaf area recovery
    - delayed maturity, which can result in water and/or heat stress around anthesis and a decreased grain fill period.
- The slow, spring wheats, LongReach Nighthawk$^{\Phi}$ and Sunlamb$^{\Phi}$ and mid to slow barley Oxford, had positive yield responses to grazing when sown early (SD1), but these positive responses declined with later sowing dates. These yield responses to grazing from the early sown spring types (i.e. SD1), was the result of delayed anthesis, leading to frost avoidance (grazing versus non-grazed).
- Varieties such as DS Bennett$^{\Phi}$ showed a positive yield response to grazing across all sowing dates, with grazing at GS30 producing a yield increase of >20% compared with the non-grazed (Figure 5).
- The milling quality winter wheats, Illabo$^{\Phi}$, EGA Wedgetail$^{\Phi}$ and LongReach Kittyhawk$^{\Phi}$, were also high yielding, with Illabo$^{\Phi}$ the best at 6.59 t/ha (grazed SD3). This yield reflects the late October rainfall.
- The very slow spring wheats, LongReach Nighthawk$^{\Phi}$ and Sunlamb$^{\Phi}$, achieved yields ≥6.0 t/ha.
- The best performed barleys were lower yielding than the better performing wheat and triticales. The mid to slow spring variety Oxford was the best performer, yielding 5.72 t/ha from the SD2 grazing treatment.



G – grazing (orange points) and NG – non-grazed treatments (blue points)

Figure 5 Grain yield (t/ha) for 15 cereal varieties at three sowing dates at Tamworth 2020.

Grain quality

Grain quality classifications and/or receival standards can limit a variety's marketing options. A wheat variety cannot be marketed above its maximum grain quality classification. Wheat varieties evaluated in this experiment included APH, AH, ASW and Feed classified wheats. The decreasing order of grain quality classifications is APH>H>APW>ASW>Feed. If a variety is able to be delivered into a higher grain quality bracket or grade (e.g. APH or H1), it will attract a price premium and the potential for overall returns will be greater.

Grain quality parameters and classifications detailed in Grain Trade Australia (GTA) trading standard (GTA 2020) guidelines were used to define quality. Screenings (% material by weight, below 2.0 mm screen) >5% was one parameter resulting in the grain being downgraded.

- LongReach Kittyhawk was downgraded from APH to AUH for some delayed sowing treatments (Table 3). Due to LongReach Kittyhawk's superior milling quality, (unlike lower grade feed varieties) it could still be marketed as a higher value grade as Australian Utility White (AUH; screenings of between 5% and 10%).
- Later sowing dates and/or grazing + later sowing dates, increased screenings in LongReach Kittyhawk$^{\Phi}$ and in Sunlamb$^{\Phi}$ for some treatments.

- Grain protein concentration for APH/AH classified wheats ranged from 15.05% for Illabo$^{\phi}$ (yielding 3.42 t/ha, non-grazed, SD1), down to 11.85% for LongReach Kittyhawk$^{\phi}$ (5.87 t/ha, grazed, SD2) These differences in grain protein content are related to the yield dilution effect, that is that yield and protein are inversely proportional.
- Only two of the milling quality wheats, EGA Wedgetail$^{\phi}$ (non-grazed, SD3) and Illabo$^{\phi}$ (non-grazed, SD1) were downgraded as a result of a low test weight <76 kg/hL.
- All of the Feed wheats in this experiment exceeded the minimum test weight of ≥62 kg/hL, and were below the maximum allowed screenings of <15%.
- The three barley varieties evaluated were Feed classified (not Australian malt accredited). Oxford achieved Feed1 (GTA, 2020) for all treatments, apart from SD1 non-grazed and SD3 grazed. In contrast, Urambie$^{\phi}$ was primarily classified as Feed2 due to low test weights and/or high screenings (test weight <62.5 kg/hL and/or screenings >15%).
- The French winter barley, Cassiopee, failed to achieve test weight standards for Feed1, apart from the SD3, downgrading it to Feed2 and Feed3.
- Based on the GTA Triticale Standards 2020/21 (GTA 2020), the two varieties evaluated met the receival standards for test weight of >65.0 kg/hL and were below maximum allowable screenings of 10.0% for all treatments.
- Triticale has no specified minimum grain protein concentration for delivery, but in this experiment it ranged from 13.9% for Endeavour (SD1; non-grazed) down to 9.8% for Cartwheel$^{\phi}$ (SD2 grazed) (Table 3).

Table 3 Grain quality parameters of 15 cereal varieties for grazing and non-grazing treatments at three sowing dates (SD1: 13 March, SD2: 2 April, SD3: 23 April) at Tamworth 2020.

Variety	SD	Seed weight (g/1000 grains)		Screenings (%)		Protein content (% DMB)		Test weight (kg/hL)	
Grazing treatment:		NG	G	NG	G	NG	G	NG	G
Barley									
Cassiopee	1	35.92	34.60	9.51	9.62	14.97	11.43	60.33	58.67
	2	33.17	35.08	7.53	6.22	16.23	11.93	61.67	60.10
	3	40.01	38.85	3.77	3.61	17.27	13.80	64.07	63.73
Oxford	1	33.47	40.89	12.74	3.76	15.17	14.17	60.77	66.23
	2	37.20	34.09	5.11	5.71	14.37	13.60	67.00	65.63
	3	35.89	31.79	11.07	24.13	14.60	14.47	66.47	62.80
Urambie	1	37.76	35.76	9.61	12.24	13.70	11.83	61.20	60.73
	2	36.85	34.03	10.94	15.03	14.70	11.83	61.90	61.37
	3	42.96	38.47	7.71	16.23	15.23	14.07	65.77	63.13
Triticale									
Cartwheel	1	33.32	27.67	2.44	4.23	12.70	11.57	72.75	70.99
	2	29.73	31.84	4.00	3.71	11.50	9.77	73.72	73.03
	3	31.37	32.39	4.62	4.75	12.87	10.20	70.53	71.13
Endeavour	1	41.01	36.36	1.89	1.99	13.87	11.73	67.61	68.13
	2	36.76	31.53	2.79	4.04	13.00	11.47	69.13	69.40
	3	35.01	36.03	3.44	3.33	13.77	12.57	69.17	69.87

Variety	SD	Seed weight (g/1000 grains)		Screenings (%)		Protein content (% DMB)		Test weight (kg/hL)	
Grazing treatment:		**NG**	**G**	**NG**	**G**	**NG**	**G**	**NG**	**G**
Wheat									
DS Bennett	1	33.96	34.64	4.38	3.74	13.16	11.93	80.40	81.43
	2	32.84	34.63	7.22	5.80	12.16	10.89	81.20	81.70
	3	34.89	36.04	8.77	6.15	12.43	11.73	79.33	78.57
EGA Wedgetail	1	35.32	33.33	2.40	2.69	14.44	13.83	77.57	78.10
	2	31.77	33.43	4.29	3.92	13.73	11.70	77.77	78.30
	3	31.88	33.65	4.99	4.42	13.57	12.87	75.87	76.70
Einstein	1	31.99	35.15	5.18	5.01	11.98	10.98	76.57	76.47
	2	34.91	37.32	6.11	4.61	11.58	9.67	72.03	70.90
	3	31.77	30.97	6.71	5.08	12.43	12.00	74.67	75.87
Illabo	1	37.00	36.89	2.51	2.51	15.05	13.05	75.67	78.70
	2	33.53	37.33	3.09	2.56	14.77	12.49	77.40	79.67
	3	36.15	32.83	3.15	4.44	13.73	12.27	77.00	77.30
LongReach Kittyhawk	1	39.24	36.79	3.55	3.11	13.58	12.91	82.97	83.50
	2	37.69	32.81	4.59	6.01	13.01	11.85	83.40	82.73
	3	34.57	34.28	5.60	5.32	13.10	12.83	81.07	80.67
LongReach Nighthawk	1	31.69	34.97	3.95	2.44	17.68	16.25	72.94	74.87
	2	32.21	34.31	3.29	2.77	14.54	13.37	77.33	80.13
	3	37.00	35.17	3.92	3.50	13.07	12.23	81.77	82.40
Manning	1	37.64	35.77	5.93	5.18	11.91	11.46	76.50	76.10
	2	37.23	34.03	4.66	4.68	10.90	10.44	67.83	69.23
	3	32.49	33.40	6.85	6.42	12.07	11.50	73.93	76.20
RGT Accroc	1	35.28	37.00	4.96	4.07	12.23	10.09	79.03	79.57
	2	36.89	37.96	5.88	6.21	11.19	8.32	79.87	78.90
	3	35.75	39.56	4.36	4.90	12.53	9.70	78.03	79.60
RGT Calabro	1	39.12	39.00	5.67	6.07	12.73	10.89	80.47	81.10
	2	45.37	41.88	4.26	6.90	12.12	10.16	79.50	81.20
	3	42.87	40.81	5.28	6.25	12.27	12.30	81.70	82.07
Sunlamb	1	31.92	32.40	2.43	2.54	15.77	15.10	79.37	79.80
	2	32.45	32.43	3.06	3.76	14.40	12.84	80.77	81.60
	3	33.57	32.05	7.08	7.48	13.07	13.20	81.37	80.10
P-value (variety)		<0.001		<0.001		<0.001		<0.001	
P-value (graze)		ns		ns		<0.001		ns	
P-value (SD)		ns		ns		ns		ns	
P-value (variety:graze)		<0.001		<0.001		<0.001		ns	
P-value (variety:SD)		<0.001		<0.001		<0.001		<0.001	
P-value (graze:SD)		ns		0.003		0.006		ns	
P-value (variety:graze:SD)		<0.001		<0.001		ns		ns	

Feed value analysis

The DM cuts from SD 1 at GS30 and GS65 were analysed for feed quality. A bulked sample was prepared for each variety from the three field replicates and analysed at the NSW DPI Feed Testing Laboratories at Wagga Wagga.

Important feed quality traits include neutral detergent fibre (NDF), ME and CP. Neutral detergent fibre is a measure of a plant's structural, slowly digested cell wall components. It includes hemicellulose, cellulose and lignin or 'indigestible fibre'. As the percentage of NDF increases, animal intake tends to decline due to increasing fibre content, which takes longer to digest in the rumen. It is also important that NDF values are not too low (i.e. <30%) to avoid stomach upsets such as acidosis. Conversely, high NDF values (i.e. >60%) can affect digestibility, limiting intake.

- Feed quality results for grazing samples taken at GS30 were within the recommended NDF values of 30–60%.
- Values for NDF ranged from 46% for Oxford up to 52% for RGT Calabro (Table 4).
- The ME of the forage taken at GS30, ranged from 11.6 MJ/kg to 13.4 MJ/kg satisfying the dietary requirements of most sheep and cattle. The results indicate that lower fibre diets (i.e. less mature plant material) are more digestible and higher in ME.
- Crude protein levels for early grazing ranged from 20.2% to 27.4%. It is important to note that CP includes both true protein and non-protein nitrogen (NPN) and doesn't differentiate between nitrates and proteins in plants. Nitrate concentrations are usually higher in younger plants and decline as plants mature. High nitrate levels can be an issue when grazing young cereal crops and producers should exercise caution and contact their veterinarian or Local Land Services livestock officer prior to grazing to discuss any potential animal health and/or management issues.
- Feed analysis for DM cuts taken at GS65 showed that NDF values increased and DM digestibility decreased as crops matured. Neutral detergent fibre values ranged from 52% for EGA Wedgetail$^{\phi}$, Einstein, LongReach Nighthawk$^{\phi}$ and RGT Calabro, up to 60% for LongReach Kittyhawk$^{\phi}$ (Table 4).
- The ME ranged from 7.4 MJ/kg for LongReach Kittyhawk$^{\phi}$ up to 10.1 MJ/kg for Cassiopee, with CP ranging from 7.5% for Manning$^{\phi}$ up to 16.5% for EGA Wedgetail$^{\phi}$.
- Based on AFIA standards for cereal hay, Cassiopee barley achieved the highest A1 grade. LongReach Kittyhawk$^{\phi}$ produced the lowest grade of D2.

Table 4 Feed quality analysis (DM basis) of wheat, barley and triticale at GS30 and GS65 for SD1, sown on 13 March at Tamworth 2020.

Variety	Growth stage	Near infrared (NIR) spectrophotometry analysis									AFIA cereal hay grade* (GS65 only)
		ADF (%)	ASH (%)	CP (%)	DMD (%)	DOMD (%)	ME (MJ/kg DM)	NDF (%)	OM (%)	WSC (%)	
Barley											
Cassiopee	GS30	31	10	24.2	81	75	12.3	51	90	11.9	–
	GS65	29	9	11.8	68	64	10.1	55	91	13.8	A1
Oxford	GS30	26	13	27.4	88	81	13.4	46	87	11.5	–
	GS65	31	9	15.3	61	59	8.9	55	91	10.7	B1
Urambie	GS30	27	14	24.6	82	77	12.6	49	86	11.3	–
	GS65	29	8	11.2	65	62	9.5	54	92	16.6	B1
Triticale											
Cartwheel	GS30	23.8	11	20.2	83	77	12.6	47	89	17.9	–
	GS65	29	8	9.6	59	57	8.5	56	92	17.4	C2
Endeavour	GS30	26	13	24.3	82	77	12.5	49	88	11.0	–
	GS65	26	9	14.6	63	60	9.2	53	91	14.9	B1
Wheat											
DS Bennet	GS30	28	13	24.0	83	77	12.7	49	87	13.0	–
	GS65	32	9	10.3	58	56	8.4	58	91	13.9	C1
EGA Wedgetail	GS30	28	13	22.7	81	76	12.4	49	87	11.6	–
	GS65	28	10	16.5	64	61	9.5	52	90	13.2	B1
Einstein	GS30	27	12	25.4	83	77	12.6	50	88	9.4	–
	GS65	28	9	13.2	66	63	9.7	52	91	18.0	A1
Illabo	GS30	30	13	22.1	77	72	11.6	51	87	11.5	–
	GS65	29	10	10.3	60	58	8.7	58	90	18.8	B1
LongReach Kittyhawk	GS30	28	9	22.6	80	75	12.2	49	88	12.6	–
	GS65	32	9	9.0	52	51	7.4	60	91	9.9	D2
LongReach Nighthawk	GS30	28	14	24.2	82	76	12.5	50	87	12.3	–
	GS65	27	8	12.8	65	62	9.6	52	92	18.8	B1
Manning	GS30	27	13	24.7	84	78	12.9	49	87	11.8	–
	GS65	26	8	7.5	66	63	9.7	53	92	24.3	A3
RGT Accroc	GS30	28	13	21.4	79	74	12.0	51	87	13.1	–
	GS65	31	10	9.6	60	58	8.8	56	90	13.7	B2
RGT Calabro	GS30	28	12	22.1	78	73	11.7	52	88	9.6	–
	GS65	29	9	9.0	62	59	9.1	54	91	20.3	B2
Sunlamb	GS30	28	14	23.4	82	76	12.5	51	86	13.2	–
	GS65	29	8	10.4	61	59	8.9	53	92	18.8	B1

ADF – acid detergent fibre (%)
ASH – ash (%)
CP – crude protein (%)
DMD – dry matter digestibility (%)
DOMD – digestibility of the organic matter contained in the dry matter (%)
ME – metabolisable energy (MJ/kg DM)
NDF – neutral detergent fibre (%)
OM – organic matter (%)
WSC – water soluble carbohydrates (%)

* Australian Fodder Industry Association (AFIA) standards for cereal hay (https://graintrade.org.au/sites/default/files/file/Commodity%20Standards/Section%2005%20-%20Fodder%20201112.pdf), which consider DMD, ME and CP when grading hay and silage. Under this system the highest grade A1, has an ME >9.5 MJ/kg, DMD >66% and CP% >10, whereas the lowest grade D4 has an ME <7.5 MJ/kg, CP <4% and DMD <53%. Lower letters (i.e. D) indicating lower ME and/or DMD higher numbers (i.e. 4) an indicator of lower CP% (Fodder Standards, 2011/12).

Conclusions

The factors to consider when selecting a dual-purpose cereal are:

- the ability of a variety to produce forage for opportunistic grazing and/or to fill a feed gap
- to recover and yield good quality grain that can be delivered into higher priced markets.

Where livestock production is an integral component of the farming system, total forage production and DM timing production are important varietal selection criteria. Disease resistance, particularly to leaf and stripe rust, needs also to be considered.

The issue confronting growers is which variety is the best option. This needs to take into account the purpose of the crop (grain versus graze versus grain and graze), sowing date timing and marketing opportunities.

Biomass at GS30

The time taken to reach GS30 varied considerably in this experiment:

- GS30 ranged from 35 days for Oxford up to 108 days for RGT Calabro, due to differences in phenology and responses to sowing date and the effective potential grazing period length.
- The slower maturing European winter wheats, RGT Accroc, RGT Calabro, and the winter barley Cassiopee were the best performing varieties in terms of DM production at GS30, producing >5.0 t DM/ha.
- Other varieties that accumulated high biomass at GS30 included Einstein and Illabo⁽ᵖ⁾ wheat, and Cartwheel⁽ᵖ⁾ triticale, producing >4.0 t DM/ha (SD1 and/or SD2).

These variety responses underline the importance of timely sowing opportunities to ensure sufficient time for biomass accumulation.

The slower maturing varieties, taking longer to reach GS30, offer an extended grazing period. The results, however, do not fully capture the effective grazing period, as these varieties are initially slow to grow, meaning they tend to accumulate more biomass later in the season. Quicker maturing varieties would produce less biomass at GS30, but earlier in the growing season.

These are factors to consider when selecting a variety to meet a feed gap and/or optimise DM production at GS30.

Biomass at GS65

Several varieties accumulated >15 t DM/ha for non-grazed treatments at GS65 including Oxford barley and the winter wheats DS Bennett⁽ᵖ⁾, Einstein, RGT Accroc and RGT Calabro. These results indicate their potential as forage hay/silage options.

DS Bennett⁽ᵖ⁾ from SD1 was the highest yielding of the non-grazed treatments (16.5 t DM/ha at GS65).

This experiment highlighted differences in feed/hay quality between varieties, with Einstein, achieving an AFIA hay grading of A1 compared with a hay grade of D2 for LongReach Kittyhawk⁽ᵖ⁾, at the same growth stage.

Biomass at GS65 response to grazing

There was an average of a 12% decline in biomass production from grazing at GS30 on subsequent biomass accumulation at GS65, across all varieties and sowing dates.

Dry matter production following grazing at GS30 also tended to decline with later sowing dates, averaging 8% for SD1, 12.5% for SD2 and up to ~15% for SD3 averaged across varieties.

- DS Bennett⁽ᵖ⁾ from SD1 was the least affected by grazing GS30, performing the best (15.2 t DM/ha at GS65).
- Cartwheel⁽ᵖ⁾ performed the worst with DM production decreasing 38% following grazing (10.9 t DM/ha non-grazed versus 6.76 t DM/ha grazed).

Grain yield

RGT Calabro and Cartwheel$^{\Phi}$ both achieved excellent yields of >7.0 t/ha from SD2 and SD3 (non grazed).

Following grazing, the best performed varieties for DM at GS30 and subsequent grain yield were the Feed winter wheats.

- Both RGT Calabro and RGT Accroc produced >5.0 t DM/ha at GS30 and yielded >6.4 t/ha of grain, from a 2 April sowing date (SD2).
- Cartwheel$^{\Phi}$ triticale was also high yielding, (6.4 t/ha for SD2), but it was slightly lower in terms of DM production at GS30 at ~3.8 t/ha.
- The higher quality AH milling wheat, Illabo$^{\Phi}$, was high yielding at ~6.6 t/ha, but only produced 2.1 t DM/ha at GS30.

There were variable yield responses to grazing at GS30. Varieties such as DS Bennett$^{\Phi}$, Illabo$^{\Phi}$ and Oxford for example, showed positive yield response to grazing. Possible reasons for responses include reduced lodging and delayed phenology (i.e. frost avoidance at anthesis).

- Cartwheel$^{\Phi}$ suffered a yield penalty of 17–23% following grazing compared with non grazed, possibly due to frost effects soon after grazing and delayed maturity, which can result in water and/or heat stress at anthesis or grain fill.

Note that these results presented are for one season only and the ability of late maturing varieties to maintain yield from delayed sowings particularly from SD3, reflects the favourable, late spring rainfall received in October 2020. This should to be taken into consideration when selecting a variety and sowing date option.

Grain quality

Grain quality receival standards and the ability of a variety to be delivered into a higher priced market are important considerations regarding varietal selection.

The two highest yielding grazed AH varieties, Illabo$^{\Phi}$ and EGA Wedgetail$^{\Phi}$ in SD3, both achieved an H2 classification.

Both RGT Calabro and RGT Accroc were high yielding, but are only Feed wheats and would both receive a considerable price discount compared with milling wheats. Likewise, grain receival prices for both feed barley and triticale would also be assumed to be considerably lower than that of higher-grade milling quality wheats, affecting returns.

Growers on the north-western slopes of NSW have access to a range of early sowing date, dual-purpose crops and varieties that can provide valuable winter forage for livestock, while also potentially achieving high yield.

Preliminary results from this experiment, indicate that the feed quality wheats RGT Calabro, RGT Accroc and Einstein offer growers both good grazing potential at GS30 and high grain yield potential. Likewise, the triticale variety Cartwheel$^{\Phi}$ was shown to provide good winter forage production at GS30 and was also high yielding. Other varieties that performed well included the AH classified milling quality wheats Illabo$^{\Phi}$ and EGA Wedgetail$^{\Phi}$.

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Dryland safflower: Response to row configuration and population, northern NSW 2016

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Key findings

- Row spacing had no effect on crop establishment, seed size or grain yield.
- Increasing row spacing from 31.5 cm to 63 cm increased plant height, but had no effect on height of lowest flowers or on the start or flowering.
- Leaf canopy area at early flowering was 22% greater when sown on wide rows, compared with narrow rows.
- Crop establishment declined with increasing target plant population to 40 plants/m^2.
- Increasing population hastened the start of flowering.
- The conventional safflower varieties Sironaria and S317 had similar structural characteristics including plant height, height of lowest flowers, stem diameter and leaf canopy area.
- Sironaria was quickest to start flowering.
- Overall yields were low. Sironaria outyielded S317: 0.44 t/ha compared with 0.2 t/ha.
- The Sironaria and S317 yield response to plant population was inconsistent.
- Seed size was 6% larger in Sironaria than S317.
- Seed size decreased as plant population increased from 10 plants/m^2 to 40 plants/m^2.

Introduction

Historically, safflower has been grown intermittently in northern NSW. Its end use has been limited to seed production for the birdseed and oleic oil markets based on public varieties released in the mid 1980s. Cotton production systems have included safflower as a biological means to manage soil compaction.

The 'Tactical agronomy of minor crops (safflower, linseed, sunflower)' (DAN00197) was a co-funded project between NSW DPI and the Grains Research and Development Corporation (GRDC). A major objective was to determine the agronomic constraints to yield potential in safflower in northern NSW.

Grower experience with safflower has been limited. Industry consultation at the beginning of the project revealed a generalised view regarding optimal plant populations and row configurations for maximising safflower yield potential.

This paper reports on the response of the two widely grown conventional varieties of safflower to four plant populations and two row spacings at Terry Hie Hie in 2016. This information will be used to develop agronomic recommendations for safflower agriculture in northern NSW.

Site details

Co-operator	Rob and David Anderson.
Location	Maneroo, Terry Hie Hie.

Soil type	Grey vertosol.
Sowing date	15 July 2016.
Starting soil water	171 mm (0–120 cm)
In-crop rainfall	491 mm.
Fertiliser	100 kg/ha Supreme® Z.
Herbicide	• Pre-emergent: 2.25 L/ha Trifluralin® (trifluralin). • Post emergent: 5 g/ha Ally® (metsulfuron-methyl), 75 mL/ha Verdict® (haloxyfop).
Harvest date:	10 January 2017; 178 days after sowing (DAS).

Soil test results

The site was sampled before sowing (Table 1).

Table 1 Soil chemical characteristics in June 2016.

Soil depth (cm)	pH_{Ca}	Nitrate N (mg/kg)	Ammonium N (mg/kg)	Phosphorus (Colwell) (mg/kg)	Potassium (Colwell) (mg/kg)	Sulfur (mg/kg)	Exchangeable sodium (%)	Salinity (dS/m)	Organic carbon (%)
0–10	7.1	15.90	39.5	8.31	467	9.1	2.53	0.13	0.71
10–20	7.5	3.97	39.3	2.47	210	8.6	3.19	0.11	0.61
30–60	8.0	4.01	19.5	9.00	205	12.4	5.29	0.19	0.60
60–90	8.1	1.28	25.8	25.10	216	18.1	7.02	0.23	0.56
90–120	8.8	<0.5	17.9	3.83	250	18.1	8	0.4	0.26

Seed quality

Seed was tested for size and germination before sowing. Tests showed abnormal seeds of around 19% in S317 and 11% in Sironaria. Seeding rates for each target population were calculated using 90% establishment rates (Table 2).

Table 2 Seed size, germination percentages and seeding rates.

Variety	Seed size (g/100 seeds)	Germination (%)	Seeding rate (kg/ha)			
			10 plants/m^2	20 plants/m^2	30 plants/m^2	40 plants/m^2
Sironaria	3.6	89	4.5	8.9	13.4	17.8
S317	3.3	71	5.2	10.3	15.5	20.5

Seeding rates were calculated based on the assumption of 90% establishment.

Sowing

The experiment was sown into soil moisture suitable for germination. Soil temperatures at 10 cm depth at 11:30 am AEST was 11.2 °C.

Site climate details

Figure 1 shows the temperature and rainfall throughout the experiment.

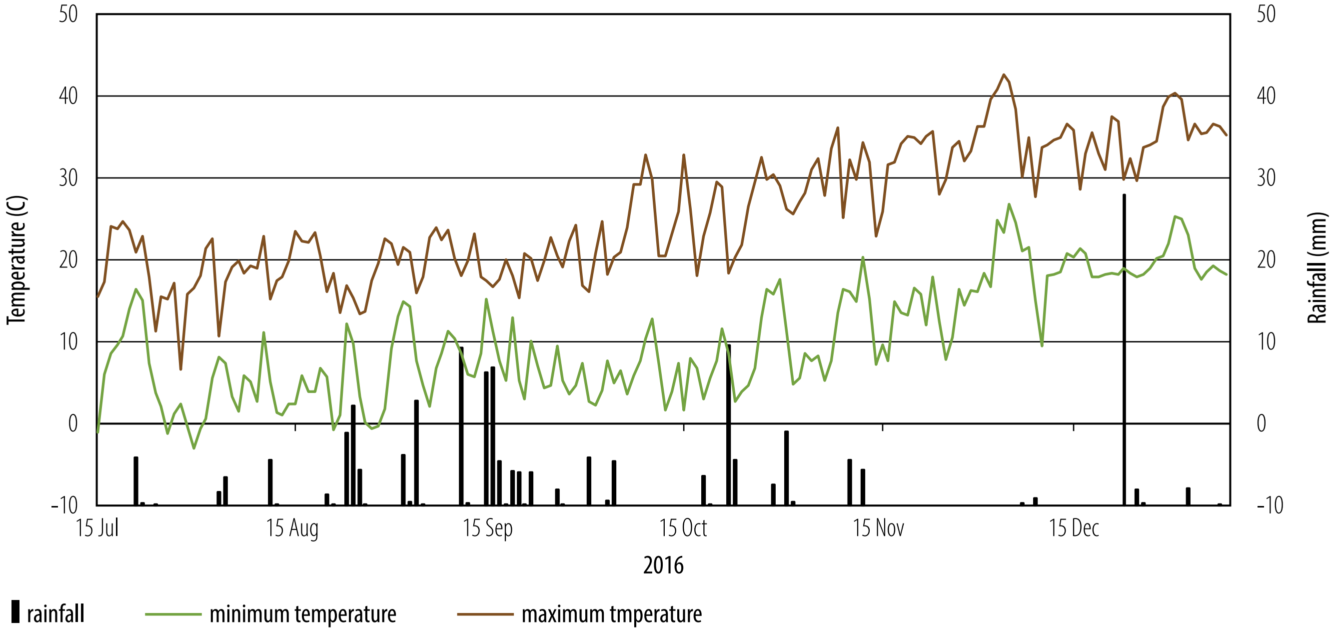


Figure 1 Experiment climate information in 2016.

A summary of temperature and rainfall during the experiment are shown in Table 3.

Table 3 Climatic conditions during safflower crop cycle in 2016.

Climate condition	2016 data
Temperature range (°C)	–2.9 to 42.7
Average minimum temperature (°C)	10.3
Average maximum temperature (°C)	25.9
In-crop rainfall (mm)	491.2

Experiment design

Split plot design with row spacing as the main block with variety and populations randomised within each block; three replications.

Treatments

- **Variety**: Sironaria, S317
- **Row spacing** (cm): 31.5 and 63
- **Population** (plants/m^2): 10, 20, 30 and 40

Results

Crop establishment

Establishment was measured 46 days after sowing (DAS). Between sowing and establishment measurements, 28 days had daily minimum temperatures below 5 °C, including seven days with sub-zero temperatures. These low temperatures coincided with 87.6 mm rainfall.

Row spacing had no significant effect on crop establishment; the site average was 22.6 plants/m^2. Varieties differed in achieving their target populations (Figure 2). S317 was notable for its declining rate of establishment, reaching just 23 plants/m^2 and 28 plants/m^2 for target populations of 30 plants/m^2 and 40 plants/m^2 respectively. The combination of cold and wet weather, seed size and quality contributed to these results. Soil-borne disease could have also been a significant factor.

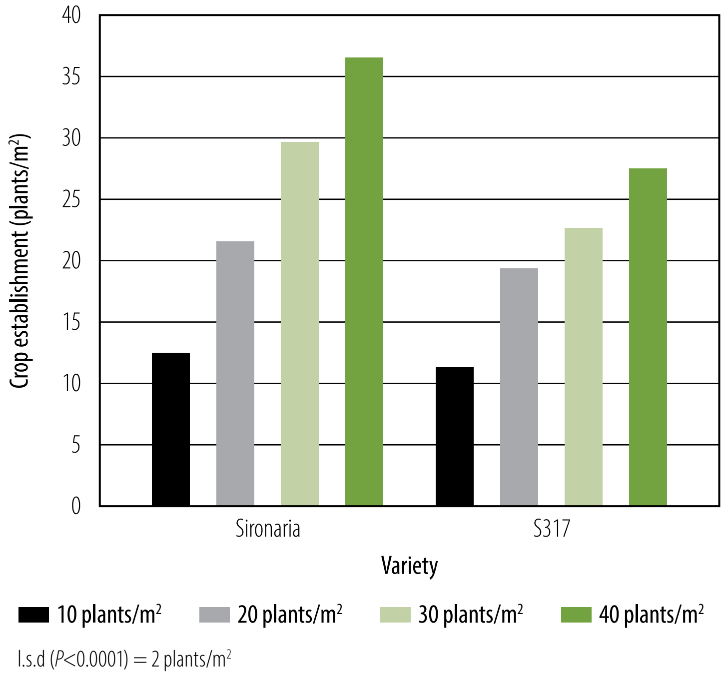


Figure 2 Interaction of variety with plant population on crop establishment in 2016.

As target population increased, establishment declined, with just 80% of seed establishing at the highest target population (Figure 3).

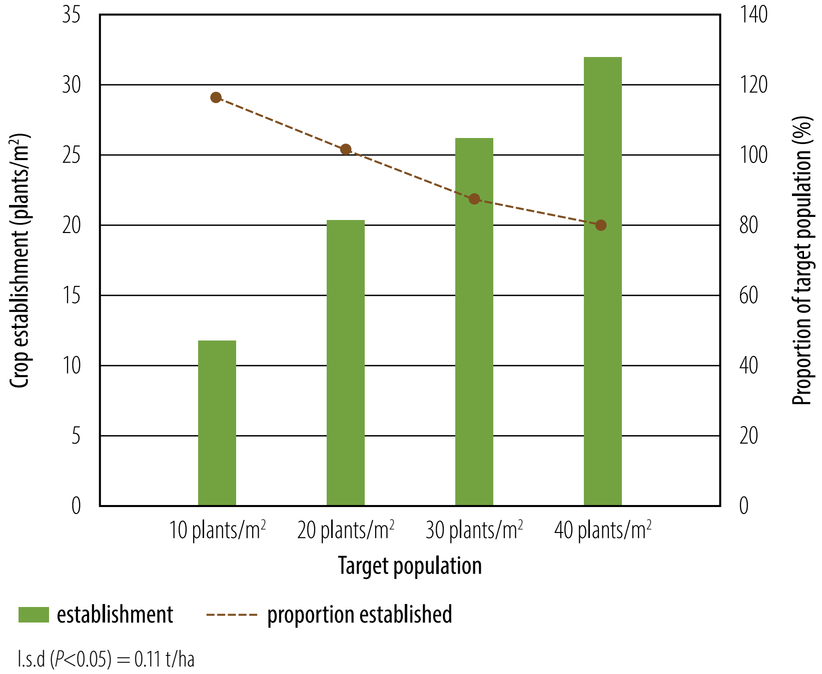


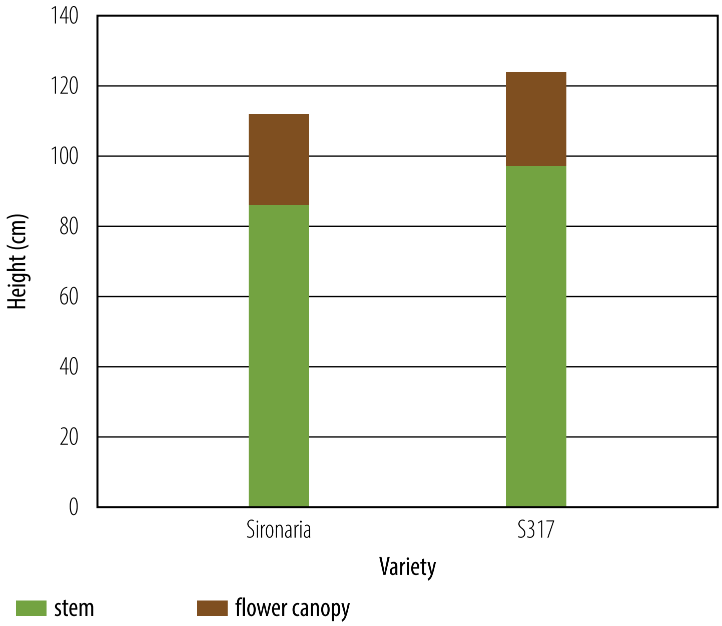
Figure 3 Interaction of variety with plant population affecting crop establishment in 2016.

Plant structure

Plant height at physiological maturity for crops sown at 63 cm row spacing was significantly taller,120 cm, than plants sown on the narrower row spacing,116 cm ($P<0.05$; l.s.d. 2.1 cm).

Row spacing had no significant effect on the height above ground of the lowest flower at harvest.

Figure 4 illustrates the plant structure of the two varieties. Each bar shows the overall plant height, with the location of flowers in the upper canopy. The stem height indicates the position of the lowest flower on the plant. S317 was significantly taller than Sironaria at 124 cm with its lowest flower also significantly higher above ground at 98 cm. These characteristics would present no difficulties at harvest in capturing all seed.



Stem height l.s.d ($P<0.005$) = 7.2 cm; position of lowest flower l.s.d. ($P<0.005$) = 7.0 cm

Figure 4 Plant structure of safflower varieties in 2016.

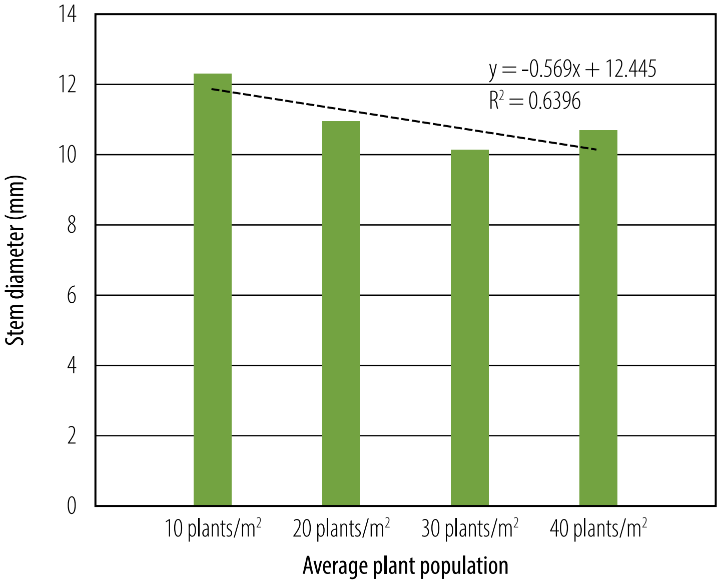
Leaf area index

Leaf area index (LAI) was measured at early flowering. LAI is a measure of the total leaf area per unit of ground area. It is directly related to the amount of light that plants intercept.

Row spacing had significant effects on LAI. The LAI of safflower sown at 31.5 cm row spacing was 2.95 m^2, compared with 3.61 m^2 of safflower sown on 63 cm wide rows ($P<0.05$; l.s.d. 0.29). Variety and plant population had no significant effect on LAI.

Stem diameter

- Row spacing had no significant effect on stem diameter.
- The difference between the varieties was significant at $P<0.06$. Sironaria averaged 10.7 mm compared with 11.4 mm in S317.
- At populations of 10 plants/m^2, stem diameter was significantly greater than all other populations ($P<0.001$; l.s.d. 0.98) (Figure 5). There was no significant difference in stem diameter in populations above 20 plants/m^2.
- The trend across all populations was a decrease in stem diameter as plant population increased. No lodging was observed.



l.s.d (P<0.001) = 0.98 mm

Figure 5 Effect of population on stem diameter in 2016.

Flowering

- Flowering started in mid November. On 15 November 2016 (122 DAS), the proportion of plants with an open flower was counted.
- Row spacing had no significant effect on timing of flowering
- Sironaria was significantly quicker to flower than S317; 41% of plants had started flowering versus 6% in S317 (P<0.001; l.s.d 11.3%).
- Plant population had a high correlation (R2 = 0.91) with flowering. Increasing plant population significantly hastened flowering (P<0.05; l.s.d. 16%).
- The percentage of plants with an open flower at populations of 10 plants/m^2, 20 plants/m^2, 30 plants/m^2 and 40 plants/m^2 was 5%, 24%, 30% and 36% respectively.

Yield

- Row spacing had no significant effect (P<0.05) on yield.
- The site average was 0.31 t/ha (expressed at 8% moisture).
- There were significant yield differences between the two varieties: Sironaria – 0.44 t/ha; S317 – 0.2 t/ha (P<0.001; l.s.d 0.05 t/ha).
- Plant population had a significant effect on yield (Table 4) even though differences were small within the narrow range of yields across all populations.
- Yield was highest at 20 plants/m^2. There was no consistent yield trend across the populations tested in this experiment.

Table 4 Effect of plant population on yield in 2016.

	Target population			
	10 plants/m^2	**20 plants/m^2**	**30 plants/m^2**	**40 plants/m^2**
Yield @ 8% moisture (t/ha)	0.26 ^{b}	0.38 ^{a}	0.29 ^{bc}	0.34 ^{abc}
Site mean	0.32			
l.s.d.	0.08			

*Values with the same letter are not significantly different at 95% (P<0.05)

The varieties' yield response to plant population was significant ($P<0.05$; l.s.d. 0.11 t/ha) (Figure 6). Sironaria attained the maximum yield at 20 plants/m^2; Sironaria yields at 20 plants/m^2 and 40 plants/m^2 were not significantly different. Sironaria yields at 10 plants/m^2 were not significantly different from any of the S317 populations. There was no significant yield difference between any S317 population.

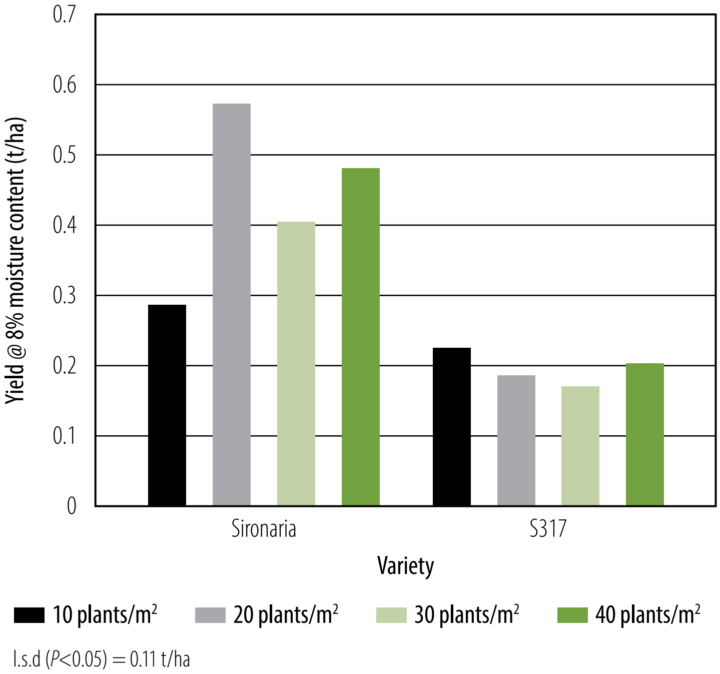


Figure 6 Interaction of variety and population on safflower yield in 2016.

Seed size

- Seed size is expressed as the weight of 100 seeds. The average seed size at 8% moisture content was 3.08 g.
- Row spacing within each variety had no significant effect ($P<0.05$) on seed size.
- There were, however, significant differences between Sironaria and S317 – 3.18 g and 2.98 g respectively ($P<0.001$; l.s.d. 0.06 g).
- Seed size declined as population increased. At 10 plants /m^2, 20 plants /m^2, 30 plants /m^2 and 40 plant s/m^2, seed size was 3.16 g, 3.07 g, 3.06 g and 3.02 g respectively ($P<0.05$; l.s.d. 0.08 g).
- Seed size decreased significantly in S317 as row spacing increased ($P<0.05$; l.s.d. 0.46 g). At row spacings of 31.5 cm and 63 cm, S317 seed size was 3.12 g and 2.83 g. The reduction in Sironaria was not significant (3.26 g and 3.11 g respectively).

Harvest index

- Harvest index (HI) is a measure of crop reproductive efficiency, calculated as the ratio of grain to above-ground dry matter. The average HI of the site was 0.14.
- Row spacing had no significant effect on HI.
- The HI of Sironaria (0.16), was significantly higher than that of S317 (0.13; $P<0.001$; l.s.d. 0.01).
- There were significant differences in HI in response to plant population ($P<0.05$; l.s.d. 0.01) (Table 5).

Table 5 Effect of plant population on harvest index in 2016.

	Target population			
	10 plants/m^2	20 plants/m^2	30 plants/m^2	40 plants/m^2
Harvest index	0.15 [a]	0.15 [a]	0.13 [b]	0.14 [ab]
Site mean	0.14			
l.s.d.	0.01			

*Values with the same letter are not significantly different at 95% (*P*<0.05)

Disease

A number of soil-borne diseases can affect safflower, including pythium, phytophthora and charcoal rot. At sowing, levels of soil borne diseases were not assessed, nor was seed treated with a fungicide.

Charcoal rot (*Macrophomina phaeolina*) was found to be present at low levels. Charcoal rot is a disease known to cause crop damage when soil temperatures exceed 32 °C. It infects the plant's vascular system, restricting the flow of water and nutrients.

At physiological maturity, the incidence and severity of charcoal rot was assessed and averaged 34%. There was no significant (*P*<0.05) interaction with row spacing, variety or population.

The severity of charcoal rot is scored on a scale of zero to five where five is complete infection of internal stem tissue and zero is the absence of infection. The severity of charcoal infection was low, averaging 0.6 out of five across the site (Figure 7).

Row spacing and variety had no significant effect on the severity of charcoal rot infection (*P*<0.05). Increasing plant population significantly reduced charcoal rot infection, however, the score was less than one in all populations (data not shown) (*P*<0.05; l.s.d. 0.2).

There was no evidence of sclerotinia or any other foliar disease.

Roots systems were not examined.

Figure 7 Stem cross sections showing the absence (left) and presence of charcoal rot infection at the base of safflower stems in 2016.

Conclusions

In 2016, Sironaria and S317 were the two most frequently grown conventional safflower varieties for the birdseed and oleic oil markets respectively. The varieties have similar plant structural traits and flowering times.

Increasing seeding rates consistently decreased crop establishment. Reduced establishment on wider row spacings is consistent with findings in other winter crops. Research in 2014 and 2015 has highlighted safflower's adaptability to a broad range of plant populations where yields were maximised at populations between 20 plants/m^2 and 40 plants/m^2.

The yields attained in this experiment were well below average yields of 1–1.2 t/ha. The low yields and lack of yield response to population in this experiment is suspected to be caused by undiagnosed soil-borne pathogen/s, affecting the crop's root system. Poor root function would induce plant stress and inhibit grain fill.

The 2016 winter crop season was notable for its frequent rainfall throughout the growing season. Frequent wet and cold weather, especially during early crop establishment, were conducive to damping-off pathogens. During grain fill, daily maximum temperatures exceeded 30 °C on most days reaching 41.7 °C and there was only one effective rainfall. These climatic conditions induced heat and moisture stress in the crop, effects that would have been exacerbated if root systems were compromised by disease.

The prevalence, incidence, and potential effects of soil-borne diseases on safflower performance is unknown. This area is an important knowledge gap for future safflower research. Growers are advised to determine soil-borne disease levels of pythium and phytophthora using, for example Predicta B (PREDICTA® B–PIRSA), before sowing and to treat seed before sowing.

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Optimising sorghum production, Moree 2020–2021

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Key findings

- Establishing sorghum at soil temperatures cooler than the commercial standard, and recommended 16–18 °C, is a viable option to move flowering and grain fill periods earlier.
- Targeting soil temperatures of greater than 12°C for the seven days after planting, and planting into good seedbed moisture are critical for even establishment.
- The earliest planting date (PD), PD1, moved the flowering window forward by three weeks compared with planting at the recommended soil temperature (PD3).
- PD1 and PD2 moved the harvest period earlier by two weeks.
- PD2 provided the optimum combination of a rapid, even establishment, earlier flowering and earlier harvest at this site. Grain yields were reduced by an unseasonable heat wave at the end of November.
- Planting date affected grain yields, reducing as planting was delayed.
- Grain test weight levels responded to varying plant populations. Lower plant populations produced higher test weights and lower screenings %.

Introduction

Dryland grain sorghum production is driven by the need to produce high yields to obtain positive gross margins for growers. One of the major limiting factors to achieving reliability and increasing sorghum yields is the combination of hot temperatures and moisture stress, which can often occur during flowering and grain fill for crops sown in the traditional September–end of October window. This planting window is based on targeting recommended soil temperatures of 16–18 °C and avoiding frosts in the early growth stages.

Alternative, earlier planting times, have been proposed through this research, where soil temperatures at planting could be as low as 12 °C. This research aims to develop knowledge around how early planting can begin, what levels of tolerance different hybrids have to cold soils, and seedling frost events.

Two sites were harvested in the 2020–21 season, a dryland experiment at Breeza on the Liverpool plains and this dryland site at Bogamildi, north of Moree. Two other dryland sites were sown: Bullawarrie north of Mungindi and Morialta south of Mungindi, but were abandoned due to mice damage.

Site details	Location	Bogamildi, Moree (29°11’681” S, 150°02’118” E)
Paddock history	2019 wheat.	
Co-operator	Geoff Manchee and JR McDonald	
Soil type and nutrition	The site was cored for starting nutrition level (Table 1) and was found to have 213 kg/ha of nitrogen (N)	

Figure 1 Sorghum nearing maturity at Bogamildi, Moree.

Table 1 Site soil chemical characteristics.

Characteristic	Depth (cm)				
	0–10	10–30	30–60	60–90	90–120
pHCa	7.2	7.8	7.9	7.2	7.1
Nitrate nitrogen (mg/kg)	6	18	21	9	7
Sulfur (mg/kg)	5.0	7.5	619.6	4314.5	1500.4
Phosphorus (Colwell) (mg/kg)	15	2	<2	<2	2
Organic carbon (OC) (%)	0.81	0.63	0.55	0.29	0.17

Starting soil water and rainfall

The soil was cored after each planting to measure starting plant available water to a depth of 1.2 m.

- PD1: 176.5 mm
- PD2: 181.1 mm
- PD3: 190.4 mm

A total of 267 mm of in-crop rainfall was recorded at the site between August 2020 and February 2021 (Table 2).

PD1 received 278.4 mm, while PD2 received of 234 mm and PD3 received 257 mm.

Table 2 In-crop rainfall at Bogamildi in 2020–21 and long-term Moree average rainfall.

Month	August	September	October	November	December	January	February
2020–21 rainfall (mm)	6.0	21.0	14.0	0.0	81.5	108.5	36.0
Moree long term average (mm)	25.4	33.9	46.4	70.4	67.2	79.1	67.3

Seasonal conditions

- The site started with a good soil moisture profile from high winter rainfall.
- PD1 was 5 August. Soil temperatures were mild and averaged 10.5 °C at 8 am over the following seven days.
- A rainfall event followed each planting date, which helped to ensure seedbed moisture was not limiting.
- A drier period occurred during October and November, combined with a heat wave during late November where temperatures reached over 40 °C. These combined to reduce the yield potential of all the planting dates, but particularly effected PD2, which was flowering at the end of November.
- Temperatures remained near average (BOM temperatures) during the rest of the season.
- There was excellent rainfall in late December and January, however, this was of little benefit to PD1 and PD2, which were both approaching physiological maturity by this time. PD3 received the most benefit from this rain as it was still in the grain fill period.

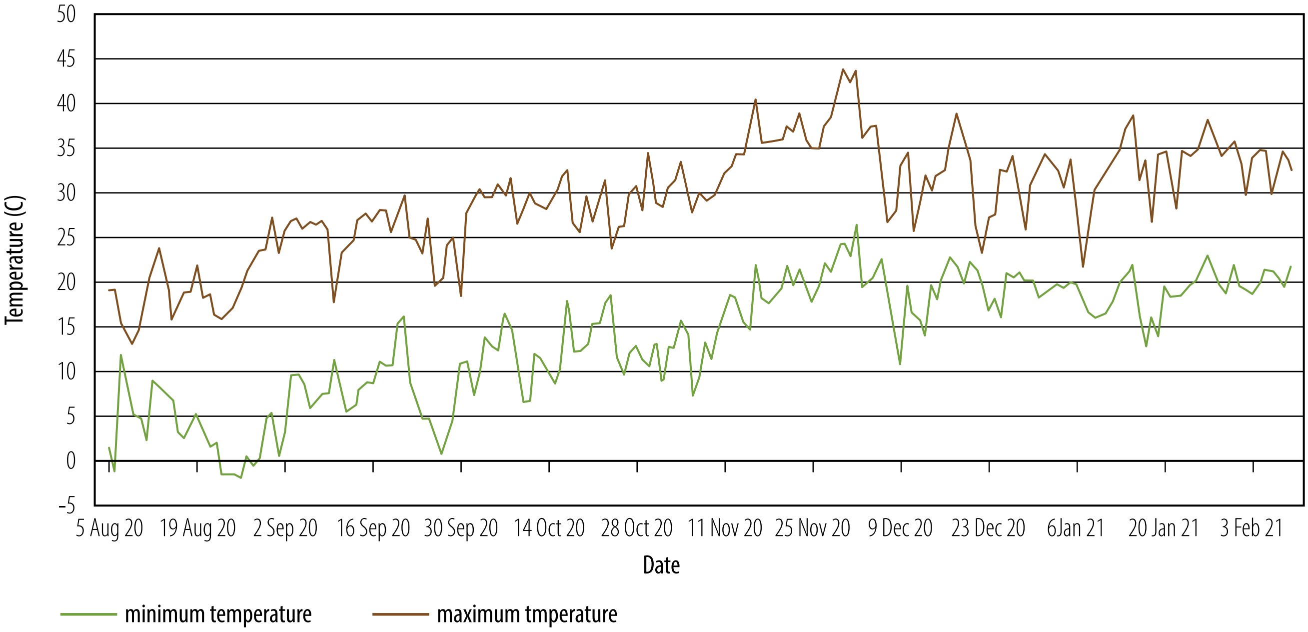

Figure 2 Maximum and minimum temperatures at Bogamildi Moree during 2020–21.

Experiment design

- Split, split plot design with planting date as the main block, then blocked for plant density.
- Hybrid was randomised.
- Sown on 100 cm solid plant rows.

Fertiliser

43 kg/ha Granulock Z was applied to all plots at planting.

150 kg/ha urea was applied pre plant.

Desiccation and harvest date

- PD1: desiccated 12 January; harvested 28 January 2021.
- PD2: desiccated 12 January; harvested 28 January 2021.
- PD3: desiccated 29 January; harvested 12 February 2021.

Treatments

Planting date and soil temperatures

- PD1: 5 August; soil temperatures 10.5 °C at 8 am for the seven days after planting.
- PD2: 2 September; soil temperatures 15.4 °C at 8 am for the seven days after planting.
- PD3: 28 September; soil temperatures 17.0 °C at 8 am for the seven days after planting.

Hybrids (8)

MR Buster, MR Apollo, MR Taurus, G33, HGS114, Cracka, Agitator, A66

Target plant populations (4)

- 3 plants/m^2 (30,000 plants/ha)
- 6 plants/m^2 (60,000 plants/ha)
- 9 plants/m^2 (90,000 plants/ha)
- 12 plants/m^2 (120,000 plants/ha)

Results

Plant establishment

The planting date, hybrid and target population affected the plant density established. The four target plant populations of 3, 6, 9 and 12 plants/m^2 were not achieved from PD1. The target populations were achieved for PD2 and PD3 when averaged across hybrids (Table 3).

The first planting date was sown into good moisture and plants counted weekly from 31 August–28 September to record emergence over time. A week of cold weather from 23–28 August reduced temperatures to just below zero. This was the only period of potential frost damage during the season. Plants emerged slowly from PD1 due to the cool soil temperatures: 10.5 °C for the seven days post planting. PD2 and PD3 had a more even, and quicker establishment.

Comparing the final plant populations from the three planting dates shows that all target populations established significantly more plants/m^2 in PD2 and PD3 than PD1 (Figure 3). There was no difference between PD2 and PD3 (Table 3).

The uniformity of the plant stand in PD1 was also variable, resulting in large gaps between plants. This was particularly evident at the lowest target population of 3 plants/m^2.

Table 3 Effects of planting date on establishment (plants/m^2) averaged across hybrids.

Target plant population (plants/m^2)	Sorghum establishment (plants/m^2)		
	PD1	PD2	PD3
3	1.2^{g}	3.1^{ef}	2.8^{f}
6	2.5^{f}	6.4^{d}	6.8^{d}
9	3.3^{ef}	9.4^{bc}	8.3^{c}
12	4.4^{e}	11.4^{a}	10.5^{ab}

Letters indicate significance at $P = 0.05$. Letters indicate significant difference between treatments.

The interaction between planting date and hybrid affected plant establishment. Averaged across plant populations, most hybrids failed to establish 50% of their targeted population at PD1. Cracka was the exception reaching just over 50%. PD1 and PD2 had vastly improved plant establishment for all hybrids when compared with PD1 (Table 4). All planting populations were sown using an expectation of 80% establishment. Any hybrids that achieved greater than 100% of the target population has achieved an establishment exceeding 80%.

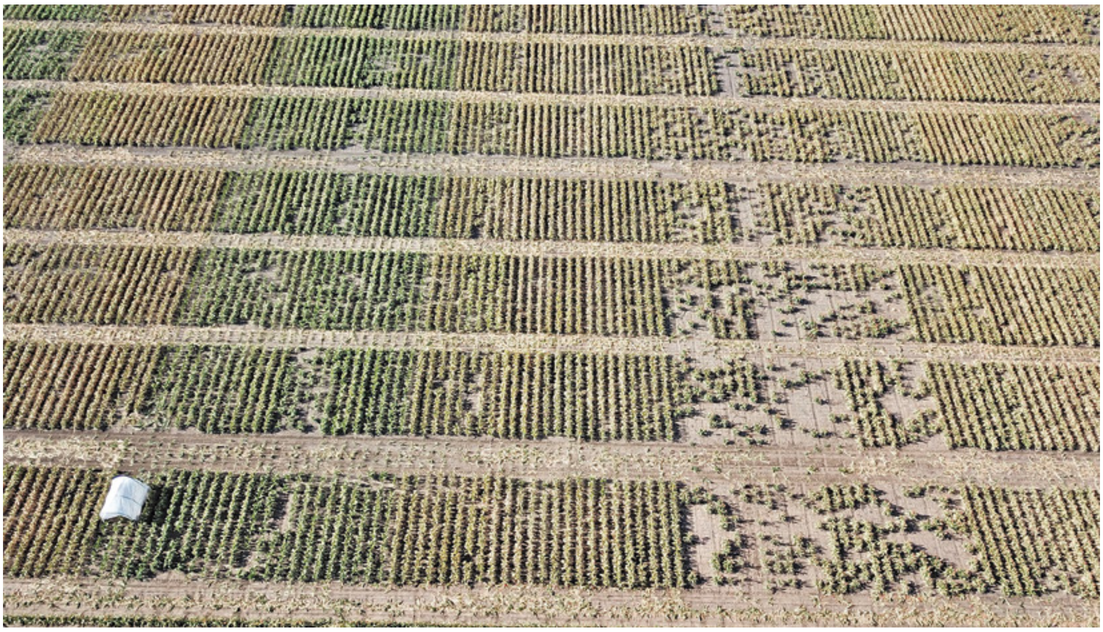

Figure 3 Low population plots from PD1 resulting in patchy establishment.

Table 4 Effect of planting date on hybrid establishment % compared with the target population (averaged across populations).

Hybrid/planting date	Establishment (% of target population)		
	PD1	PD2	PD3
MR Buster	33.16 ^{ijk}	114.58 ^{ab}	98.38 ^{cde}
MR Bazley	21.93 ^{kl}	114.81 ^{ab}	103.59 ^{bcd}
Sentinel IG	29.57 ^{jk}	116.49 ^{ab}	118.63 ^{a}
G33	42.55 ^{hi}	111.75 ^{abc}	97.97 ^{cde}
A66	24.42 ^{kl}	87.15 ^{ef}	69.44 ^{g}
Cracka	50.98 ^{h}	94.68 ^{def}	80.38 ^{fg}
HGS114	17.77 ^{l}	101.45 ^{cd}	104.63 ^{bcd}
Agitator	40.39 ^{hij}	99.77 ^{d}	99.25 ^{cde}

Letters indicate significant difference between treatments ($P = 0.05$).

Tiller production

The total tiller production increased as the planting date moved later this season. The number of fertile tillers (i.e., contained any amount of grain) was significantly higher from PD3 at 14.8/m^2 compared with PD1 and PD2, which averaged 4.8 m/^{2} and 2.9 /m^2 respectively. The number of fertile tillers increased as plant population increased.

Hybrids varied in their production of fertile tillers (Table 5). Data comparing fertile tiller production, averaged across planting dates and populations, shows that high tillering hybrids such as MR Buster and MR Bazley had high fertile tiller numbers. In contrast, a low tillering hybrid such as Agitator, had fewer fertile tillers and total head numbers, but had a similar number of primary heads. There were also differences in the number of fertile tillers each hybrid produced (Table 5).

Head production

Planting date, plant population and hybrid all affected the number of heads produced. More heads were produced from the later planting dates. The differences between PD3 and the two previous planting dates were significant, most likely as a result of PD3 benefiting from the rain events in December and January which occurred too late in the season to benefit PD 1 and PD 2.

As the established plant population increased, so did the number of primary heads. The lowest numbers were produced by A66 and HGS114, while G33 produced the most (Table 3), however, there was no significant difference between G33 and several other hybrids. The total number of heads produced showed a similar trend. PD3 produced the highest number of heads/m^2. Similarly, the number of heads produced rose as the plant population increased (data not shown).

Table 5 Hybrid differences in fertile tillers and head production/m^2 across planting dates and plant populations.

Hybrid	**Number of fertile tillers (tillers/m^2)**	**Total number of heads (head/m^2)**	**Number of primary heads (heads/m^2)**
MR Buster	7.986 ^{ab}	14.09 ^{abc}	6.108 ^{ab}
MR Bazley	9.211 ^{a}	15.14 ^{a}	5.924 ^{abc}
Sentinel IG	7.896 ^{abc}	13.89 ^{abc}	6.008 ^{abc}
G33	8.033 ^{ab}	14.36 ^{ab}	6.342 ^{a}
A66	7.516 ^{bcd}	12.37 ^{cd}	4.853 ^{d}
Cracka	7.085 ^{bcd}	12.68 ^{bcd}	5.597 ^{bc}
HGS114	6.321 ^{cd}	11.67 ^{d}	5.379 ^{cd}
Agitator	6.112 ^{d}	11.76 ^{d}	5.980 ^{abc}

Letters indicate significant difference between treatments ($P = 0.05$).

Days to 50% flowering

Planting, population and hybrid significantly affected the number of days taken to reach 50% flowering. Planting date had the largest effect on days to flowering – the earlier the PD the more days required to reach flowering. PD1 took an average of 97 days to reach 50% flowering. This reduced to 73 days for PD2 and 62 days for PD3. Delaying planting from PD1 to PD2; a period of four weeks; reduced the time to 50% flowering by 24 days. The difference between PD2 and PD3 was smaller, at 11 days even with a four week difference in planting date (Figure 4).

Planting date influenced differences in maturity between hybrids. For the earlier planting dates, these differences were smaller between hybrids. At PD1, the slowest hybrid to reach 50% flowering was Sentinel IG in 98 days, and the quickest was Agitator at 95 days, a spread of only three days between the eight hybrids. PD2 had the largest difference between hybrids at seven days; with HGS114 flowering in 77 days and MR Bazley flowering in 70 days. PD 3 hybrids flowered between 61days and 65 days.

The effect of different plant populations on flowering time was very small. Increasing plant population resulted in no change, or at most were four days quicker to reach flowering (Figure 4).

The earliest planting time, PD1, moved the flowering window for all hybrids forward by around three weeks compared with planting at the recommended soil temperature (PD3). This meant flowering was completed before the onset of very high temperatures at the end of November (Figure 5).

Dry matter production

Dry matter (DM) production varied depending on the planting date and plant population. Sentinel IG produced the highest DM at 6.12 t/ha. Agitator produced less dry matter than all other hybrids except G33 and MR Bazley, otherwise the differences were insignificant (data not shown)

PD3 averaged 6.6 t/ha DM/ha, which was significantly higher than 5.8 t/ha for PD2 and 5.0 t/ha for PD1. The population of 12 plants/m^2 produced the most biomass and 3 plants/m^2 the least showing that as plant population increased, so did DM production. The difference between the 6 and 9 plants/m^2 was not significant.

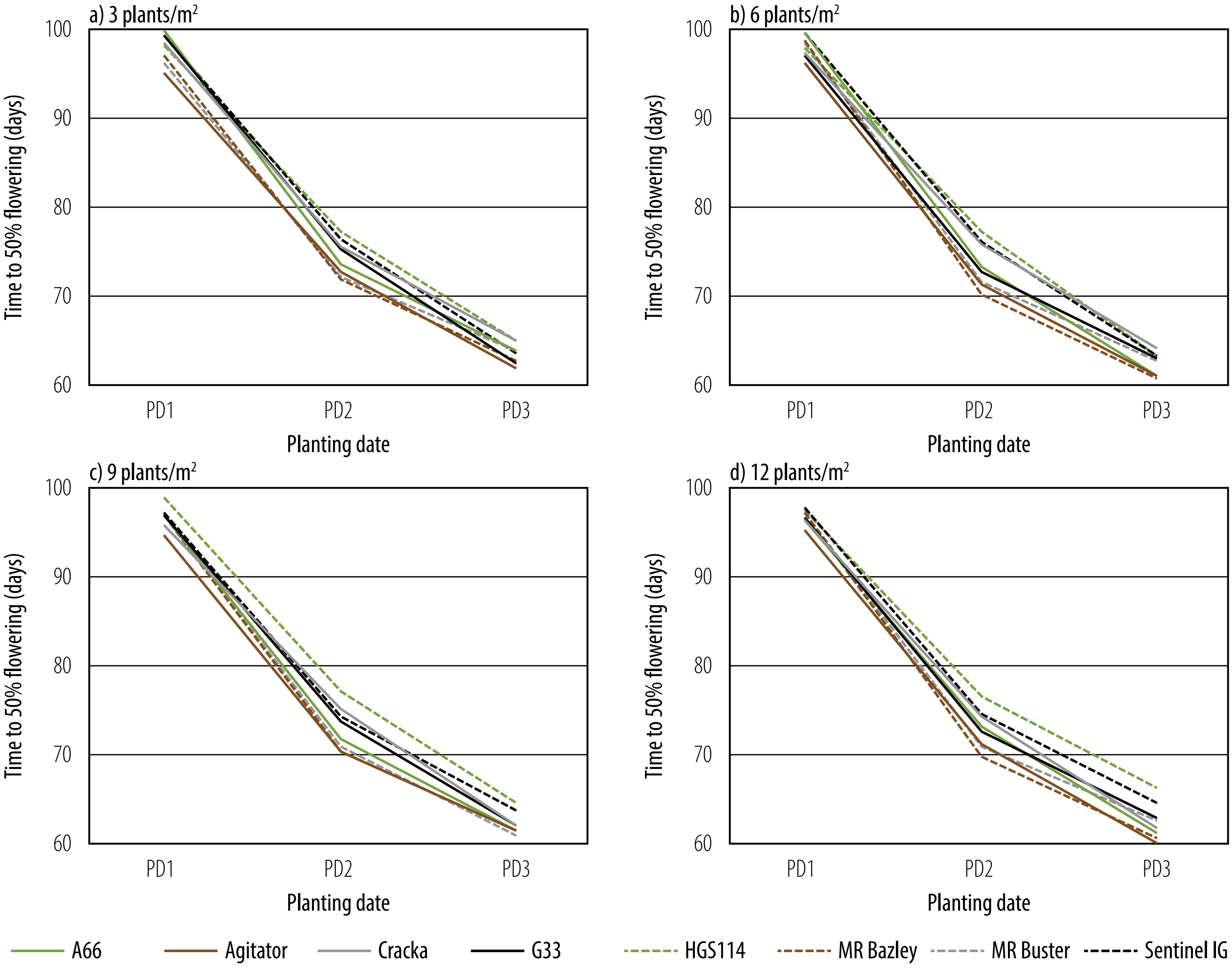

Figure 4 Days to 50% flowering for each hybrid at a) 3 plants/m², b) 6 plants/m², c) 9 plants/m², d) 12 plants/m² for three planting dates (PD).

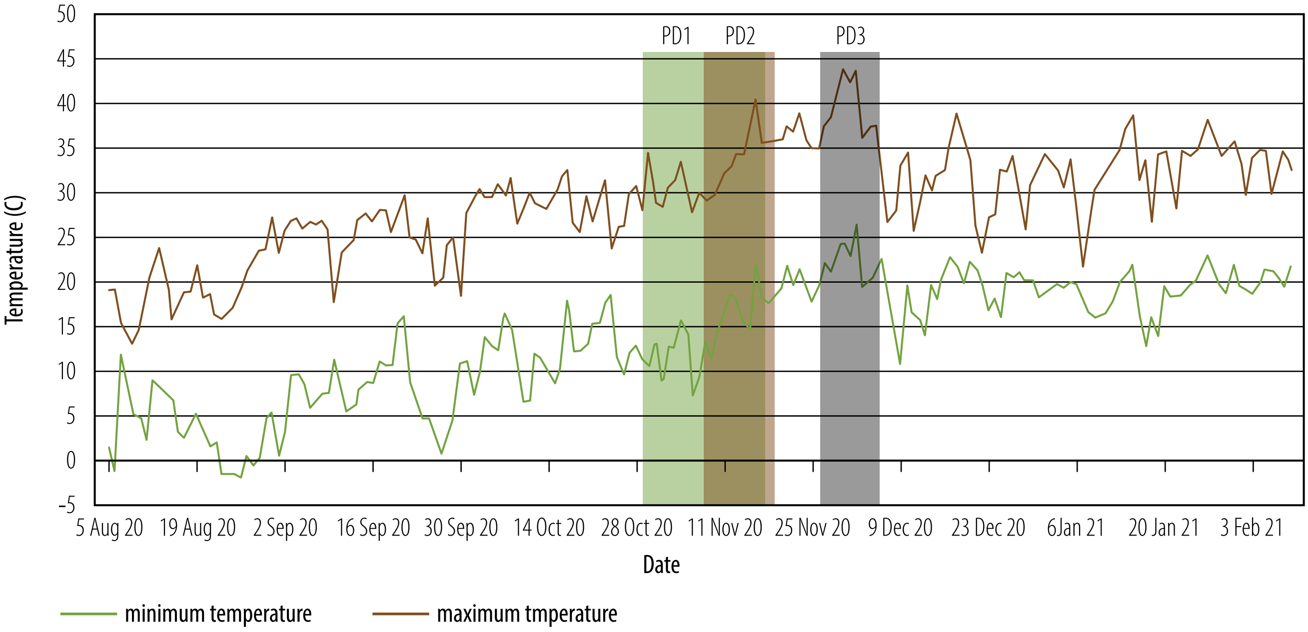

Figure 5 The window of flowering (shaded) for PD1, 2 and 3 at Bogamildi Moree 2020–21.

Harvest index

Harvest index (HI) is used as a measure of efficiency within the plant. The ratio compares the amount of grain against the amount of biomass produced. In this study, plants were partitioned into primary and tiller stems for each sample and then heads were removed and threshed to obtain the HI. Samples were partitioned to compare the contribution of primary heads vs tillers to final grain yield.

The HI of the primary stems was quite variable, ranging from 54.6% down to 14% across the three planting dates. Hybrid responses were consistent over the different planting dates. MR Buster and MR Bazley had a high HI while Cracka, Agitator and Sentinel IG had the lowest HI (Figure 6).

Similarly, the HI for tiller stems was variable between hybrids. The differences were only significant in PD1 and PD2 with MR Bazley producing the highest and Cracka producing the lowest. Planting date had a large effect on tiller HI with PD1 averaging 37.7% followed by PD2 at 16.2% and PD3 at 2.6%. All hybrids produced low tiller HI at PD3 (Figure 6).

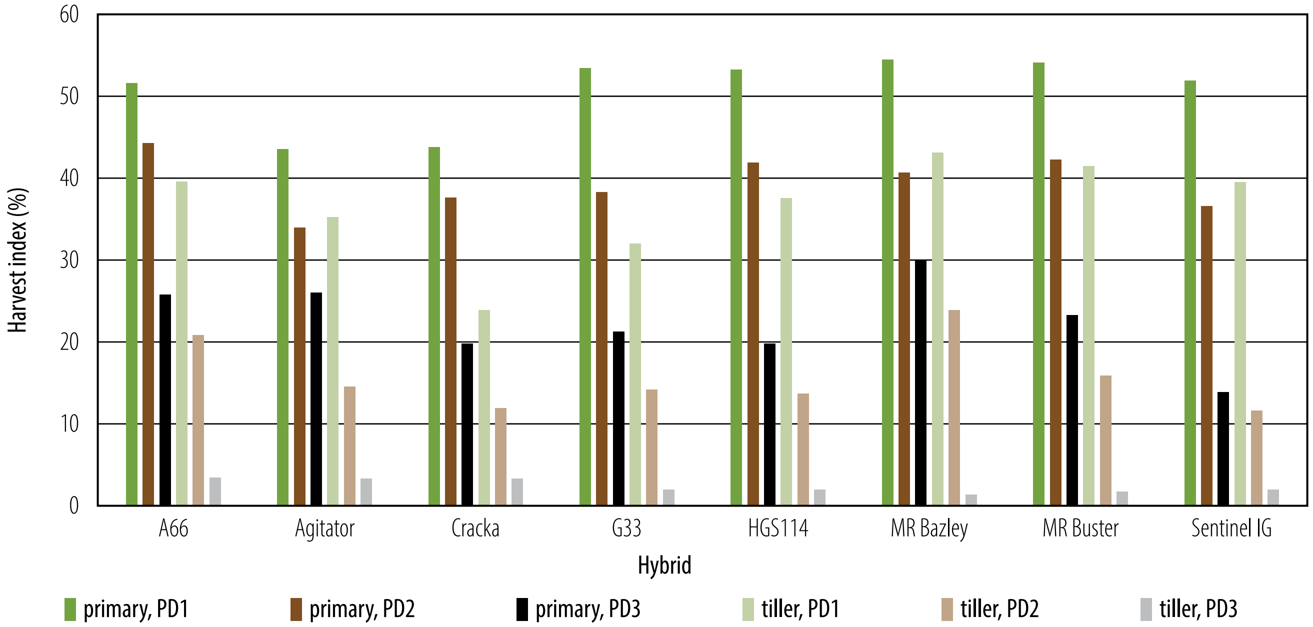

Figure 6 Harvest index of primary and tiller stems at of hybrids planted on three dates (averaged across plant populations).

Grain yield

The site mean yield was 1.4 t/ha at Bogamildi in 2020–21. Grain yields for PD2 were affected by the heat wave at the end of November and PD3 was particularly affected by mouse damage. This damage was scored and used as a co-variate in analysing the yield date. The mouse damage ranged from quite minor at around 10% up to 95%. Some hybrids seemed to be more affected, such as HGS114 and Cracka at 63–65% mouse damage, while MR Bazley was one of the least affected hybrids overall. This effect was most likely correlated to hybrid maturity as well as proximity to the edge of the experiment.

There was a significant interaction between planting date, hybrid and plant population (Figure 7), with grain yields declining as planting date was delayed. PD1 yielded more than PD2 or PD3. There was a trend for yields to decrease as plant population increased, however, this was not consistent across hybrids or planting dates. PD2 showed the most consistent response to plant population.

The hybrids performed differently across different planting dares. Overall, the most consistent was MR Bazley, averaging 1.69 t/ha across planting dates. There was less difference in hybrid yields from PD2 and PD3 as yields lowered. PD1 had the greatest difference in yields of the hybrids, with MR Bazley at 2.83 t/ha, Sentinel IG at 2.86 t/ha, A66 at 2.56 t/ha, HGS114 at 2.60 t/ha.

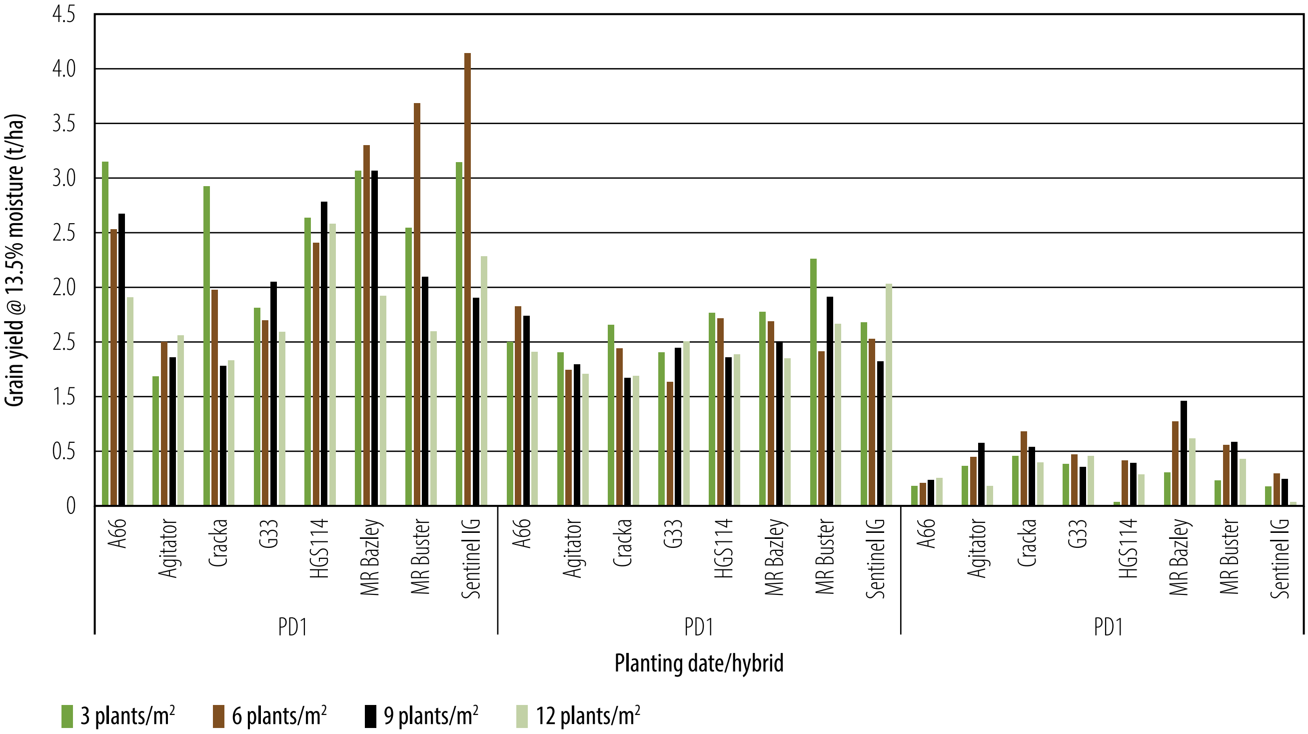

Figure 7 Grain yield at Bogamildi at 13.5% moisture in 2020–21.

Grain quality

Grain protein

Grain protein (GP) was significantly less at PD1 (11.28%) compared with PD2 or PD3 at 11.88% and 11.9% respectively. GP varied across hybrids; HGS114 produced the lowest GP at 11.46%, A66 the highest at 11.9% with a range of <0.5% across hybrids (data not shown).

The primary interest in grain protein in sorghum is as an indicator of nitrogen deficiency, which limits yield. There is not a receival standard for protein in sorghum as it is primarily sold to the feed market.

Test weight

Test weights were generally low this season and screenings were high. Only Cracka, MR Bazley, HGS114 and G33 at PD3 achieved the required test weight to be classified as Grade 1 sorghum (>71 kg/hL) (data not shown). There was an interaction between planting date and plant population, with PD3 producing higher test weights. It was also most common for the lowest plant population 3 plants/m^2, to produce the highest test weight for each planting date.

Screenings

Planting date, population and hybrid (data not shown) affected screening percentages. PD3 had significantly lower screenings at 8% compared with PD1 at 13.7% and PD2 at 28.9%. Hybrid interactions were also significant, with MR Bazley averaging the lowest screenings at 13.3% while G33 and MR Buster had the highest between 19–22%. Based on these levels, only PD3 would have been accepted as Sorghum 1 grade as the maximum screenings level is 11%. PD1 would have fallen into Sorghum 2, which has a maximum level of 25%.

Plant population also affected screenings, with the lowest population of 3 plants/m^2 producing 13.4% screenings compared with 19.8% at the 12 plants/m^2 population. This is an inverse relationship to test weight; lower populations resulting in lower screenings.

Thousand grain weight

The interaction between planting date, plant population and hybrid significantly affected the thousand grain weight (TGW). The TGW was significantly heavier at PD3 than either of the other planting dates. Sentinel IG produced the highest TGW at 24.1 grams while G33 averaged the lowest at 19.3 grams (data not shown).

Conclusions

Planting grain sorghum from early August is a viable option at Moree, but could result in slow, patchy emergence due to high variability in soil temperatures, commonly less than 12 °C, over the seven days after planting.

Planting in late August and early September (PD2) provided rapid, even plant establishment, while moving the flowering window significantly earlier than waiting for the recommended soil temperatures of late September (PD3).

Grain yields were optimised from PD1 in this experiment, even with a reduced plant establishment, compared with PD2 and PD3. The PD1 and PD2 harvesting date was also two weeks earlier than PD3, which means the fallow period was able to start sooner than usual.

Planting date had a significant affect on flowering time. The flowering window was moved forward by around three weeks for all hybrids from PD1, compared with planting at the recommended soil temperature (PD3). This meant that flowering for PD1 was completed before the heat wave at the end of November, which reduced yields primarily for PD2 sown at the beginning of September.

Planting earlier also means it takes longer for hybrids to reach 50% flowering. For example, for PD1, the hybrids flowered between 95–98 days after planting. For PD2, the range was 70–77 days and for PD3 the range was 61–65 days.

Grain quality affects from varying planting date were the opposite to grain yields. Overall, the PD3 grain quality was improved for protein, screenings and TGW. Lower plant populations also produced higher test weights and lower screenings % in this season.

The combined benefits of earlier flowering time, improved grain yields and earlier harvesting, which have resulted from the earlier planting dates, have continued to outweigh the risk of reduced plant establishment in this series of experiments.

The 2021–22 season will present an opportunity to further investigate the effect of earlier planting dates on other plant traits such as in-crop water use.

Acknowledgements

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Spring soybean evaluation, Grafton, NSW 2020–21

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Key findings

- The highest yield (5.79 t/ha) was produced by variety Gwydir⟑ from the earliest planting date (PD1, 8 September 2020).
- Richmond⟑ and Gwydir⟑ were the highest yielding varieties across three spring planting dates (PD1: 8 September, PD2: 13 October, PD3: 13 November).
- Burrinjuck⟑ and Moonbi⟑ produced the lowest yields across all planting dates.
- The southern NSW variety, Burrinjuck⟑, showed susceptibility to powdery mildew in the northern NSW environment and low pre-harvest weathering tolerance, which led to grain quality downgrading.
- Maturity of the varieties in PD1 ranged from 118 days to 163 days, with harvesting ranging from 4 January to 18 February 2021 respectively.
- The risk factors for soybean crops planted 4–8 weeks before the commencement of the traditional coastal planting window include: inadequate soil moisture to establish dryland crops; slower germination and emergence due to cold soil temperatures; early incursions of insect pests particularly pod sucking bugs and the potential for leaf diseases such as powdery mildew or soybean leaf rust to develop during cooler spring conditions.

Introduction

The Australian Soybean Breeding Program (ASBP) conducts field evaluation of new breeding lines of soybean (*Glycine max*) to improve profitability of the diverse farming systems and production regions of northern New South Wales (NSW), including the North Coast, Northern Tablelands and Slopes. Development of varieties to suit a wider range of planting windows is a high priority for the program.

In 2019, a group of growers and agronomists representing Soy Australia visited the mid-west cropping region of the United States of America (USA) to learn from American growers and identify opportunities to improve the Australian industry. An obvious difference was that crops were planted in early spring into cooler soil temperatures in the mid-west of USA compared with northern NSW where the crop is traditionally planted from late spring (November) to late summer (February) when soil temperatures are much higher (>16oC).

On 8 September 2020, an experiment was established at the NSW DPI Grafton Primary Industries Institute (GPII) to evaluate five varieties of soybean for suitability to early spring plantings (three dates) in a coastal environment. Included were three commercial standard varieties and two unreleased lines from the ASBP with early maturity (T171A-2, subsequently released as Gwydir⟑ in 2021 and NK94B-25, which has not been released).

Site details

Location	NSW DPI, Grafton Primary Industries Institute, Experiment Farm Road, Grafton, NSW 2460. Latitude 29°37′16.0″ S, Longitude 152°56′58.5″ E

Paddock history	• Laser levelled in 2017–2018 and converted to raised beds. • Controlled traffic system with furrows at 1.8 m centres and plantable bed top width of 1.5 m. • 2019: triticale. • 2019-20: soybean. • 2020: triticale.
Soil type and nutrition	Deep alluvial loam. Soil analysis is presented in Table 1.
Rainfall and temperature for summer 2019-20	A total of 880 mm of rainfall was received during the growing season, predominantly from December to March, which was above the long-term monthly average (Figure 1). The remaining months of the season were below average rainfall. In 2020, the rainfall total for August was below average. To enable the first planting date, 15 mm of water was applied to the site in late August using overhead irrigation.
Experimental design	• Five varieties and four replicates • Randomised, complete block design. • To enable timely harvesting, each planting date was blocked.
Fertiliser	• 130 kg/ha of sulphate of potash was broadcast three weeks before to planting • 280 kg/ha of superphosphate with molybdenum was applied at planting
Target plant population	The recommended plant population for traditional early December sowing in coastal NSW was used for PD3 (NSW DPI Summer Crop Management Guide 2019, Table 2). This was adjusted down for PD2 and PD1 to minimise the potential risk of lodging due to excessive vegetative growth at earlier planting dates (Table 2).
Weed management	1L/ha Crucial® (540 g/L glyphosate), 1 L/ha Dual Gold® (960 g/L S-Metalochlor) and 140 g/ha Spinnaker® (700 g/kg imazthepyr) applied post-plant, pre-emergence at each planting date.
Insect management	• 200 mL/100 kg seed Legion® (500 g/L fipronyl) applied to seed, targeting Lucerne crown borer (*Zygrita diva*) • 250 mL/ha Shield® (200 g/L clothianidin) applied on 2 December, targeting green vegetable bug (*Nezara viridula*) and large brown bean bug (*Riptortus serripes*). • 1.5 L/ha Lannate L® (225 g/L methomyl) applied on 7 December, targeting vegetable bug (*Nezara viridula*) and large brown bean bug (*Riptortus serripes*). • 2.5 L/ha Decis®Options (50 g/L deltamethrin) with 0.5% common salt (NaCl) adjuvant applied on 5 January, targeting redbanded shield bug (*Piezodorus oceanicus*).
Disease management	350 mL/ha Folicur®430SC (430 g/L tebuconazole) applied on 10 November 2020, to manage soybean leaf rust.

Harvest date	Varieties were harvested when mature ranging from early January to April 2020.

Table 1 Soil chemical analysis of the experiment site at NSW DPI Grafton, NSW.

Characteristic/analyte	Unit	Soil depth 0–20 cm
pH_{Ca}	pH units	4.3
pH_{Water}	pH units	5.2
Electrical conductivity	dS/m	0.119
Sulfur (KCl40 test)	mg/kg	14.0
Phosphorus (Bray test)	mg/kg	40.0
Phosphorus (Colwell test)	mg/kg	132.0
Phosphorus Buffer Index		142.5
Organic carbon	%	1.1
KCl extractable ammonium-N	mg/kg	7.8
KCl extractable nitrate-N	mg/kg	36.1
Total nitrogen	%	0.2
Chloride	mg/kg	27.0
Boron	mg/kg	0.6
DTPA Cu	mg/kg	1.9
DTPA Zn	mg/kg	7.5
DTPA Mn	mg/kg	67.3
DTPA Fe	mg/kg	127.5
Exchangeable aluminium	cmol(+)/kg	0.8
Aluminium saturation	%	8.3
Exchangeable calcium	cmol(+)/kg	7.8
Exchangeable calcium	%	64.0
Exchangeable potassium	cmol(+)/kg	0.6
Exchangeable potassium	%	5.2
Exchangeable magnesium	cmol(+)/kg	2.5
Exchangeable magnesium	%	20.8
Exchangeable sodium	cmol(+)/kg	0.2
Exchangeable sodium	%	1.7
Cation exchange capacity	cmol(+)/kg	11.9
Calcium:magnesium		3:1

Table 2 Target plant populations for soybean varieties included in the experiment.

Variety	Target plant population (plants established/ha)		
	PD1: 8 Sept	P2: 13 Oct	PD3: 13 Nov
Burrinjuck	320,000	360,000	400,000
Moonbi	320,000	360,000	400,000
Gwydir	280,000	320,000	360,000
NK94B-25	280,000	320,000	360,000
Richmond	280,000	320,000	360,000

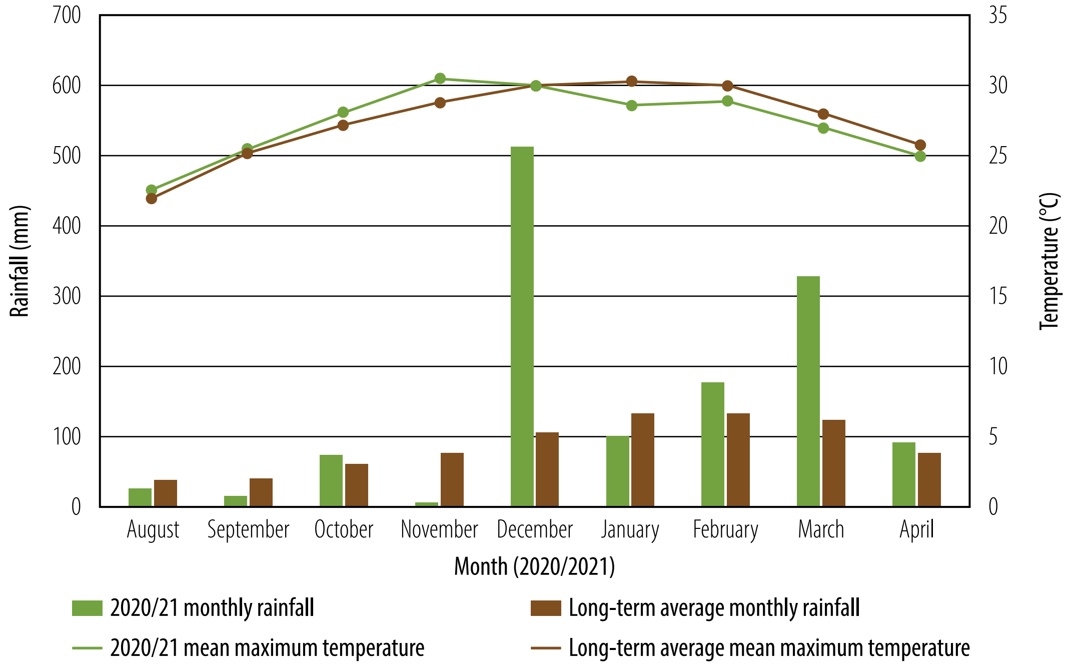

Figure 1 Rainfall and temperature for summer 2020-21 compared with long term averages at NSW DPI Grafton.

Treatments

Varieties

The five varieties in this experiment were chosen for the reasons described in Table 3.

Planting dates

- PD1: 8 September
- PD2: 13 October
- PD3: 13 November 2020.

Table 3 Soybean varieties included in the experiment.

Variety	Traits and reason for inclusion
Burrinjuckᶲ	Southern NSW variety preferred for irrigated production in the Riverina with high yield potential and high grain quality (protein and seed size). Included in this experiment due to anticipated faster maturity when moved north of its zone of adaptation, unknown yield potential, maturity and disease susceptibility in northern NSW.
Gwydirᶲ (line T171A-2)	Recently (2021) released variety for northern NSW (northern slopes and coastal production regions), high yield potential and grain quality (grain protein concentration and large seed size). First variety released for NSW with resistance to soybean leaf rust. High tolerance to lodging.
Moonbiᶲ	Suited to early planting dates in NSW coast, tablelands, Liverpool Plains and Central West regions. Fast maturing with high tolerance to lodging.
NK94B-25	Unreleased line from the ASBP, high yield potential for summer planting dates in coastal NSW, average seed size and protein, average weathering tolerance, high tolerance to lodging. Included in this experiment to test potential for high yield at early planting dates.
Richmondᶲ	Suited to early-mid planting dates in NSW coast and slopes regions, high yield potential, high tolerance to pre-harvest weathering and lodging, and high grain quality (protein and seed size).

Results

Observations of crop growth and maturity

Slower emergence was observed for the earlier planting sowing dates of PD1 and PD2, compared with traditional December plantings. Even plant populations were achieved, and no seedling diseases were observed.

The time taken from planting to reach flowering (F50 stage) is presented in Table 4 and the time required from planting to reach physiological maturity (P95) is presented in Table 5. Data from the ASBP early variety evaluation, which was sown in the same field adjacent to the spring soybean experiment on the 8 of December 2020, has been included in Tables 4 and 5 for comparison.

Planting dates were four to five weeks apart, however, the critical maturity stages were not reached in a proportionately separated time frame.

For example, Richmond$^{(D)}$ took 57 days (PD1) to reach flowering (Table 4) and 155 days to reach physiological maturity (Table 5). At a traditional planting date of early December (3 months later than PD1), Richmond$^{(D)}$ took 53 days to reach flowering and 135 days to reach maturity (i.e. four days less to reach F50 and 20 days less to reach P95).

No lodging due to excessive vegetative growth or longer time spent in the field compared with traditional early December planting dates was observed.

Days from planting to reach P95 are presented in Table 5.

Table 4 Days after planting (DAP) to reach F50 (50% of plants with opened flowers) compared with F50 data from traditional early December planting date.

Variety	Time to reach F50 (days after planting)			
	PD1: 8 Sep	PD2: 13 Oct	PD3: 8 Jan	ASBP[a]: 8 Dec
Burrinjuck	46	46	46	38
Gwydir	55	46	51	53
Moonbi	56	51	49	45
NK94B-25	57	54	54	51
Richmond	57	54	54	53

[a] Australian Soybean Breeding Program data from the early variety evaluation conducted in the same field, adjacent to the spring planting experiment, N. Moore, pers. comm.

Table 5 Days after planting (DAP) and date to reach P95 compared with P95 data from traditional early December planting date.

Variety	Time to reach F95 (days after planting, date)							
	PD1: 8 Sep		PD2: 13 Oct		PD3: 13 Nov		ASBP[a]: 8 Dec	
Burrinjuck	118	4 Jan	118	8 Feb	122	21 Mar	124	10 Apr
Moonbi	148	3 Feb	148	10 Mar	137	26 Mar	128	14 Apr
NK94B-25	163	18 Feb	162	24 Mar	150	4 Apr	140	26 Apr
Richmond	155	10 Feb	156	18 Mar	140	2 Apr	135	21 Apr
Gwydir	157	12 Feb	160	22 Mar	143	2 Apr	135	21 Apr

[a] Australian Soybean Breeding Program data from the early variety evaluation in the same field, adjacent to the spring planting experiment, N. Moore, pers. comm.

Grain yield

- The data was analysed using ANOVA (Table 6). Differences between results that exceed the estimate of least significant difference (l.s.d.) can be regarded as statistically significant at the 5% critical value ($P<0.05$).
- Gwydir$^{(D)}$ produced the highest yield (5.79 t/ha) from PD1 followed by Richmond$^{(D)}$ at 5.22 t/ha from PD2 (Table 6).
- Richmond$^{(D)}$ is an industry standard for large seed size, high protein and high yield potential at the traditional early planting window (late November to early December).

Table 6 Yield of spring soybean evaluation for 3 planting dates, NSW DPI Grafton, 2020-2021.

Variety	Yield (t/ha)[b]		
	PD1: 8 Sep	PD2: 13 Oct	PD3: 13 Nov
Gwydir	5.79	4.24	4.67
Richmond	5.01	5.22	4.18
NK94B-25	5.01	4.59	4.13
Moonbi	3.97	4.13	3.10
Burrinjuck	3.29	3.54	2.14
l.s.d. ($P<0.05$)	0.58	0.89	0.64

[b] Grain yield is expressed at 12% moisture

Conclusions

Varieties with potential for spring planting

The locally adapted varieties Gwydir⍉ and Richmond⍉ produced the highest yields in this experiment, demonstrating that they are suitable for consideration for spring planting on the NSW North Coast. This experiment did not investigate variable plant populations or crop configuration, which is required to optimise yield and minimise lodging in this environment with high growth potential.

The unreleased line NK94B-25 produced yield similar to Richmond⍉ at all planting dates, but it will not be released by the ASBP as it does not have the high level of tolerance to pre-harvest weathering and large seed size possessed by Richmond⍉.

The variety Burrinjuck⍉ is an industry benchmark in southern NSW, but in this environment it was the lowest yielding, and showed susceptibility to powdery mildew and pre-harvest weathering damage. It was included in this experiment to assess potential as an early maturing variety for spring-planting. Whilst it was faster to mature than the other varieties, its susceptibility to powdery mildew and pre-harvest weathering make it unsuitable for northern NSW.

Risk factors

Growers must consider risk factors when contemplating spring planted soybean crops. A soil temperature of 13°C rising is recommended for optimum soybean germination, as soybean is not frost tolerant. September is traditionally the driest month of the year in north eastern NSW, therefore, having adequate soil moisture available at planting in non-irrigated (dryland) crops is critical. A full soil moisture profile is recommended for soybean planting (100-120 cm of wet soil is ideal). This is not always available in double cropping systems on the north coast, however, in-crop rainfall usually compensates.

Other risks include September frost events; early incursions of insect pests particularly *Helicoverpa* and pod-sucking bugs and, the development of leaf diseases, such as powdery mildew and soybean leaf rust due to cooler temperatures earlier in the crop cycle.

Excessive vegetative growth during favourable conditions can lead to lodging, however, this problem was not observed in this experiment this season.

In this experiment repeated incursions of the pod-sucking pests green vegetable bug (*Nezara viridula*) and large brown bean bug (*Riptortus serripes*) required two pesticide treatments for control. An incursion of redbanded shield bug (*Piezodorus oceanicus*) also required pesticide control. Isolated, early-sown soybean crops in the region may attract insect pests earlier as they reach the flowering and pod-filling stages sooner than the surrounding summer-sown crops. If not controlled, these pests could present a risk to yield and quality and may also impact surrounding crops later in the season.

A higher frequency of weathered seed was observed in the PD1 samples. This may have been due to the warmer conditions experienced in February as pods were maturing and drying down compared with the cooler conditions experienced in April, when traditional summer-sown crops are maturing.

Additional investigations are required to determine if this was an isolated seasonal effect or if it could be a major constraint to spring planted crops in this environment.

Opportunity for coastal sugar cane systems

Richmond$^{\phi}$ and Gwydir$^{\phi}$ from PD1 reached P95 on the 10 and 12 of February 2021 respectively. As soybean crops can be planted in February in coastal NSW farming systems, the results of this experiment suggest that coastal sugar cane farming systems in NSW may have the opportunity to complete a spring-planted soybean crop followed by a second soybean crop if appropriate varieties are used. Soybean variety Hayman is proven to produce yield and quality grain at late summer (i.e. February) planting dates in coastal NSW. The harvest date for late planted soybean crops is around mid-June, which fits the sugar cane planting window (>September). In near coastal environments the risk of frosts in June is usually low, however, frost risk must be considered as soybean is not frost tolerant.

Due to the multi-year nature of the sugar cane phase that follows a soybean rotation crop, the risk of building up diseases and insect pests such as lucerne crown borer in the soybean phase is anticipated to be low, however, experimental validation for this concept is required.

Reference

Serafin L, Hertel K and Moore N 2019. Summer Crop Management Guide, NSW Department of Primary Industries [online] [Accessed 29 November 2021]

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Soybean variety evaluation, Grafton, NSW 2019–20

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Key findings

- The late 23 January sowing date and low rainfall during pod-fill affected crop growth.
- The variety HaymanA performed well in the experiment maturing 126 days after planting (DAP) and yielding 3.95 t/ha. It had a large seed size (24.5 g/100 seed), high protein (45.9% dry matter basis (DMB)), a weathering tolerance of 66.9% unweathered grain and a low lodging score (1.2).
- The yield of the variety New Bunya HB1$^{\Phi}$ was statistically equivalent to the variety Hayman$^{\Phi}$, however, its low weathering tolerance of 56% unweathered grain is a concern for coastal soybean production.
- None of the breeding lines evaluated in this experiment produced yield significantly higher than Hayman$^{\Phi}$, however, 12 lines produced a yield that was statistically similar.
- The breeding lines 19-7 and 19-58 have potential for high yield and weathering tolerance equivalent to current commercial varieties. These lines will be advanced to future evaluations.

Introduction

The Australian Soybean Breeding Program (ASBP) field evaluates new soybean (Glycine max) breeding lines to assess suitability to the diverse farming systems and production regions of northern New South Wales (NSW), including the north coast, Northern Tablelands and slopes.

Lines are evaluated for yield potential and other traits that confer superior agronomic performance and profitability, including tolerance to diseases and lodging, maturity, and tolerance to pre-harvest weathering damage. Grain protein and oil concentrations, and seed size are also assessed. Advanced lines are included in experiments on a range of sowing dates from mid November to late January. This report presents the results of the late (23 January) sowing date variety evaluation from the 2019–20 summer.

Site details

Location	NSW DPI, Grafton Primary Industries Institute, Experiment Farm Road, Grafton, NSW (Latitude 29°62′53.77″ S, Longitude 152° 96′09.75″ E). Paddock 19A: 29°37′16.0S 152°56′58.5E.
Paddock history	The experiment site was cropped to Bogong triticale in winter 2019 and soybean in summer 2018–19. This paddock was converted to a raised bed, controlled traffic farming system in 2017. The beds have furrows at 1.8 m centres and a plantable bed top width of 1.5 m, on which four rows of soybean are planted on 30 cm row spacings.
Soil type and nutrition	Deep red loam. Soil analysis is presented in Table 1.

Table 1 Site soil chemical characteristics for 0–10 cm depth.

Soil measurement and unit	Value (highest)	Value (lowest)
Soil pH (1:5 water)	5.92	5.45
Sulphate sulfur (mg/kg)	17	16
Nitrate nitrogen (mg/kg)	57	55
Ammonium nitrogen (mg/kg)	0.6	1
Phosphorus (mg/kg) [Bray 1 test][a]	3.3	3.8
Phosphorus (mg/kg) [Bray 2 test][a]	6.3	7.4
Phosphorus (mg/kg) [Colwell P test]	19	21
Potassium (%)	7.3	7.4
Calcium (mg/kg)	1084	873
Magnesium (%)	10.9	14.1
Sodium (mg/kg)	16	<15
Aluminium (mg/kg)	<1	<1
Electrical conductivity (dS/m)	0.107	0.097
Effective cation exchange capacity (ECEC) (cmol+/kg)	6.75	5.72
Zinc (mg/kg)	0.8	1
Copper (mg/kg)	0.8	0.8
Iron (mg/kg)	42	53
Manganese (mg/kg)	96	99
Silicon (mg/kg)	37	35
Boron (mg/kg)	0.51	0.54

[a] Bray 1 and Bray 2 analyses use different concentrations of ammonium fluoride extractant to give an estimation of P reserves in the soil.

Rainfall and temperature for summer 2019–20

A total of 880 mm of rainfall was received during the growing season, predominantly during the months of January and February, which were above the long-term average (Figure 1). The remaining months of the growing season were below average rainfall. Growing degree days (GDD) (using a base of 10) for this experiment totalled 2306. (The base number when referring to GDD, is the plant's optimal base temperature e.g. winter crops have base five and many summer plants are base 10).

Experiment design

- 36 entries.
- Four replicates in a randomised, complete block design.
- Plot size was four rows wide and eight metre long.

Sowing date

23 January, 2020.

Fertiliser

- 130 kg/ha of sulphate of potash applied on 1 December.
- 280 kg/ha of superphosphate with molybdenum applied at planting.

Plant population

The target plant population was 45 plants/m^2, which is recommended for later sowing dates in this location. The result was 42 plants/m^2 for most plots, except for three breeding lines, which has been accounted for in spatial analysis of the data.

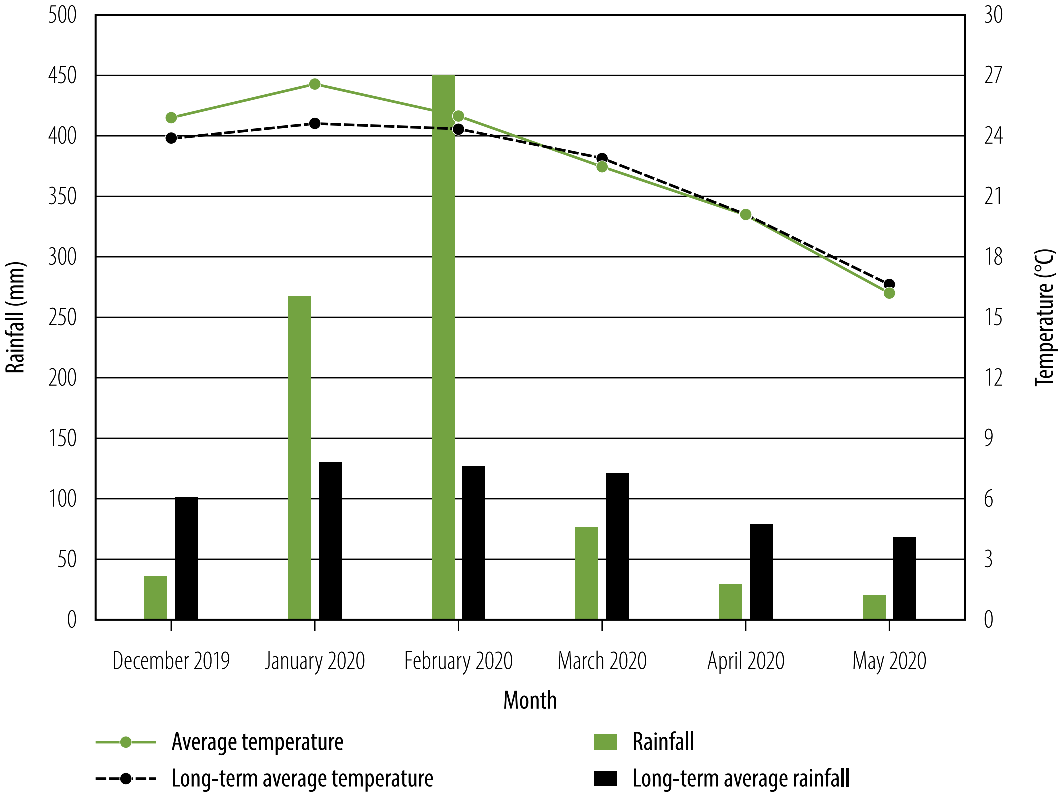


Figure 1 Monthly total rainfall and monthly average temperature for summer 2019–20 and long-term averages at NSW DPI Grafton.

Weed management	Pre plant knockdown: Roundup® 2 L/ha (540 g/l glyphosate) + Terrain® 30 g/ha (500 g/kg flumioxazin) applied 20 December 2019. Pre emergence: Roundup® 500 ml/ha (540 g/l glyphosate) + Dual Gold® 1 L/ha (960 g/L S-metolachlor) + Spinnaker® 140 g/ha (700 g/kg imazethapyr) applied on 24 January 2020.
Insect management	Targeting *Zygrita diva:* Legion® 200 ml/100 kg seed (500 g/L fipronil) applied 23 January 2020. Targeting *Helicoverpa* spp.: ViVus Max® 150 mL/ha (5 × 109 polyhedral inclusion bodies of the nucleopolyhedrovirus of *Helicoverpa armigera* per millilitre) applied 1 February and 11 February 2020 Targeting *Nezara viridula* and *Melanacanthus margineguttatus*: Shield® 250 mL/ha (200 g/L clothianidin) applied 3 March. Targeting *Nezara viridula* and *Melanacanthus margineguttatus*: Lannate L® 1.5 L/ha (225 g/L methomyl) applied 24 April 2020. Targeting *Nezara viridula* and *Melanacanthus margineguttatus*: Decis® 0.5 L/ha (50 g/L deltamethrin) applied 6 May 2020
Disease management	Targeting soybean leaf rust: Folicur® 350 mL/ha (430 g/L tebuconazole) applied 6 May 2020.
Harvest date	Each variety was harvested when mature from mid May to mid June, 2020.

Treatment

Varieties (36)

Thirty breeding lines from the ASBP were advanced from experiments in previous seasons based on maturity suited to the late planting widow for this region (January) and yield. Six commercial varieties were included in the experiment as benchmarks for various traits. For example, A6785 is a benchmark for small seed size, low grain protein levels and high yield potential. Hayman$^{\phi}$ is an industry benchmark for large seed size, high grain protein levels and high yield potential with January sowing dates.

Results

Analysed data

The data were analysed by Stephen Morris (Biometrician, NSW DPI Wollongbar) using spatial analysis with an ASReml package (Butler et al. 2017) in the R environment (R Development Core Team 2017). Differences between results that exceed the estimate of least significant difference (l.s.d.) can be regarded as statistically significant at the 5% critical value ($P<0.05$).

In this experiment, 13 varieties, including Hayman$^{\phi}$, produced significantly higher yield than the other varieties (l.s.d. 0.33 t/ha). The analysed data are presented in Table 2 and in Figure 1, with the industry standards highlighted in red (Hayman$^{\phi}$ and A6785).

The 13 highest yielding varieties in this experiment all produced grain protein of >40% DMB, which is the critical industry receival standard for soybean.

In relation to weathering tolerance, lines 19-102, New Bunya HB1$^{\phi}$ and T1834-2 have low levels, equivalent to the variety Warrigal, which is the low benchmark for this trait (50% unweathered grain). Weathering tolerance data are presented in Figure 2 with the industry benchmark for this trait highlighted in red (variety Zeus is the high benchmark for this trait).

Lodging is a measure of a plant's ability to remain upright. The lodging score applied to this experiment is measured on a 1 to 5 scale where 1 is erect and 5 is flat (Table 2).

Table 2 Analysed data of soybean breeding line evaluation 2019-20, NSW DPI Grafton. Data are ranked for yield.

	Variety	Yield (t/ha)[a]	Maturity (DAP)[b]	Plant height (cm)	Protein (% DMB)[c]	Oil (% DMB)[c]	Seed size (g/100 seed)	Seed size (# seed/kg)	Weathering tolerance (%)[d]	Lodging[e]
1	19-102	3.98	136	78.8	43.3	19.5	25.8	3880	53.7	2.4
2	19-58	3.98	137	75.5	44.3	18.2	30.5	3282	79.3	2.4
3	HaymanΦ	3.95	126	95.3	45.9	18.3	24.5	4077	66.9	1.6
4	New Bunya HB1Φ	3.86	129	76.0	45.9	17.5	24.0	4161	56.0	1.9
5	16-181	3.83	139	96.0	42.7	19.0	19.7	5068	69.7	3.3
6	19-7	3.83	114	65.4	44.7	18.1	20.8	4801	79.4	1.4
7	19-160	3.82	131	87.4	42.6	19.6	24.4	4098	63.2	2.3
8	19-123	3.78	118	58.8	44.2	18.2	22.7	4405	68.1	1.9
9	19-78	3.78	134	83.3	44.4	18.7	26.3	3807	71.8	2.0
10	T1834-2	3.76	127	60.5	45.4	18.1	27.8	3596	49.9	1.8
11	Warrigal	3.74	127	70.2	44.0	19.1	22.7	4415	50.0	2.6
12	19-54	3.73	135	82.9	44.3	17.9	27.6	3628	65.8	2.5
13	T075-7	3.73	131	71.0	44.1	18.8	21.2	4708	62.2	1.9
14	16-149	3.64	137	94.4	44.4	18.2	19.7	5086	61.9	3.7
15	18-15	3.64	137	95.1	43.0	19.3	25.4	3940	65.9	2.7
16	19-30	3.63	127	72.4	43.0	19.5	22.1	4523	61.5	2.3
17	19-51	3.62	128	77.1	44.9	18.0	24.0	4165	75.4	2.4
18	19-64	3.62	137	82.0	44.1	18.2	25.2	3976	66.0	2.3
19	19-169	3.58	135	70.7	40.9	19.6	26.6	3765	65.0	2.6
20	16-135	3.57	135	90.0	44.5	18.6	19.9	5015	58.4	3.3
21	19-55	3.56	137	73.5	44.3	18.6	26.7	3740	74.3	2.4
22	19-12	3.53	136	91.1	43.5	19.0	22.5	4450	63.8	3.5
23	A6785	3.53	126	73.2	43.2	19.6	16.4	6083	60.0	2.9
24	19-113	3.48	135	77.6	42.5	19.7	22.5	4437	60.4	2.7
25	Zeus	3.47	108	63.7	44.7	19.0	24.2	4137	76.8	1.0
26	19-117	3.46	133	70.7	43.7	18.9	24.7	4055	58.7	2.6
27	19-101	3.45	138	94.2	44.6	18.1	28.1	3556	65.8	2.3
28	19-39	3.43	134	82.7	44.4	18.9	25.3	3960	46.7	2.7
29	19-99	3.42	131	81.9	43.7	19.3	26.2	3818	78.8	2.2
30	19-166	3.37	141	91.0	43.5	19.1	29.5	3386	77.3	2.9
31	19-46	3.23	133	91.4	45.7	17.8	22.0	4554	65.8	3.3
32	19-116	3.22	126	80.9	43.2	18.9	26.4	3784	51.3	2.5
33	18-9	3.02	136	98.6	43.3	19.1	23.0	4346	53.9	3.3
34	19-31	2.99	135	87.5	43.2	19.3	20.4	4912	49.4	3.5
35	19-45	2.7	136	84.9	44.9	18.3	22.5	4437	50.1	3.8
36	Burrinjuck	2.28	108	59.9	46.4	18.4	22.1	4535	43.5	1.1
	se	0.12	1	3.5	0.4	0.2	0.4		1.2	0.3
	l.s.d. ($P<0.05$)	0.33	4	9.5	1.0	0.6	1.2		3.3	0.7

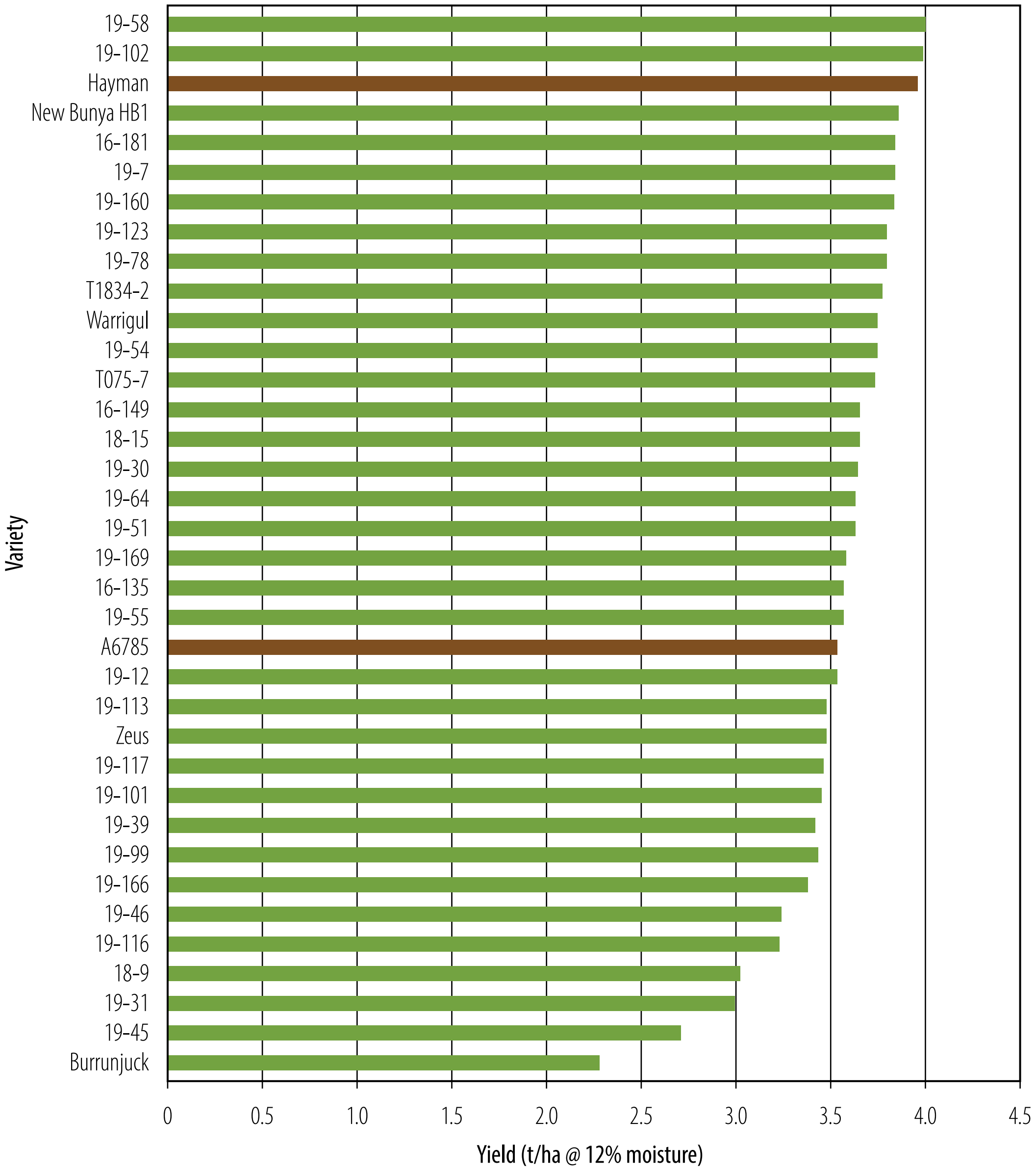
[a] Grain yield is expressed at 12% moisture

[b] Maturity is expressed as days after planting to reach the P95 stage of physiological maturity for soybean, where 95 % of the pods are at full maturity.

[c] Grain protein and oil concentrations are expressed as % DMB

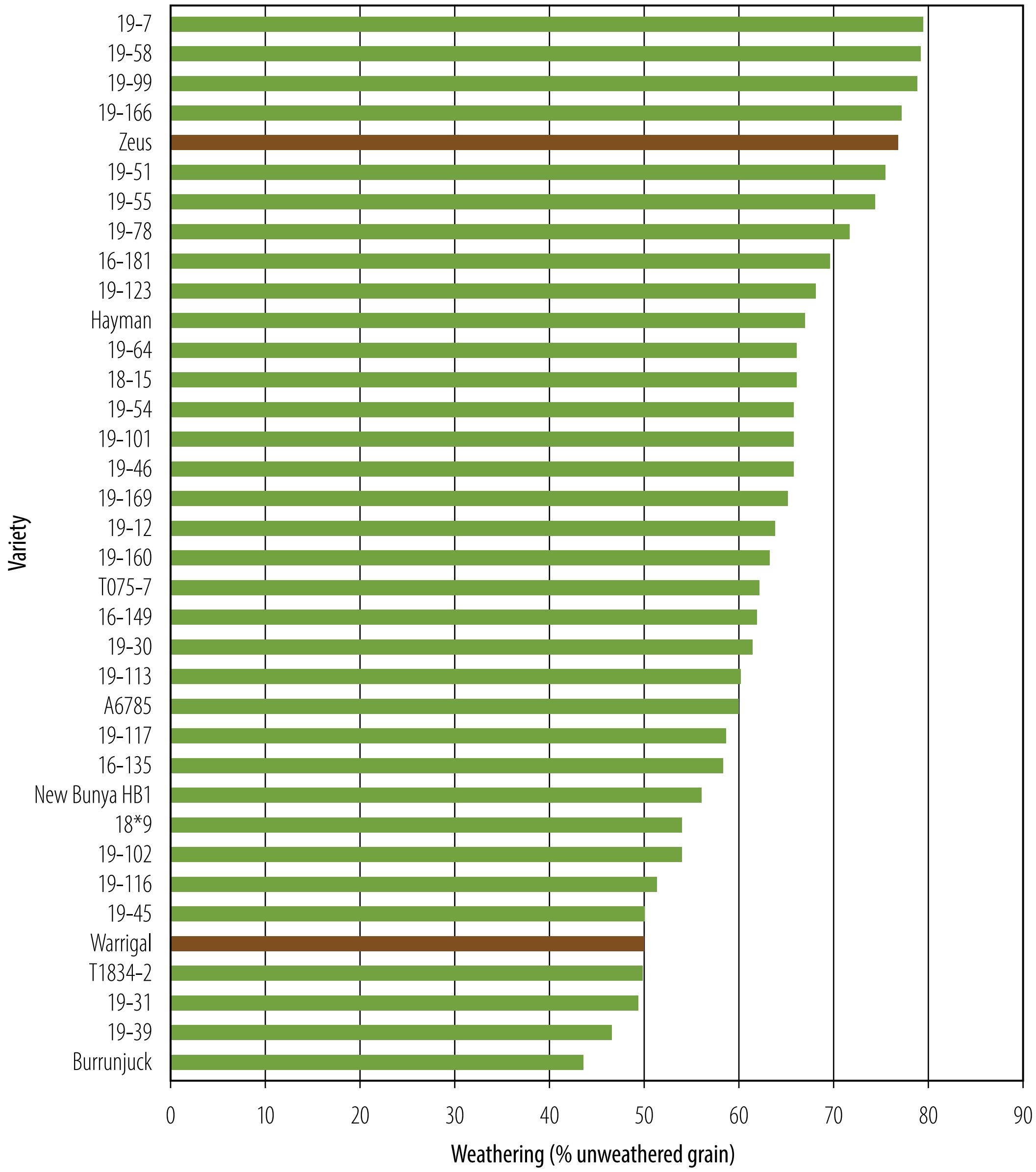
[d] Weathering tolerance is expressed as % unweathered grain

[e] Lodging: 1 = erect; 5 = flat



l.s.d. ($P<0.05$) = 0.33 t/ha

Figure 2 Grain yield of 36 soybean varieties in a variety evaluation at Grafton NSW. Industry benchmark varieties for high yield at a January sowing date (Hayman$^{\Phi}$ and A6785) are highlighted in brown.



l.s.d. ($P<0.05$) = 3.28%

Figure 3 Weathering tolerance of 36 soybean varieties sown at Grafton NSW. Industry benchmark varieties for high (Zeus) and low (Warrigal) weathering tolerance are highlighted in brown.

Conclusions

The late planting date and low rainfall during pod fill was a good test for the breeding lines. In these conditions the variety Hayman$^{\phi}$ performed well, maturing 126 days after planting and yielding 3.95 t/ha with large seed size (24.5 g/100 seed), high protein (45.9 % DMB), an acceptable level of weathering tolerance (66.9 % unweathered grain) and a low lodging score (1.2 out of 5). None of the breeding lines evaluated in this experiment produced significantly higher yield than Hayman$^{\phi}$, however, 12 other lines had a statistically similar yield to Hayman$^{\phi}$.

New Bunya HB1$^{\phi}$, a variety released in 2020 for Queensland, yielded 3.86 t/ha, which is statistically similar to Hayman$^{\phi}$. A concern is the variety's low weathering tolerance rating, which was anticipated due to the known low weathering tolerance of its parent variety Bunya. The low weathering tolerance of New Bunya HB1$^{\phi}$ is a risk for growers in coastal production regions where heavy rain at harvest time is common and can reduce grain quality and yield.

Breeding lines 19-7 and 19-58 will be advanced for future evaluation due to high yield and weathering tolerance. Lines 19-51, 19-55 and 19-99 will also be further evaluated due to their very high levels of weathering tolerance, a critical trait for crop security in coastal production regions.

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Crop protection

Seed treatment efficacy on aphids in pulse crops

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Key findings

- Blue green aphids (BGA, *Acyrthosiphum kondoi*) did not establish colonies on faba bean or chickpea, indicating that these are not its primary hosts.
- Cowpea aphid (CPA, *Aphis craccivora*) had the highest number of live adults (41.8) and nymphs (181) in faba bean plants among the three aphid species tested
- Pea aphid (PA, *Acyrthosiphum pisum*) showed the fastest multiplication rate in both of the host plants and reached the highest mean number of nymphs (58) on the untreated chickpea.
- CPA and PA adult counts were reduced on chickpea and faba bean plants grown from imidacloprid treated seed three, seven and 14 days after infestation (DAI).

Introduction

Aphids are known as destructive pests, especially if infestation occurs shortly after emergence. They can reproduce extremely quickly and can cause severe feeding damage, especially in favourable weather conditions. Dense aphid colonies cause loss of vigour, leaf deformation, yellowing and wilting in sensitive young plants. The aphid honeydew deposits encourage saprophytic fungi growth. However, more than direct feeding damage, aphids can damage crops by transmitting a range of viruses.

In chickpea and faba bean there are several aphid-transmitted viruses that are major problems, such as *Bean leafroll virus* (BLRV) and *Alfalfa mosaic virus* (AMV). The key aphid species important as virus vectors in pulses in Northern NSW (NNSW) are CPA, PA BGA and the GPA (IPM guidelines, 2017). In autumn these aphids often attack the terminal shoots in young seedlings and can start to form colonies in the crop. Weekly monitoring during the emergence phase is important to decide whether an aphicide application to control spread is needed. Economic thresholds have been developed for several crops, including faba bean, but are not established for chickpea. The recommendation for faba bean is to control low aphid levels to prevent virus transmission (Hertel et al., 2013).

Management control options depend on the level of infestation, crop growth stage, the presence of natural enemies or predators, and weather conditions. Among insecticides available, growers often use seed treatment with neonicotinoids (such as imidacloprid) as a preventive measure and can help to protect crops from sucking insects such as aphids (Shobharani et al., 2017; Hassan et al., 2018; Kirkland et al., 2018; Shehawy and Qari, 2019). To address the lack of data on managing local aphids in pulse crops, the study analysed how effective imidacloprid seed dressing was in faba bean and chickpea, targeting the most common aphid species in these crops in northern NSW.

Methodology

Aphid colonies

Pea aphid and CPA colonies were maintained in 2020 on both faba bean (cv. Fiord) and chickpea (PBA HatTrick$^{\phi}$) plants in entomological cages under glasshouse, temperature-controlled conditions at Tamworth Agricultural Institute (TAI). The BGA colonies were raised on lucerne (cv. Hunter River) since neither faba bean nor chickpea were suitable hosts.

Plants

Treated and untreated seeds were sown in pots containing standard potting mix. An application rate of 1.2 ml/1 kg of seed of Gaucho 600® (600 g/L imidacloprid) was used. Tests were conducted on detached plant parts placed in 0.5% water agar in plastic boxes. For faba bean, the stem was cut under the top two leaves when the plants had three leaves unfolded (2–3 weeks after sowing). For chickpea, the plants were cut close to the ground when the fourth multifoliate leaf was unfolded. Ten adult aphids were placed on to the plant after which the boxes were covered with aphid-proof mesh. The experiment design was a randomised complete block with four boxes as replicates.

Data analysis

On days one, three, seven and 14 DAI, live aphid adult and nymphs were counted. The effect of host plant and seed treatment on aphid survival and progeny production were examined using R statistical program (R Core Team, 2020). Henderson-Tilton's formula was used to calculate the percentage efficacy of seed treatment against adult aphids:

$$\% \text{ control} = \left(1 - \frac{\text{n in Co starting population} \times \text{n in T 1,3,7,14 DAI}}{\text{n in Co 1,3,7,14 DAI} \times \text{n in T starting population}}\right) \times 100$$

n = adult aphid numbers, T = treated, Co = untreated.

Results

Blue green aphid can be found on various legume plants with lucerne its main host. Faba bean and especially chickpea appear to be less suitable as hosts as adult numbers dropped down rapidly on both untreated and treated plants (Figure 1).

Both CPA and PA persisted and reproduced on untreated faba bean and chickpea. The highest mean number of live adults (41.8) and nymphs (181) was recorded for CPA on untreated faba bean plants 14 DAI. Pea aphid showed an ability to quickly adapt to new host plants once established and PAs multiplied rapidly to reach the highest mean number of progeny (163) at seven DAI on untreated faba bean (Figure 1). The progeny numbers dropped as a result of overcrowding and insufficient food at 14 DAI. At the same time, CPA and PA numbers were lower on chickpea compared with faba bean, probably because of malic and oxalic acids in leaf exudates. Nevertheless, PAs managed to reproduce on chickpea, reaching the highest mean number of nymphs (58) on untreated chickpea at seven DAI.

Cowpea and pea aphid numbers dropped in response to imidacloprid seed treatment at three, seven and 14 DAI (Figure 1), offering effective aphid control. These results confirmed Shehawy et al.'s results (2019), which found that imidacloprid treated seed reduced CPA numbers by 25.6–66.6% early in the season. This ranged from 33–81% on chickpea and 17–81% on faba bean and the PA results ranged from 39–76% on chickpea and 28–70% on faba bean (Table 1). However, Henderson-Tilton's formula showed low efficacy for both cowpea and pea aphids at one DAI (1–18%) on faba bean and chickpea. These results imply that imidacloprid seed treatment does not provide rapid protection against aphids, so viruliferous (virus-carrying) aphids can still transmit the virus. The seed treatment did not completely stop PA and CPA reproduction, but did reduce the number of adult aphids, suggesting a potential slowdown of later aphid activity.

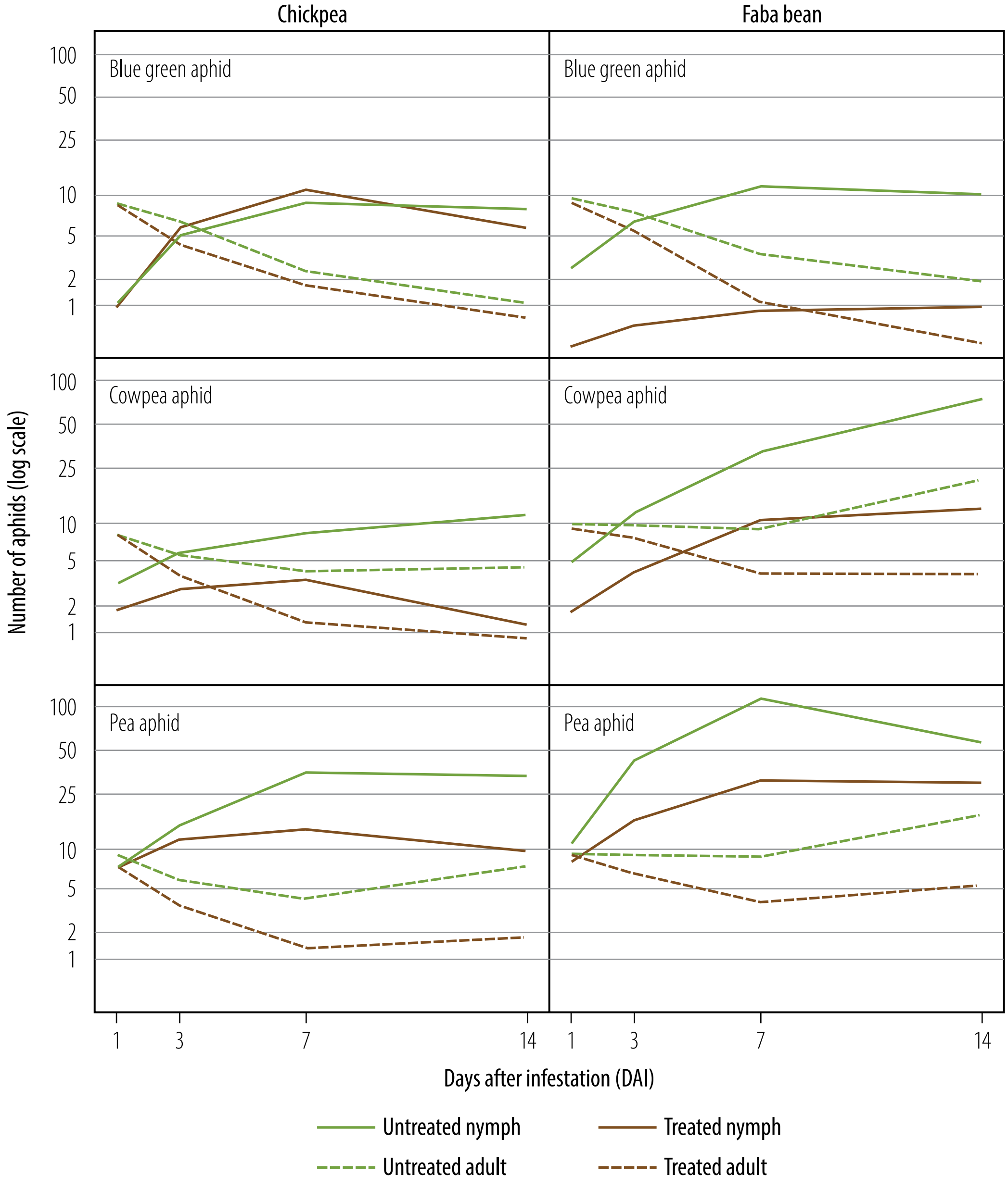

Figure 1 Mean numbers of adults and nymphs of blue green aphid (BGA), cowpea aphid (CPA) and pea aphid (PA) on seed untreated and treated chickpea and faba bean plants, 1, 3, 7 and 14 DAI.

Table 1 Mean number of CPA and PA adults across four replicates and level of control.

Aphid species	**Plant**	**Treatment**	**1 DAI**		**3 DAI**		**7 DAI**		**14 DAI**	
			Mean No	**Control (%)**	**Mean No**	**Control (%)**	**Mean No**	**Control (%)**	**Mean No**	**Control (%)**
Cowpea aphid	Chickpea	Untreated	8.3	-	5.8	33.2	4.3	67.9	4.6	81.0
		Treated	8.6		3.9		1.4		0.9	
	Faba bean	Untreated	10.0	6.2	9.7	17.3	9.3	55.6	21.1	80.8
		Treated	9.4		8.1		4.1		4.1	
Pea aphid	Chickpea	Untreated	9.5	18.4	6.1	39.1	4.3	66.6	7.7	75.7
		Treated	7.7		3.7		1.4		1.9	
	Faba bean	Untreated	9.7	1.2	9.4	28.0	9.1	56.2	18.6	70.5
		Treated	9.6		6.7		4.0		5.5	

Conclusions

In this glasshouse study, imidacloprid seed treatment was effective at three, seven and 14 DAI in reducing CPA and PA numbers, but the treatment was not effective at one DAI. Although it can reduce aphid numbers in the crop and therefore slow virus spread, treatment cannot prevent aphid migration, feeding or probing. Seed treatment could be particularly ineffective in controlling non-persistent viruses, which can be transmitted immediately after a short feed on an infected plant. Further experiments are needed to investigate the effect of seed treatments on aphid numbers in the field and these are planned for next year.

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How wide is the distribution of Russian wheat aphid in northern NSW and is sorghum an alternative summer host?

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Key findings

- Russian wheat aphid (RWA) was found in northern NSW in 2019 in barley, wheat, durum and barley grass. To date, Tamworth is the most northern site where the aphid has been confirmed in Australia.
- Sorghum (Sentinel IG) is an alternative summer host. RWA survival in sorghum in northern NSW depends on climatic conditions. High temperature and humidity can supress RWA survival and reproduction in sorghum.
- Millet (Jandowae) is not a suitable host for RWA.
- Severe symptoms on young sorghum plants include red tips on the leaves and patches at the place of feeding.
- Wheat and barley are the most suitable host and where the highest RWA population developed, followed by oats, sorghum and triticale.
- Typical RWA damage is found on its primary hosts (barley and wheat), while little or no symptoms were observed in its secondary hosts (oats, sorghum, triticale).

Introduction

Russian wheat aphid – *Diuraphis noxia* (Kurdjumov) (Homoptera: Aphididae) is known worldwide as a pest of cereals. It originates from central Asia, the Middle East and southern Russia; its presence has been confirmed across cereal growing regions in Asia, Europe, Africa, North and South America and, since 2016, in Australia (Kindler and Springer, 1989; Hughes, 1996; Yazdani et al., 2018). The RWA's primary hosts are barley, wheat and durum wheat, but it can infect triticale, rye and oats. Its host range also includes winter, and some summer wild grasses.

The RWA is easily distinguishable from other cereal aphids such as the oat aphid (*Rhopalosiphum padi*), corn aphid (*Rhopalosiphum maidis*) and rose-grain aphid (*Metopolophium dirhodum*). RWA is a small, pale green, spindle-shaped aphid, which is often covered with fine wax. It has dark eyes, antennae shorter than half its body length, almost invisible cornicles and an appendage above the cauda giving it the appearance of having two tails (Figure 1).

Figure 1 Russian wheat aphid – *Diuraphis noxia.*

It feeds on plant sap and affects host plants by injecting toxins while probing and feeding. In response, cereal plants start to develop various symptoms including chlorosis, necrosis, wilting, stunting, leaf streaking with whitish, yellow and purple longitudinal leaf markings, and rolled leaves. If probing occurs when the head is being formed, trapped awns or bleached heads could develop, or flowering might not occur (Figure 2).

Figure 2 Developed symptoms (a) leaf strips, rolled leaves; (b) trapped awns.

Wheat and barley are suitable hosts for RWA for a large part of the year. However, wild grasses are also very important for persistence of populations over summer and provide a bridge for cereal infestations over autumn. This study was conducted to identify the distribution of RWA in northern NSW, potential hosts and the possibility of migration, survival and reproduction on sorghum, the major summer cereal grown in the northern region.

Methods

Distribution survey

The distribution survey was carried out on autumn-sown cereals, volunteer crops and winter grasses in order to determine the presence of RWA in northern NSW. Samples collected were: wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), durum wheat (*Triticum durum*), barley grass (*Hordeum leporinum*), prairie grass (*Bromus cathartions*), oats (*Avena sativa*), couch grass (*Cynodon dactylon*), Johnson grass (*Sorghum halepense*), phalaris (*Phalaris aquatica*), liverseed grass (*Urochloa panicoides*), and Queensland blue grass (*Dichanthium sericeum*). Samples were cut at ground level, collected and transported in plastic bags, and placed in Berlese funnels in the laboratory for three to four days. Extracted insects were observed under a stereomicroscope and the results were included in an interactive RWA map (http://www.cesaraustralia.com/sustainable-agriculture/rwa-portal/).

RWA sorghum field study

The preliminary RWA field study was conducted on irrigated paddocks near the Tamworth Agricultural Institute. This was to examine RWA over-summering and reproduction habits on the major summer grains in northern NSW: sorghum (Sentinel IG) and millet (Jandowae). The experiment was set up in summer 2019–2020 under aphid-proof tents, with two replicates. The first inoculation of RWA on both sorghum and millet was at the 3-leaf growth stage. One plant per tent was inoculated with 10 wingless aphids. The second inoculation was at the 5-leaf growth stage.

RWA winter grains field study

The 2020 RWA winter grains study was established to analyse the possible migration of aphids from winter to summer cereals (sorghum). Aphid-proof tents were half sown with wheat (LongReach Lancer$^{\Phi}$) or barley (Commander$^{\Phi}$). The other half of each tent was sown with sorghum (Sentinel IG) at the end of the 2020 winter season, before the wheat and barley were ready to be harvested. At the tillering stage, 10 wheat/barley plants in each tent were infested with 10 wingless RWA. The RWA colonisation and distribution on winter, as well as migration onto summer grain hosts were studied till December 2020.

RWA host preference study

Both the amount of damage and the RWA host preference was investigated in the glasshouse on barley (Commander$^{\Phi}$), wheat (LongReach Lancer$^{\Phi}$), oats (Yiddah$^{\Phi}$, Mannus$^{\Phi}$, Nile), sorghum (Sentinel IG), and triticale (Endeavour$^{\Phi}$). Ten plants from each host were infested with 10 wingless adults. Adults and nymph counts were observed two, seven and 14 days after infestation (DAI).

Results and discussion

Distribution survey

Since the first report of RWA in South Australia in 2016 (Yazdani et al., 2018), it has spread rapidly through the eastern grain belt including South Australia, Victoria, parts of southern New South Wales and Tasmania (Yazdani et al., 2018). The data from 2019 showed that Tamworth was the most northern site where RWA has been confirmed in Australia (Figure 3). Out of 21 collected samples in 2019 there were three positives in barley, one positive in wheat, one positive in durum wheat, and three positives in barley grass. In 2020, 58 cereal and grass samples collected from various sites in the Liverpool Plains showed no positives. The RWA population suppression could be explained by the hot, dry 2019 summer and the lack of an over-summer green bridge. Australia's warmest and driest year on record, 2019, with the dry summer followed by the coolest and wettest autumn in New South Wales since 2012 (BOM, 2020 a, b).

A temperature over 20 °C is unfavourable for RWA and it cannot survive at temperatures over 37 °C. Furthermore, RWA prefers relatively warmer, drier climates, where summer rainfall is 300–400 mm. Heavy rainfall can wash aphids off the upper leaves and 30 mm rainfall can cause 50% mortality (Huges, 1996; GRDC, 2017).

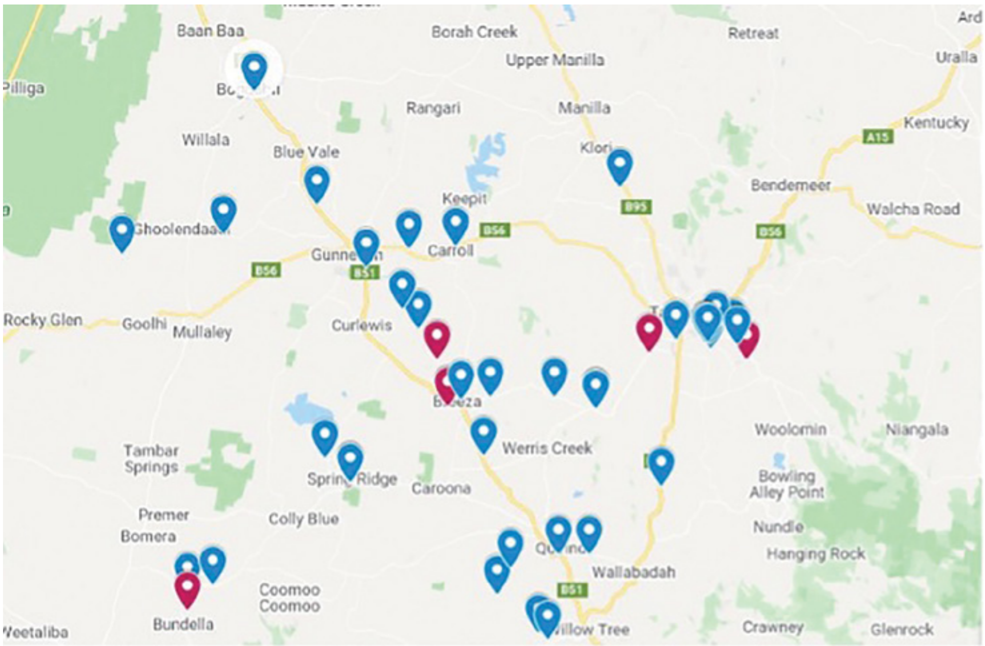

Figure 3 Detail of map of RWA positive (📍) and negative (📍) samples in 2019 and 2020.

RWA sorghum field study

A second inoculation in the field study in December 2019 was successful in establishing RWA in sorghum, but not in millet, which was found to not be a suitable host plant for RWA.

The aphids were initially observed at the inoculation points of the upper side of the sorghum flag leaf, before migrating to the back side of the leaf, mainly next to the central leaf vein (Figure 4) and starting reproduction. During January 2020, aphids migrated to neighbouring leaves in the lower canopy, which was likely to be due to the better protection from high temperatures with a population up to 30 individuals developed on the inoculated tiller. When the sorghum reached the flowering/grain filling stage (end of February 2020), established RWA colonies were observed on three neighbouring plants out of the 10 plants inside the tents. Although no symptoms were observed, this result demonstrates that RWA was able to survive on sorghum plants during the 2019–20 summer. Similarly, Harvey and Kofoid (1993) found three sorghum lines that supported RWA for at least a month. Since RWA is generally found as a minor pest in sorghum, there is a possibility that the aphids would have moved to more favourable host plants in an open field study.

Figure 4 RWA colony on the back side of sorghum leaf.

RWA winter grains field study

An established population of 3–10 adults of RWA was noticed on all infested plants six days after inoculation on 12 June 2020. The first symptoms were observed in 1–3 out of 10 infested barley/wheat plants per tent. The plant response to the RWA toxic secretion was quick and only a small number of RWA aphids can cause symptoms on plants in less than seven days.

The symptoms were characteristic white to purple stripes, and leaf-rolling on both wheat and barley leaves. At 15 DAI, both wingless and winged forms were found in colonies and after 5–7 days additional plants were infested. One month after infestation 30% of plants showed typical symptoms and two months after infestation all plants inside the tents were infested with moderate to high populations. Later symptoms that developed in barley and wheat included stunted growth, trapped awns, and twisted and distorted heads.

By mid September 2020, both barley and wheat became unfavourable hosts due to ripening and, since the majority of RWA dispersal occurs by flying (Hughes, 1996), high numbers of winged aphids were noticed inside the tents. After the sorghum emerged on 13 October, the winged aphids migrated from barley and wheat to the young sorghum plants and started to reproduce. Both winged and wingless aphids with their progeny were observed on the young sorghum plants (Figure 5a). Symptoms such as red tips on the leaves and patches at the place of feeding (Figure 5b) were observed. Similar to that reported by Harvey and Kofoid (1993), the aphids successfully infested and damaged the susceptible sorghum plants.

The aphids first infested the leaf tips and edges, and then moved to the leaf base leaving skins behind. This type of damage could cause plant death in a short time, however, in October 2020 the daily temperatures inside the tent were too hot for RWA development. Temperatures above 40 °C were recorded for two to six hours in both the morning and early afternoon for most of October, with the highest, 53.15 °C, recorded on 21 October. The RWA population on sorghum quickly decreased, as they cannot survive long enough to reproduce at high temperatures. A few surviving individual adults with a small number of progeny were observed on sorghum in a couple of tents at the end of October. No aphids were observed in November and the sorghum plants recovered. However, this result indicates that with favourable conditions, RWA could use sorghum as alternative host in late spring to early summer.

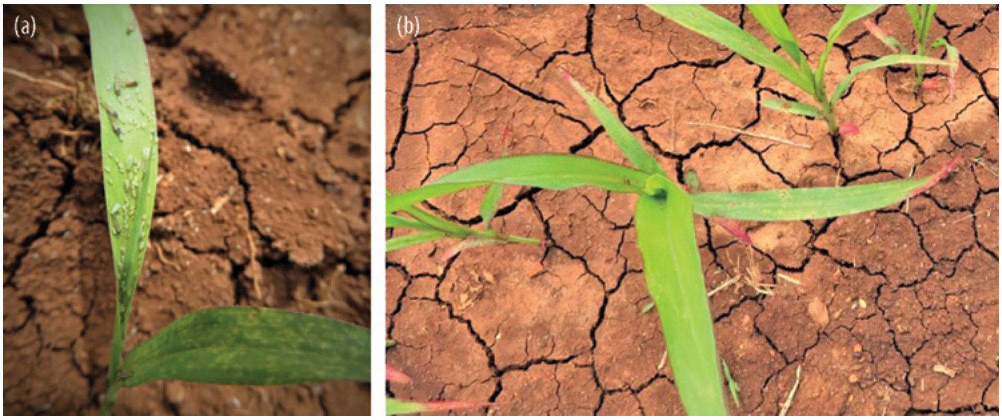

Figure 5 Russian wheat aphid (a) infestation and (b) damage, to young sorghum plant.

RWA host preference study

In the host preference study, at 14 DAI, the best RWA establishment was on wheat, with a mean number of 49 adults and 148 nymphs, and barley with 42 adults and 140 nymphs. The highest number of established aphids on oats was found on variety Yiddah$^{\phi}$ (nine adults and 28 nymphs), followed by Mannus$^{\phi}$ (nine adults and 26 nymphs) and Nile (five adults and 16 nymphs). The lowest numbers were in sorghum (nine adults and nine nymphs) and triticale (four adults and nine nymphs) (Figure 6). Sorghum appeared as one of the least favourable host plants even though RWA did establish on all the plants tested; further studies are required in order to achieve a clearer result.

Symptoms occurred seven DAI on wheat and barley, but not until later on other host plants. At 14 DAI, both barley and wheat leaves were covered with aphids and the leaf skins, and had developed symptoms including yellow stripes and rolling. Plants started wilting, another symptom making winged adults more noticeable. The secondary hosts showed little or no symptoms. The oat leaves had chlorotic, hardly visible yellow lines with the aphids concentrated on leaf tips, on the upper and back side of the leaf. On triticale, the RWA population remained at the base of the young leaves and inside rolled leaves. Yellow stripes were hardly visible. On sorghum, RWA were usually based on the upper side of the leaf. Red patches developed at the place of feeding on the plants where the RWA became established (Figure 7).

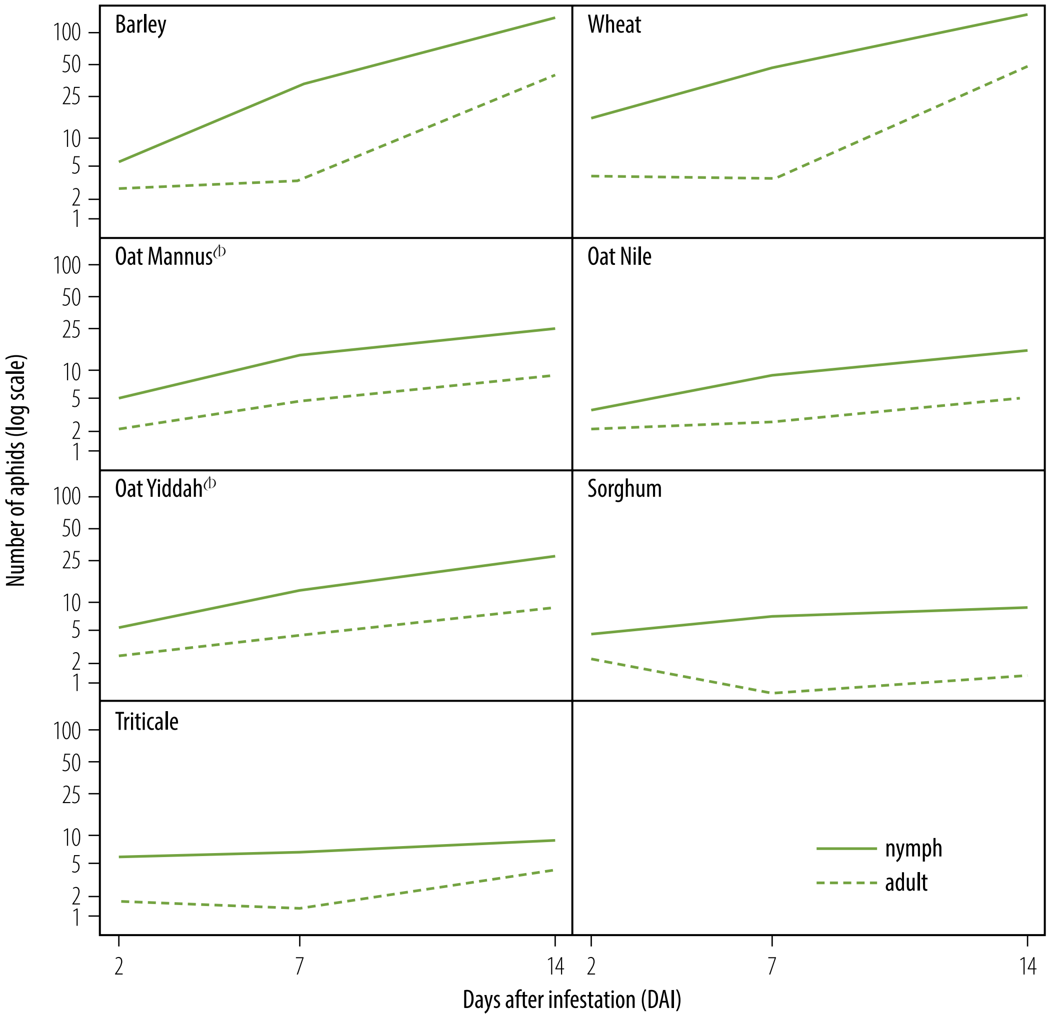

Figure 6 Mean number of RWA adults and nymphs on different hosts at 2, 7 and 14 DAI.

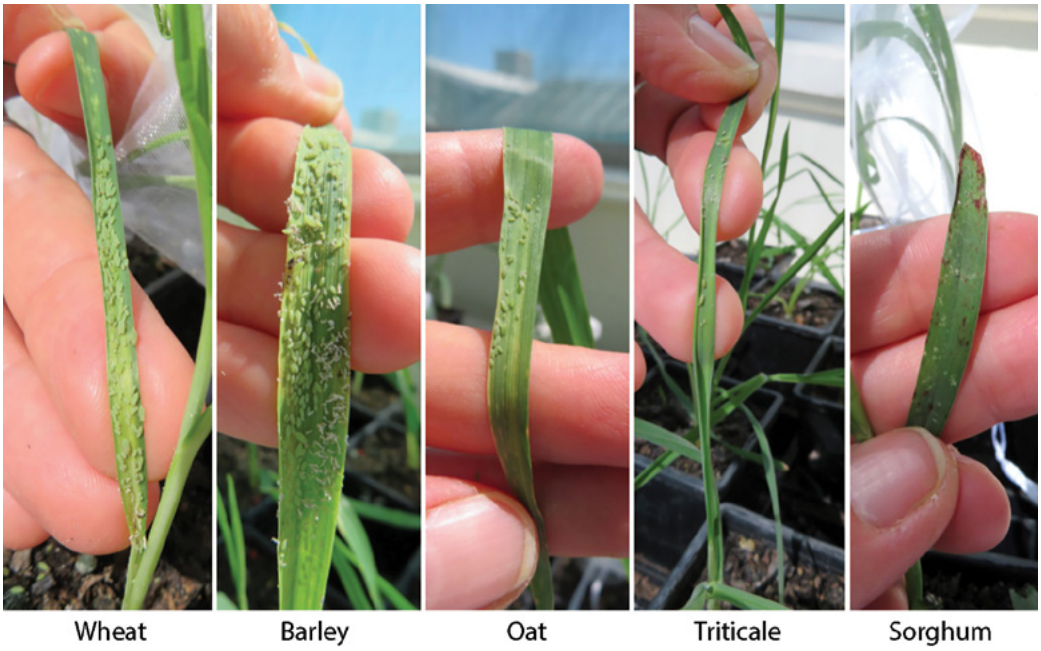

Figure 7 Symptoms caused by RWA at 14 DAI on wheat, barley, oat, triticale and sorghum seedlings.

These studies confirm that wheat and barley are the preferred hosts for RWA, with oats, triticale and sorghum being poor hosts. However, the host range of RWA includes more than 140 species (GRDC, 2017), and there is a great possibility for RWA to maintain its population using these secondary hosts, including oat, triticale and sorghum, during winter and summer and thus providing a green bridge winter cereal infestation.

Conclusion

RWA has been confirmed in South Australia, Victoria, New South Wales and Tasmania. In 2019 it was found in barley, wheat, durum wheat and barley grass in the Tamworth Region.

The results from this study show that sorghum can provide a host for RWA, especially on young plants in late spring and at the beginning of summer. However, additional field studies are needed to address its risk to the northern wheat industry.

While RWA forms well-established colonies and shows typical symptoms on its primary hosts – barley and wheat, the aphid can also maintain small colonies and develop symptoms that include red patches at the place of feeding on sorghum leaves, and barely visible yellow lines and rolled leaves on oat and triticale.

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Insecticide resistance in fall armyworm

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Key findings:

- Fall armyworm (FAW) has minimal resistance to selective insecticides containing the actives emamectin benzoate, chlorantraniliprole, spinosad and spinetoram.
- Reduced sensitivity to indoxacarb is probably due to naturally higher tolerance in FAW compared with Helicoverpa species.
- FAW has moderate resistance to carbamates.
- High resistance to synthetic pyrethroids in FAW is due to metabolic resistance.
- A strategic approach to insecticide selection and rotation is required to minimise further resistance development and optimise the cost-effectiveness of insecticide applications.

Introduction

Fall armyworm (*Spodoptera frugiperda*) is a highly migratory, invasive pest that was first reported in Australia in February 2020. It quickly established across parts of northern Australia's tropical and sub-tropical regions, including north Queensland, the Northern Territory and parts of Western Australia.

This pest was first detected in NSW in September 2020 north of Moree, with subsequent detections at Narrabri, Wee Waa, Dubbo, Breeza and Maitland in October 2020. By December 2020 FAW had spread to the north coast, central west, Riverina, Murray and south-eastern districts of NSW.

Plants within the grass family (Poaceae) including maize, sweetcorn, sorghum and C4 pastures are favoured hosts of FAW. However, in Australia populations have also been detected on several other crops including chickpea, soybean, melon, green beans and pastures.

Reliance on chemical control for managing FAW on a global scale over many decades has led to the development of insecticidal resistance to at least 29 active ingredients in six mode-of-action groups. To understand how this will impact the effectiveness of chemical control options, NSW DPI has conducted research to establish the toxicity profiles of these groups currently registered under permit for FAW in Australia. This report details the findings from this research, which is aimed at supporting growers to decide the most appropriate course of action for managing outbreaks of FAW if sprays are warranted.

Methods

Insect populations

Eleven FAW populations were established from larvae collected in maize fields at various locations in NSW and across Qld and WA. Populations were tested within five generations of establishment in the laboratory. It was not possible to source a susceptible laboratory strain of FAW for this study. Since all insecticides tested in this experiment were also registered for *Helicoverpa armigera* (cotton bollworm), the dose response in the laboratory strain and 20 field populations of *H. armigera* was used as a standard for comparing the relative efficacy of the products in FAW control.

The laboratory strain of *H. armigera* was originally established from larvae sourced during the mid-1980s from collections in cotton fields in the Namoi Valley and was susceptible to all insecticides tested. Field strains of *H. armigera* were collected from a range of host crops and tested in either the F1 or F2 generation. Field strains were collected in cotton, sorghum, pigeon pea, maize and pulses across major cropping areas across NSW and Qld and tested within three generations of establishment in the laboratory.

Larval stages of both species were reared using a standard artificial diet comprising soy flour, wheat germ and brewer's yeast. Adults were housed in 5 L containers open at the top and covered with cloth liners and secured around the container lip to provide an oviposition substrate. Moths were fed a 4% honey/sugar solution through a cotton wick. Eggs were harvested every two or three days. Hatched neonates were individually transferred to rearing trays with an artificial diet (Figure 1). Trays were heat sealed with perforated film to prevent escape. All insect strains were maintained in a laboratory environment of 25 ±2 °C with 14:10 (light–dark) hour photoperiod and ambient relative humidity (RH).

Figure 1 FAW feeding on artificial diet containing different insecticides.

Insecticides

The insecticide mode of action groups tested in this study are registered under permit with the APVMA for FAW control (Table 1).

Selective groups were supplied as formulated insecticides:

- emamectin benzoate (1.9% active ingredient), Syngenta Crop Protection
- chlorantraniliprole (35% active ingredient) and indoxacarb (15% active ingredient), DuPont Australia Ltd
- spinetoram (12% active ingredient) and spinosad (24% active ingredient), Corteva Agriscience Australia.

Broad-spectrum mode of action groups were supplied as technical grade insecticides:

- alpha-cypermethrin (99.5%) and gamma-cyhalothrin (99.9%), FMC Australia
- methomyl (98%) and piperonyl butoxide (PBO) (90%), Sigma-Aldrich Pty Ltd.

Table 1 Summary of permits for fall armyworm control in Australia at March 2021.

Active constituent	MOA Group	Permit number
Methomyl	1A	PER89279, PER89293, PER89400, PER89330
Alpha-cypermethrin	3A	PER89279, PER85447, PER89425, PER89330
Gamma-cyhalothrin	3A	PER89358
Spinetoram	5	PER89241, PER89331, PER89327, PER89284, PER89390
Spinosad	5	PER89870
Emamectin benzoate	6	PER89285, PER89263, PER89300, PER89344, PER89371, PER89330
Indoxacarb	22A	PER89306, PER89279, PER89278, PER89311, PER89530, PER89286, PER90374, PER89330
Chlorantraniliprole	28	PER89290, PER89366, PER89281, PER89353, PER89384, PER89259, PER89354, PER89457, PER89330, PER90621

Resistance screening procedure

Screening procedures were adapted from those previously developed for laboratory-based resistance testing in *Helicoverpa*. Testing of broad-spectrum, contact insecticides was done by topical application of insecticide as a backline treatment to FAW larvae. Specifically, technical grade insecticide was dissolved in 99.9% acetone and serially diluted to produce a range of concentrations that would induce 0-100% mortality. Larvae within a weight range of 30–40 mg were treated by administering 1 µl of acetone/insecticide solution applied to the dorsal thorax using a 50 µl micro-syringe in a repeating dispenser.

Selective insecticides are more active by ingestion than by contact and were therefore tested by performing bioassays on artificial diets containing formulated insecticide. Specifically, two-fold serial dilutions of insecticide that were expected to induce 0-100% mortality were added to 200 ml of diet and vigorously shaken to produce a homogenous mixture. Insecticide-incorporated diet was then dispensed into rearing trays and fed to late second or early third instar larvae.

Inhibition bioassays were used to determine metabolic enzyme involvement of in resistance. Bioassays were performed by dissolving a metabolic inhibitor (PBO) in analytical grade acetone at a concentration known as the maximum concentration that causes no mortality in *H. armigera* (50 µg/µl). A 1 µl of acetone/PBO solution was applied to the dorsal thorax of third or fourth instar larvae within a weight range of 30-40 mg. This was followed by applying serial dilutions of acetone/pyrethroid solution using a 50 µl micro-syringe in a repeating dispenser.

Bioassays were performed in triplicate with individual treatments (insecticide concentrations) in replicates consisting of a minimum of 20 individuals. Acetone alone was used as the control in topical bioassays, acetone/PBO (50 µg/µl) was used as the control in inhibition bioassays and untreated diet was used as the control in diet incorporation bioassays. Treatments were maintained for three and seven days in topical and diet bioassays, respectively, under the same conditions described above for larval rearing. Larvae were considered dead if they were unable to perform coordinated movement.

Data analysis

Bioassay data were corrected for control mortality and analysed using probit regression to estimate LC_{50} and $LC_{99.9}$ values. The insecticides toxicity ratio was calculated by dividing the LC_{50} of each population by the LC_{50} of the laboratory or field strain. Synergism ratio (SR) was a measure of the extent to which resistance was supressed by PBO and was calculated by dividing the LC_{50} of the strain tested with pyrethroid alone by LC_{50} of the strain tested with pyrethroid + PBO.

Results

- Spinetoram had a similar level of toxicity (efficacy) in both FAW and *H. armigera* at all levels of the dose response (Figure 2).
- At the median lethal concentration of emamectin benzoate, FAW was two-fold less sensitive than *H. armigera*. Mortality at the $LC_{99.9}$ level was similar in both species (Figure 3).
- At the median lethal concentration of chlorantraniliprole, FAW was two-fold less sensitive than *H. armigera* (Figure 4). There was a similar level of mortality in FAW and *H. armigera* at high doses of chlorantraniliprole.
- Indoxacarb toxicity was significantly lower in FAW compared with *H. armigera*. At the median lethal concentration, FAW was 28-fold less sensitive than laboratory *H. armigera*, and 13-fold less sensitive than field *H. armigera*. There was also significantly lower mortality at the $LC_{99.9}$ level in FAW compared with the field *H. armigera* population (Figure 5).
- There was a three to 11-fold reduction in sensitivity to methomyl in FAW larvae compared with *H. armigera* and there was significantly higher larval survival at concentrations of methomyl that are effective on *H. armigera*. There was approx. 50% mortality in FAW at the diagnostic dose for *H. armigera* (1000 ppm) (Figure 6).
- FAW were 50-fold less sensitive to the synthetic pyrethroids alpha-cypermethrin (Figure 7) and gamma-cyhalothrin (Figure 8) compared with susceptible *H. armigera*. There was significantly higher larval survival at concentrations of pyrethroid that are effective on *H. armigera* with <10% mortality at the diagnostic doses of alpha cypermethrin (125 ppm) and gamma cyhalothrin (62.5 ppm) (Figure 8).
- Results from an inhibition experiment showed PBO caused high high-level suppression of pyrethroid resistance, indicating that resistance to pyrethroids in FAW is mediated by metabolic mechanisms (Table 2). Metabolic resistance is an important mechanism, which is also known to confer very high levels of SP resistance in *H. armigera*.

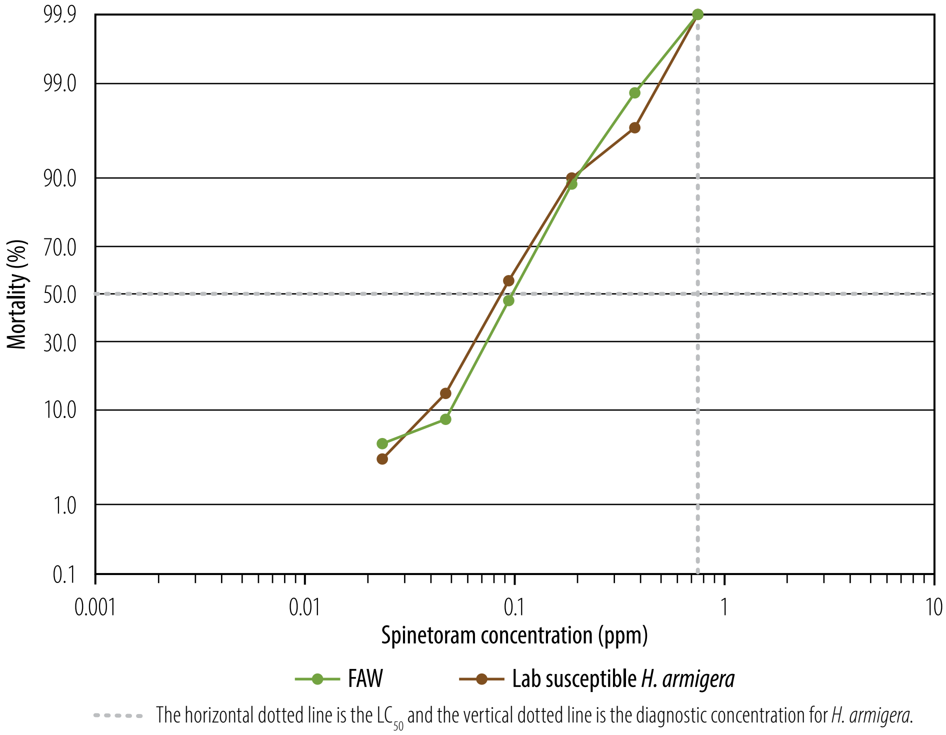
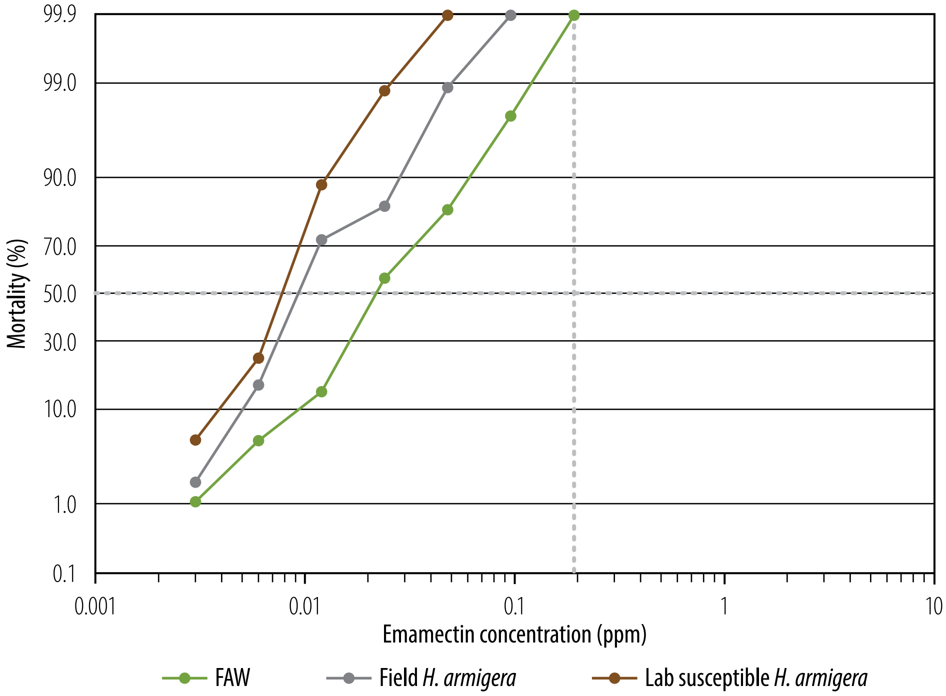
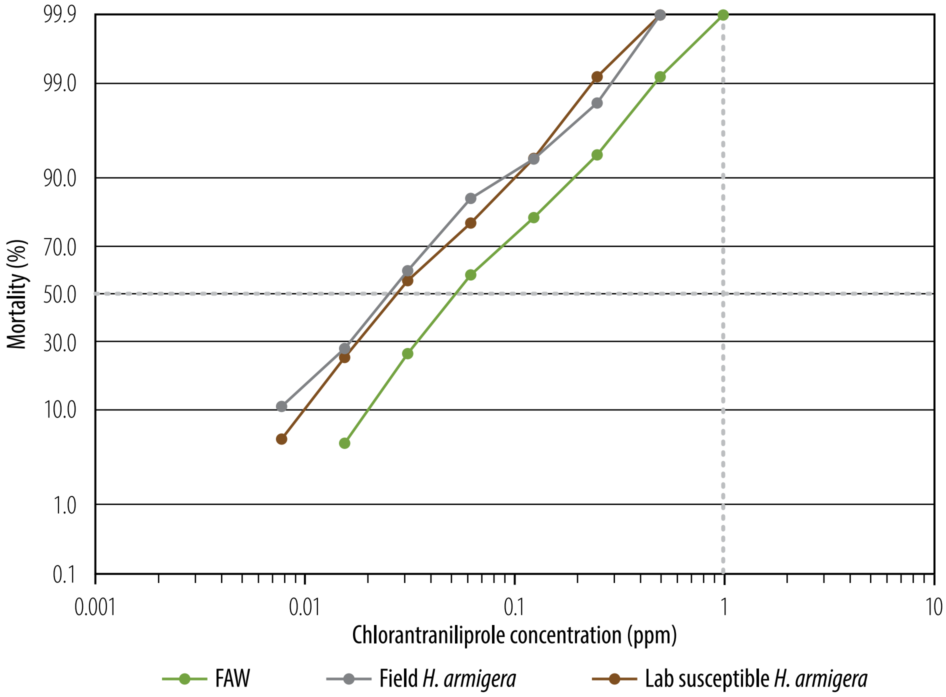


Figure 2 Comparison of spinetoram dose response in FAW with a laboratory strain of *H. armigera*.



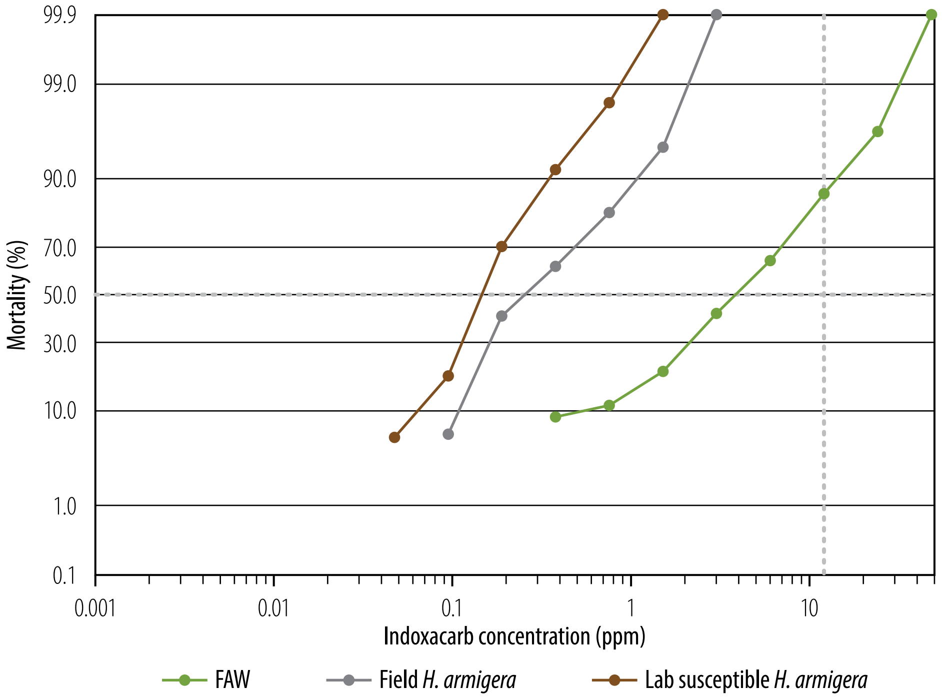
The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera*.

Figure 3 Comparison of emamectin benzoate dose response in FAW field and laboratory strains of *H. armigera*.



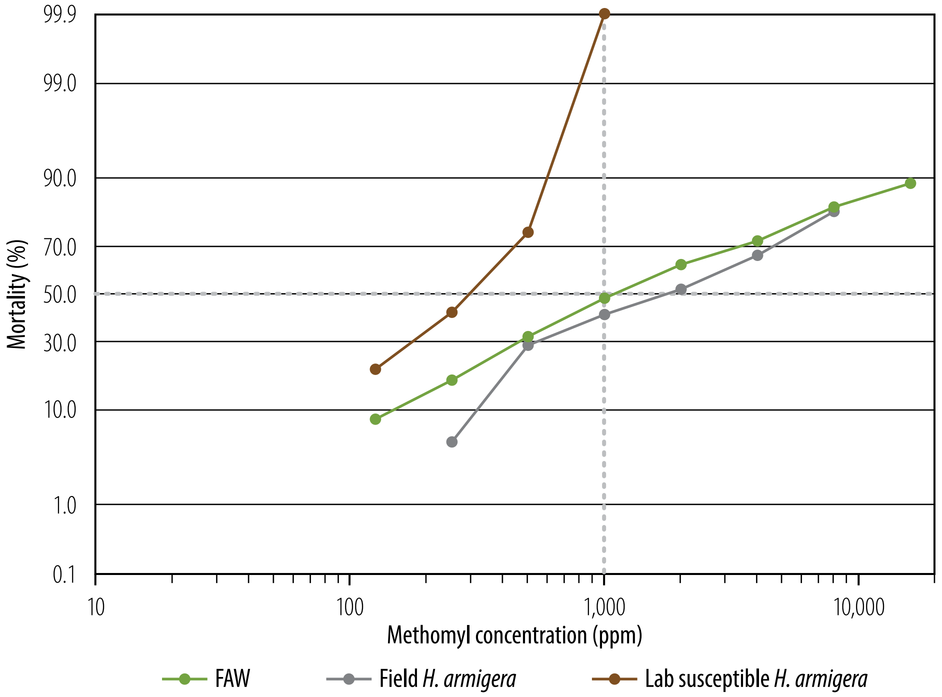
The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera*.

Figure 4 Comparison of chlorantraniliprole dose response in FAW field and laboratory strains of *H. armigera*.



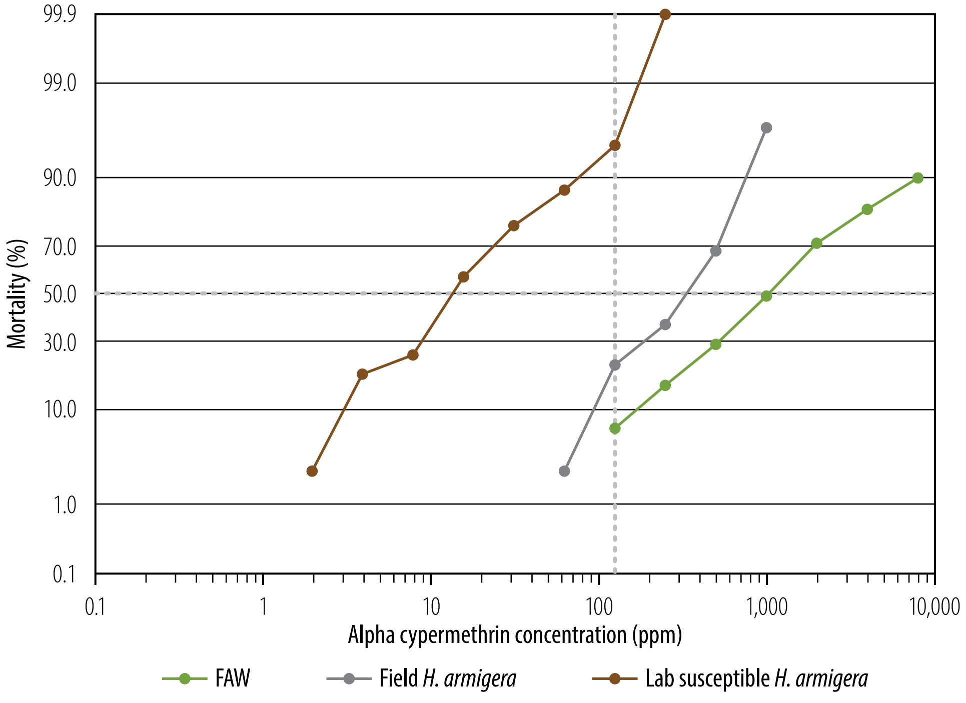
The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera.*

Figure 5 Comparison of indoxacarb dose response in FAW, field and laboratory strains of H. armigera.



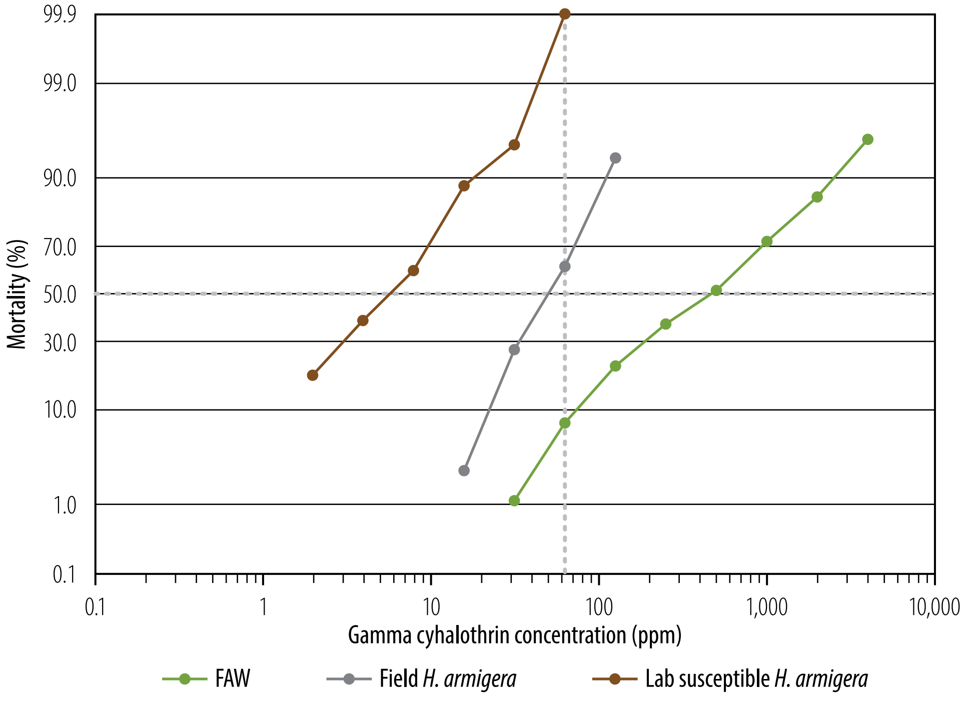
The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera.*

Figure 6 Comparison of methomyl dose response in FAW, field and laboratory strains of *H. armigera.*



The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera.*

Figure 7 Comparison of alpha cypermethrin dose response in FAW with field and laboratory strains of *H. armigera.*



The horizontal dotted line is the LC_{50} and the vertical dotted line is the diagnostic concentration for *H. armigera.*

Figure 8 Comparison of gamma cyhalothrin dose response in FAW with field and laboratory strains of *H. armigera.*

Table 2 Toxicity of synthetic pyrethroids with and without PBO.

Insecticide	n	LD50 [µg/µl] (95% FL)	Fit of probit line			SR‡
			Slope±SE	X2 (df)	P	
Gamma cyhalothrin alone	926	0.279 (0.202, 0.403)	1.8 ± 0.2	12.47 (4)	0.014	-
Gamma cyhalothrin + PBO	1093	0.004 (0.003, 0.006)	1.3 ± 0.2	12.42 (4)	0.015	69.8
Alpha cypermethrin alone	886	0.676 (0.569, 0.793)	1.3 ± 0.1	2.45 (5)	0.784	-
Alpha cypermethrin + PBO	639	0.019 (0.017, 0.022)	2.0 ± 0.1	6.75 (5)	0.240	35.6
Deltamethrin alone	720	0.334 (0.291, 0.384)	1.9 ± 0.1	4.24 (4)	0.374	-
Deltamethrin + PBO	500	0.012 (0.010, 0.015)	1.5 ± 0.1	4.09 (4)	0.394	27.8

‡ SR (synergistic ratio) = LC_{50} without PBO / LC_{50} with PBO

Conclusions and implications for management

High levels of metabolic resistance to pyrethroids and the presence of genetic markers for resistance to carbamates indicate that broad-spectrum insecticides are unlikely to provide effective FAW control. Given the levels of resistance to broad-spectrum insecticides, growers are strongly advised to avoid using these chemical groups and instead consider adopting integrated pest management (IPM) strategies to help optimise the cost of controlling FAW by taking advantage of natural enemies present in crops.

High levels of susceptibility to spinetoram indicates this insecticide will be an effective option for FAW management. Emamectin benzoate and chlorantraniliprole are also likely to provide effective control. However, control could be marginal at rates below the full field rate of these insecticides.

A natural tolerance to indoxacarb in FAW suggests this insecticide might not provide effective control in crops with high insect pressure. However, indoxacarb could be useful for achieving population suppression in low pressure situations and for providing an additional rotation option for resistance management.

As with any insect pest, there is considerable potential for further selection of resistance in FAW to selective insecticides if usage increases. Overuse of selective insecticides could also threaten *Helicoverpa* resistance management if there is an increase in the frequency of in-crop sprays where the two species occur together. As a first step toward pre-emptively managing resistance to pivotal selective insecticides used in to manage FAW, NSW DPI has developed resistance screening procedures to increase capacity for detecting field resistance in this species. Diagnostic concentrations of spinetoram, spinosad, emamectin benzoate chlorantraniliprole and indoxacarb have been established for detecting future changes in resistance to these insecticides, which will be a critical component of a future resistance management strategy (RMS).

Although there is currently no RMS for FAW, the key principles of resistance management and IPM should be applied when making spray decisions. This includes regular monitoring to identify early outbreaks, timely applications of selective insecticides on above threshold populations, and rotating selective insecticides with different modes of action.

Following these guidelines will help to optimise the cost of applications and control of FAW while making the most of natural enemy populations present in the crop, the benefits of which will be destroyed by broad-spectrum insecticides that are unlikely to provide effective control.

Acknowledgement

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What diseases kept NSW cereal pathologists busy in 2019 and 2020?

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Key findings

- The prevalence of different winter cereal diseases can vary markedly between years due to seasonal conditions.
- In 2020, five times the number of diagnostic samples/enquiries occurred compared with 2019 due to the wetter season, which favoured the development of a range of diseases. These were mainly leaf pathogens, in particular stripe rust.
- In 2020, 21% of samples received for diagnostics were not related to disease. This was 28% in 2019.
- This highlights the importance of correct diagnosis to ensure that growers implement appropriate management strategies.

Introduction

Through co-investment, NSW DPI and the Grains Research and Development Corporation (GRDC) provide a 'no-additional charge' cereal diagnostic service to NSW cereal growers and their advisers.

Evidence based methods are used to confirm diagnosis which include a combination of:

- visual symptoms
- crop management history
- paddock distribution
- recovering/identifying the causal pathogens (microscopy, humid chamber or plating).

Any suspect virus samples are confirmed using ELISA antibody testing at the NSW DPI Elizabeth Macarthur Agricultural Institute at Menangle.

Wheat, barley and oat rust samples (stripe, leaf and stem) are sent to the Australia Cereal Rust Control Program (ACRCP). Samples sent to ACRCP facilitate tracking pathotype populations and distribution across the cropping belt of NSW and Australia including a new interactive map (Australian Cereal Rust Survey 2020 Sample Map – Google My Maps). The ACRCP regularly updates the map throughout the growing season allowing growers to see which pathotypes are dominant in their region. This can be very important to guide in-crop management decisions given five different stripe rust pathotypes were present at varying levels across NSW in 2020. Individual wheat varieties can have vastly different reactions to these pathotypes, so knowing which ones are dominant where and when can guide seasonal in-crop management.

The projects also record direct disease enquiries received (phone and email) and resulting management advice provided to growers and advisers throughout each season. Such project activities support NSW cereal producers in correct diagnosis of diseases during the season, and independent advice on appropriate management strategies to limit economic impacts. This is assisting to limit the unnecessary application of in-crop fungicides by growers, reducing input costs and potential risks of selecting for fungicide resistance within fungal pathogen populations.

Location

Across NSW

Results

Which 'diseases' dominated in 2019 and 2020?

Table 1 is a collation of the NSW data and provides an annual snapshot of the key biotic and abiotic constraints to cereal production.

Table 1 Cereal diagnostics and enquires processed across NSW in 2019 and 2020.

Disease/issue	2020	2019
Stripe rust (wheat)	194	13
Spot form of net blotch (barley)	65	32
Physiological/melanism	65	10
Scald (barley)	65	4
Fusarium crown rot	61	14
Powdery mildew (wheat)	53	1
Frost damage	45	4
Leaf rust (wheat)	35	2
Other non-disease (e.g. soil constraint, leaf blotching)	34	24
Bacterial blight (wheat and barley)	30	0
Rusts crown and stem (oats)	29	4
Herbicide damage	28	6
Net form of net blotch (barley)	23	0
Bacterial blight (oats)	22	3
Barley grass stripe rust	20	1
Barley yellow dwarf virus	19	1
Septoria tritici blotch (wheat)	17	13
Nutrition	16	2
Take-all	16	1
Rhizoctonia	12	7
Powdery mildew (barley)	12	0
Yellow leaf spot (wheat)	10	4
Fusarium head blight	10	0
Loose smut (barley)	9	1
Seedling root disease complex (*Pythium*, crown rot, *Rhizoctonia*, Take-all)	8	2
Septoria (oats)	3	2
Wheat streak mosaic virus	3	1
Common root rot	2	3
Rye grass rust	2	0
Ergot	1	0
Red leather leaf (oats)	1	7
Sclerotium rolfsii	1	2
Spot blotch (barley)	1	0
Ring spot	0	1
Total	912	165

Note: Disease/issues ranked in order of frequency in 2020.

Individual seasons have a strong influence on the level of diagnostic support required by NSW growers/advisers, with over five-times the number of samples and enquiries in the wetter 2020 season compared with the drier 2019 (Table 1). This increase was due to more conducive conditions for cereal leaf disease development (e.g. rusts, scald, net-blotches, *Septoria*) in 2020 (537 samples) compared with 2019 (77 samples).

In 2020, the four main cereal diseases were:

- wheat stripe rust (widespread distribution of newer Yr198 pathotype)
- the spot form of net blotch (SFNB) in barley
- scald in barley
- fusarium crown rot in different winter cereal crops.

In comparison, the four main cereal diseases in 2019 were:

- SFNB
- fusarium crown rot
- wheat stripe rust
- septoria tritici blotch

The levels of yellow leaf spot (*Pyrenophora tritici-repentis*) diagnosed in both seasons was relatively low. However, wheat samples with leaf blotches or mottling suspected to be caused by yellow leaf spot were submitted each year. There is an ongoing difficulty with correct diagnosis of this particular leaf disease by growers and their advisers as it is often confused with septoria tritici blotch (*Zymoseptoria tritici*), septoria nodorum blotch (*Stagonospora nodorum*) and physiological responses to abiotic stress (e.g. frost yellowing, nitrogen mobilisation and herbicide damage).

The 2020 season also highlighted that root diseases such as take-all, which have not been seen at damaging levels for many years, can quickly re-emerge at significant levels under conducive conditions. Conversely, fusarium crown rot remains a significant issue across seasons.

In 2020, a number of rust and powdery mildew samples were received from susceptible wheat varieties. This highlights the importance of genetic resistance of varieties as a component of an integrated disease management system. Susceptible varieties are more reliant on fungicide applications to limit disease levels and associated yield loss, which can increase the risk of developing fungicide resistance. Additionally, selection for fungicide resistance might not necessarily be occurring in the main fungal pathogen targeted for control by the fungicide application. For example, heavy reliance on fungicide applications in susceptible stripe rust varieties could inadvertently select for resistance in wheat powdery mildew populations when they co-infect plants. Preliminary research conducted in collaboration with Curtin University's Centre for Crop Disease Management (CCDM) in 2020 unfortunately indicates issues with reduced sensitivity to azoles (DMIs, Group 3) and resistance to strobilurins (QoIs, Group 11) fungicides are already widespread in wheat powdery mildew populations in NSW and Victoria.

Importance of correct diagnosis

In 2020, the symptoms of 21% of plants received for diagnosis were not related to disease. In 2019 this number was 28%. These samples were either diagnosed as being plant physiological responses to stress, frost damage, herbicide injury, crop nutritional issues or other non-disease issues (Table 1). All of the samples submitted were suspected of having disease issues.

Conclusions

These findings highlight the ongoing importance of the diagnostic service provided to NSW growers and their advisers to support correct identification and implementation of appropriate management strategies, including the unnecessary application of foliar fungicides. Growers and their advisers are urged to never be afraid of seeking a second opinion from a NSW DPI plant pathologist. We are here to help.

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Summer crop choice in northern farming systems: pathogen and AMF impacts

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Key findings

- Summer crop choices are complex and should consider the effects they have on pathogens and beneficial soil biota, such as arbuscular mycorrhizae fungi (AMF).
- Mungbean resulted in the greatest increase in AMF populations. However, mungbean also elevated the disease risk for charcoal rot and the root lesion nematode (*Pratylenchus thornei*, (Pt), compared with sorghum, cotton, maize, sunflower and millet.
- Growing summer crops generally reduces the risk of fusarium crown rot (FCR) for the following winter cereal crops, but there is variation in this effectiveness.
- Maize, cotton, sorghum and mungbean appear to be potential alternative hosts for the winter cereal pathogen *Bipolaris sorokiniana* (common root rot), while sunflower appears not to be.
- Quantifying individual summer crop choices on pathogen levels has highlighted research areas requiring further work to improve managing these biotic constraints across the northern farming systems.

Introduction

Crop choice decisions often involve trade-offs between different aspects of farming systems. In particular, crop choice should consider:

- the need to maintain residue cover
- soil, water and nutrient availability
- managing pathogen inoculum loads using non-host crops to avoid risk from problematic diseases (e.g. fusarium crown rot).

These decisions are increasingly challenging as many cropping systems face evolving disease and weed threats. Therefore, understanding how different crops affect these obstacles is critical.

Limited water affects crop rotation options in the northern grains region and summer crops offer break crop advantages within cropping sequences. Incorporating a mix of summer and winter crops allows variation in herbicide and weed management options, often serving as a disease break within the system. For example, sorghum is known to be resistant to the root lesion nematode *Pratylenchus thornei* (Pt), allowing soil populations to decline. However, the increasing use of summer crops in many regions has caused an increased frequency of other diseases (e.g. charcoal rot caused by the fungus *Macrophomina phaseolina*).

Similarly, using long fallows to transition from the summer to winter crop phases can induce low population levels of the beneficial arbuscular mycorrhizae fungi (AMF), which is associated with long-fallow disorder.

In this experiment, we analyse the data collected from northern farming systems research sites over the past six years to examine how different summer crop options effect both pathogen and AMF populations within farming systems.

Location

Experiment sites:

- Four sites in NSW (Liverpool Plains; Narrabri; Trangie; red and grey soil)
- Four sites in Queensland (Billa Billa, Pampas, Mungindi and Emerald).

Experiment design

Eight research sites were established in 2015 to test a range of different farming systems in different environments across northern NSW, southern and central Qld.

Pathogen soil testing

- Soils were sampled and analysed (0–30 cm) at sowing and, for the life of the project, after harvest each summer.
- We used the Northern-PreDicta® B quantitative PCR (qPCR) DNA analysis to examine how pathogens and other soil biology have varied over a range of crop sequences.
- We used these measurements to calculate relative changes or multiplication factor for populations over their growing season for the various summer crop rotation options. This multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0) in pathogen levels following different summer crops.
- The effects of summer crops grown in these sequences has been examined to calculate the extent of the change in the DNA populations of pathogens and AMF associated with the crop choices.
- No sites were artificially inoculated, with populations developing naturally within each system.
- Data from site-crop combinations where a particular pathogen or AMF was absent or below testing detection limits was excluded, as this does not provide a useful indication of a crop choice effect on a particular pathogen or AMF population.

Results

Root lesion nematodes

Root lesion nematodes (RLN, *Pratylenchus* spp.) are microscopic plant parasites that feed on crop roots. Two important species are known to infect crops in eastern Australia: *Pt* and *Pratylenchus neglectus* (Pn). Pt is known to be the more important species in higher clay content soils in northern NSW and southern Qld while Pn is generally more prevalent in lighter soil types in south-eastern Australia. *Pratylenchus neglectus* generally feeds and causes root damage in the top 15 cm of soil while Pt can feed and damage roots down the entire profile. Root damage restricts water and nutrient uptake from the soil causing yield loss in intolerant winter cereal and chickpea varieties. Only Pt densities were high enough across northern farming system sites to examine the effect of summer crop options on their RLN populations. Low Pn numbers prevented a similar analysis with this RLN species.

Summer crops are known to vary in their susceptibility to Pt:

- Sorghum, cotton, millet and sunflower are considered moderately resistant–resistant (MR–R).
- maize is considered susceptible–MR (S–MR) while mungbean is S–moderately resistant/moderately susceptible (MRMS). See Strategies to help reduce losses caused by root lesion nematodes, *GRDC root lesion nematode fact sheet* (https://grdc.com.au/__data/assets/pdf_file/0031/385627/GRDC_FS_RootLeNematodesNorth_1902_13.pdf).
- The range in resistance ratings can relate to differences between varieties with the results from this experiment supporting these findings.

Mungbean crops resulted in the highest average increase in Pt populations, while sorghum had the lowest (Table 1).

Table 1 Effect of summer crop choice on *Pratylenchus thornei* soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.4	8.3	3.2	2.0	3.4	5.0
Range	0.2–6.6	4.0–21.3	0.8–13.7	1.4–2.8	3.2–3.7	4.0–6.0
Number of observations	31	20	10	5	3	2

*Multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0).

Charcoal rot

Charcoal rot is primarily a summer crop disease including sorghum, maize, cotton, mungbean (Figure 1) and sunflower in northern NSW and Qld. Infection causes light brown lesions on crowns and roots and results in increased lodging and/or premature plant death when stressed by dry weather late in the growing season. *Macrophomina phaseolina* has a wide host range of more than 500 weed and crop species including winter cereals.

All six of the summer crops grown increased charcoal rot populations by between 3.9–150.0 times, demonstrating the known wide host range of this fungal pathogen (Table 2). However, considerable differences were evident between the various summer crop options with mungbean elevating populations approximately 5–40 times more than the other crops (Table 2).

Table 2 Effect of summer crop choice on charcoal rot soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	9.5	150.0	20.8	7.2	28.9	3.9
Range	1–27	5–1191	1–117	4–11	6–50	2–6
Number of observations	23	23	9	4	3	2

*Multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0).

Figure 1 Charcoal rot in mungbean, Gordon Cumming.

Arbuscular mycorrhizae fungi

Arbuscular mycorrhizae fungi are beneficial fungi that colonise the roots of host plants and develop a hyphal network in soil that helps the plant to access phosphorus and zinc. Low levels of AMF have been associated with long-fallow disorder in dependent summer (cotton, sunflower, mungbean and maize) and winter (linseed, chickpea and faba beans) crops. Although wheat and barley are considered to be low and very low AMF-dependent crops respectively, they are hosts and it is generally recommended that these are grown before sowing AMF-dependent crops to elevate AMF populations.

There are two PreDicta B qPCR DNA assays for AMF with combined results from both assays presented. It is important to remember that in contrast to all the other pathogen assays outlined, AMF is a beneficial fungus, so higher multiplication factors are good within a farming system context.

Mungbean had in the highest average increase in AMF populations, whilet sorghum was the lowest (Table 3). Interestingly, even though millet was grown as a short cover crop twice within these farming systems, it resulted in around a 7-fold increase in AMF populations. Hence, millet could be a good option for restoring ground cover over summer and AMF populations, both of which decline following extended dry conditions.

Table 3 Effect of summer crop choice on arbuscular mycorrhizae fungi (AMF) soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.5	26.8	10.7	5.7	12.0	7.2
Range	0.4–12.4	2.2–61.5	1.8–32.0	3.4–8.0	6.3–17.6	6.5–7.9
Number of observations	41	22	10	4	3	2

*Multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0).

Fusarium crown rot

Two PreDicta B qPCR DNA assays detect variants of *Fusarium pseudograminearum* with a separate third combined test detecting *F. culmorum* or *F. graminearum*. All three Fusarium species cause basal infection in winter cereal stems resulting in fusarium crown rot and the expression of whiteheads when heat and/or moisture stress occurs during grain filling. Fusarium crown rot has increased in northern farming systems with the adoption of conservation cropping practices, including retaining standing winter cereal stubble. Yield effects can be offset by higher amounts of plant available water levels being available during grain fill, compared with conventional tillage systems. The *Fusarium* spp., which causes this disease, can survive 3–4 years within winter cereal stubble, depending on the rate of residue decomposition.

Recent research from PhD student Toni Petronaitis has also highlighted that inoculum levels can increase during fallow and non-host crop periods, with saprophytic vertical growth of the pathogen inside standing stubble under wet conditions. Inoculum within standing winter cereal stubble can then potentially be redistributed across a paddock in following seasons with the shorter harvest heights of break crops such as chickpeas. Hence, changes in fusarium crown rot DNA levels might not represent actual hosting of the pathogen; rather they potentially include inoculum dynamics associated with saprophytic growth and/or redistribution of winter cereal stubble inoculum during harvest. DNA data for all three tests were combined for this interpretation to provide an overall level of *Fusarium* spp. DNA.

Limited observations were available to support conclusions on the relative effect of summer crops on *Fusarium* spp. which were:

- cotton and maize appeared most effective at reducing inoculum loads (Table 4)
- sorghum and mungbean results were more variable, but both generally reduced or only moderately increased fusarium crown rot inoculum levels.

Table 4 Effect of summer crop choice on *Fusarium* spp. soil populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	1.7	2.9	0.4	0.5	–	–
Range	0.03–10.3	0.4–9.7	0.1–1.0	0.2–0.8	–	–
Number of observations	19	8	3	2	–	–

*Multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0).

Inoculum dynamics associated with the potential redistribution of *Fusarium* spp. saprophytic growth while harvesting summer and winter break crops, and the role of grass weed hosts, appears worthy of further investigation to improve disease management across farming systems.

Common root rot

Common root rot (CRR) primarily infects the sub-crown internode of winter cereal crops causing dark brown to black discolouration of this tissue. Common root rot reduces primary root system's efficiency in susceptible wheat and barley varieties resulting in reduced tillering and general ill-thrift in infected crops.

This disease has increased in prevalence across the northern region over the last decade as increased adoption of earlier and deeper sowing of winter cereals has exacerbated infection.

There is little information on the effect of summer crop options on *B. sorokiniana* levels within Australian farming systems. One international study from Pakistan determined that millet, sorghum, mungbean and maize were *B. sorokiniana* hosts, while sunflowers were a non-host (Iftikhar et al. 2009). Similar research has not been conducted in Australia.

Although limited observations were available to support conclusions on the relative effect of summer crops on *B. sorokiniana* populations, the data appears to support the only previous study of the host range.

- Mungbean, sorghum and maize appear generally to increase populations.
- Sunflower decreased pathogen levels considerably (Table 5).
- Cotton, which was not included in the Pakistan study, also appears to increase *B. sorokiniana* soil populations (Table 5).

These results indicate that the role of summer crops needs to be considered when managing CRR in northern farming systems, with further research required to confirm the host range of this increasingly important pathogen.

Table 5 Effect of summer crop choice on *B. sorokiniana* populations.

	Sorghum	Mungbean	Cotton	Maize	Sunflower	Millet
Multiplication factor*	3.9	2.6	6.8	7.4	0.04	–
Range	0.5–9.6	0.3–9.3	0.3–12.0	na	na	–
Number of observations	12	6	3	1	1	–

*Multiplication factor highlights the extent of increase (>1.0), maintenance (= 1.0) or decrease (<1.0).

Conclusions

Summer crop choice remains a complex balancing act, but this research has highlighted some of the effects on pathogen and AMF populations. For example, mungbean had the largest increase in beneficial AMF levels, but had the negatives of elevating charcoal rot and Pt risk, compared with the other summer crop options examined.

Mungbean did not appear to be as effective at reducing fusarium crown rot risk for subsequent winter cereal crops compared with other summer crop options. The underlying reasons behind these apparent differences requires further investigation of FCR inoculum dynamics within a farming systems context.

These northern farming systems experiments have further highlighted the different roles of summer crops as alternative hosts of the CRR pathogen *Bipolaris sorokiniana*, supporting an overseas study.

Using PreDicta® B qPCR analysis in these experiments is unique in allowing the relative changes in pathogen or AMF levels associated with various summer and/or winter crop choices to be quantified. This is more valuable than simple presence/absence data, allowing growers and their advisers to understand and manage potential changes in disease risk within their paddocks, which can impact profitability.

Reference

Iftikar S, Asad S, Munir A, Sultan A and Ahmad I. (2009). Hosts of *Bipolaris sorokiniana*, the major pathogen of spot blotch of wheat in Pakistan. *Pakistan Journal of Botany*. 41: 1433–1436.

Acknowledgements

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Growth of the fusarium crown rot pathogen in post harvest cereal stubble over a summer fallow, Breeza 2019–20

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Key findings

- The fusarium crown rot pathogen (*Fusarium pseudograminearum* (Fp)) can, over a summer fallow, grow vertically to the height the cereal stubble was cut at harvest. It can progress further in taller stubble (i.e. 25 cm or 38 cm above ground level i.e., harvest height) versus stubble cut shorter.
- Pathogen growth was restricted at or after harvest by cutting the stubble shorter (i.e., 13 cm harvest height).
- Altering harvest height of cereal crops can affect stubble-borne pathogen dispersal such as Fp during the subsequent harvest of lower stature crops, such as chickpea. Any implications this has on the disease risk for successive cereal crops within a rotation sequence is yet to be determined.
- Cereal stubble management treatments did not significantly affect soil moisture levels after a summer fallow or the following chickpea break crop performance in 2020 at Breeza.

Introduction

The impacts of fusarium crown rot (FCR), caused by the fungus *Fusarium pseudograminearum* (Fp), have increased in Australia over the past four decades. It is associated with the adoption of conservation-agriculture practices such as cereal stubble retention. Despite the yield penalties associated with FCR, stubble retention is important for soil structure, moisture and fertility in the northern grains region (NGR) of northern NSW and southern Qld. Finding ways to limit the negative effects of disease while retaining cereal stubble is therefore essential.

Cropping practises are continually evolving, and new cropping trends could be reducing the efficacy of current disease management strategies. For example, adopting higher harvest heights (i.e. stripper-fronts), light tillage (i.e. Kelly chaining) and rotations with shorter stature break crops (e.g. chickpea, *Cicer arietinum*) are becoming common in the NGR. The stripper front harvesting systems improve harvest efficiency by rapidly stripping the heads of the plant at harvest, and increases retained stubble biomass (as standing stubble height is increased). It is unknown how such an increase in vertical cereal stubble height will affect the survival and/or Fp growth.

Fusarium pseudograminearum is capable of surviving in post harvest cereal stubble for ~three years and can continue to colonise (i.e., grow) in post harvest cereal stubble by a process known as saprophytic colonisation. Additional stubble remaining from stripper front harvested cereal crops could increase Fp colonisation as there is more vertical stubble to colonise compared with the growth possible in stubble remaining from conventional or shorter harvest heights. Lowering or modifying an Fp-infected cereal crop harvest height might restrict standing cereal stubble colonisation , which could be beneficial for preventing further increases in Fp inoculum levels during fallow or non-host periods.

The effects of harvest height modification on Fp vertical colonisation over a summer fallow was investigated at Breeza using a range of cereal harvest height and stubble management options in a two-year (durum wheat–chickpea) rotation spanning the 2019–20 growing season. Soil moisture and chickpea yield under the different cereal stubble management treatments established in the 2019 season were measured during the 2020 season.

Site details

Location	Liverpool Plains Field Station, Breeza, Latitude 31° 17′54.47″S, Longitude 150° 42′8.51″E.
Rainfall	In 2019 296.5 mm of rainfall was recorded at the site, of which 215.8 mm fell in the growing season (Table 1). The fallow rainfall (2019–20) was 438.8mm. In 2020, 939.2 mm of rainfall was recorded at the site, of which 302.6 mm fell in the growing season.
Chickpea variety	PBA Seamer$^{\phi}$.
Chickpea sowing date	28 May 2020.
Fertiliser	40 kg/ha Granulock Z®.
Sowing rate	Target 30 plants/m2.
Insect management	Targeting *Helicoverpa* spp: Fastac Duo® 250 mL/ha (alpha cypermethrin 100 g/L) applied on 17 October.
Disease management	Seed treated with P-Pickel T® (1:5 water dilution applied at 1 L/100 kg seed). Chlorothalonil 720 (1 L/ha) applied on 24 August 2020 to control ascochyta blight.
Harvest	Desiccated with Spray.Seed 250® (135 g/L paraquat, 115 g/L diquat) on 16 November 2020. Harvest on 19 November 2020

Table 1 Rainfall (mm) for Breeza during 2019 and 2020.

Season	2019 growing season							2019-20 fallow						2020 growing season						
Month	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (month)	55.0	25.4	17.8	2.0	23.0	26.6	66.0	0.8	58.4	188.6	92.2	57.6	41.2	43.6	47.0	38.0	23.8	128.6	21.6	198.6
Rainfall (season)	215.8							438.8						302.6						
Rainfall (annual)	296.5								939.21											
Decile year*	< decile 1 (456)								> decile 9 (916)											
Long term average (annual)	676.9																			

* Decile values are for nearby town of Quirindi, NSW.
Totals for each year and season are reported alongside the long-term average (with decile year indicators)

Treatments

Cereal stubble treatments (established 2019–20)

In 2019, cereal stubble from durum wheat, DBA Lillaroi$^{\phi}$ with extensive Fp colonisation was established via inoculation (2 gm–1 row of Fp-colonised grain inoculum). A range of cereal harvest heights (low, medium or high) and harvest trash (trash returned to plot or trash removed off plot) treatments were applied at harvest in 2019.

Stubble heights were measured after wheat harvest:

- low stubble height averaging 13 cm
- medium stubble height averaging 25 cm
- high stubble height averaging 38 cm.

Before sowing in 2020, an additional stubble management treatment (Kelly chain) was applied to a selection of plots. This treatment was applied in combination with the harvest height treatments, to plots that had previously had trash retained (Figure 1).

Experiment design and statistical analysis

Design:

- Randomised block design, with three replicate blocks
- cereal stubble management treatments (factorial combination of cereal harvest height and harvest trash, plus Kelly-chain treatments) were randomly assigned to plots.

Analysis:

- The response variables, length of maximum colonisation and soil moisture content (SMC) percentage, were analysed across sampling times using a linear mixed model framework. Treatments, sampling time and their interaction were the fixed effects, while structural terms were fitted as the randoms.
- Response variables related to chickpea crop performance were also analysed.
- All models were fit using the ASReml-R package in the R statistical computing environment.

Figure 1 Differing stubble heights at Breeza

Results

Colonisation of cereal stubble by Fp over fallow (2019–20)

The maximum height the Fp colonised in the post harvest cereal stubble increased significantly over the 2019–20 fallow in medium and tall stubble ($P < 0.001$, Figure 2). Maximum colonisation height increased significantly in medium (+11.1 cm) and tall (+22.2 cm) cereal stubble over the fallow period (Figure 2).

However, Fp height did not change in the short cereal stubble because the fungus had already reached the cut height by harvest in 2019.

The high rainfall (439 mm; Table 1) over the summer period was conducive to Fp saprophytic colonisation.

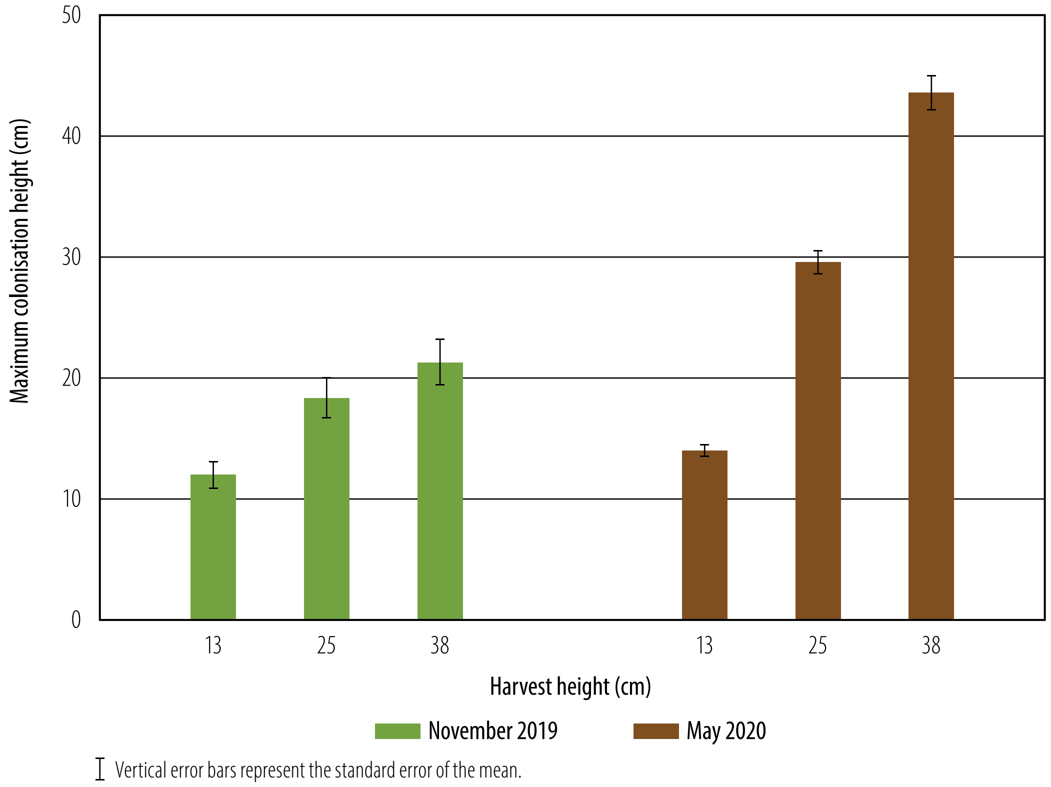

Figure 2 Maximum vertical colonisation (cm) of cereal stubble by *Fusarium pseudograminearum* at the start (November 2019) and end (May 2020) of summer fallow in Breeza.

In November 2019, maximum colonisation was significantly lower in the short cereal stubble than in the medium and tall stubble. The retained standing cereal stubble was sampled after cutting at harvest, so even if Fp was present above the average cut height of 13 cm, it could not be measured in the short stubble treatments.

Fusarium pseudograminearum stubble colonisation was beyond the average harvest height applied to the stubble (e.g., in May 2020, Figure 2). This was caused by variations in individual tiller lengths within a plot.

There was no effect of cereal trash treatment (retained, removed or Kelly chained) on maximum colonisation at each time point ($P > 0.1$).

These results demonstrate that Fp will continue to colonise to the cut cereal stubble height and suggests that lower cereal harvest heights might be effective at preventing Fp progression in infected standing stubble during the fallow period.

Chickpea establishment (2020)

The different cereal trash treatments had a significant effect on chickpea establishment ($P = 0.05$). The Kelly chained treatments resulted in slightly higher chickpea establishment (32 plants/m^2) compared with the trash retained (plus) treatment (28 plants/m^2) (Figure 3).

Plots receiving the Kelly chain treatment could have been warmer and had better seed-soil contact with the disc seeder used to sow this experiment. Still, the magnitude of difference is small and did not affect the final chickpea performance.

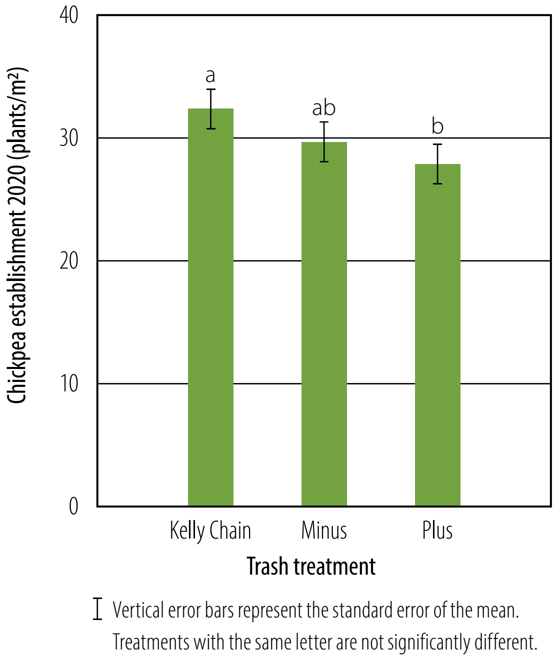

Figure 3 Trash management i.e. Kelly chaining, trash removed ('minus') and trash retained ('plus') treatments resulted in a significant difference in chickpea establishment at Breeza in 2020.

Chickpea grain yield (2020)

Cereal stubble management treatments applied in 2019–20 at Breeza did not affect chickpea yield in the 2020 season. This includes cereal stubble height (harvest height) ($P = 0.96$), harvest trash (trash retained, trash removed or Kelly chain) ($P = 0.19$) or an interaction between harvest height and trash treatments ($P = 0.14$) (data not shown).

Good fallow and in-season rainfall (Table 1) could have evened out any influence that the differential cereal stubble heights and loads might have had on chickpea yield. However, yields were low (1.0–1.4 t/ha) due to damage from *Helicoverpa* species and marginal ascochyta blight infection.

Height to lowest pod and crop height (2020)

The lowest pod height did not significantly differ as a result of standing cereal stubble height ($P = 0.99$), trash treatment (trash retained, trash removed or Kelly chain) ($P = 0.46$) or due to an interaction between harvest height and trash treatments ($P = 0.82$) (data not shown).

Final chickpea plant height (measured from soil level to top of canopy) was significantly shorter (3–9 cm) in the Kelly chained treatments compared with the standing stubble treatments, within the tall stubble treatments only ($P = 0.04$) (data not shown). There was no difference in chickpea height between the Kelly chained and the corresponding standing stubble treatments in the short and medium stubble height treatments (13 cm and 25 cm, respectively). There appeared to be no flow-on effects to yield or lowest pod height.

Soil moisture profiles (2019–20)

There were no significant differences in SMC as a result of cereal harvest height or trash treatments, or their interaction, when the chickpea was sown in May 2020 ($P > 0.45$) There appeared to be no detrimental effects of cereal stubble management treatments on the SMC. The good rainfall at Breeza over the 2019–20 fallow, which would have increased soil moisture over the period, could have evened out any soil moisture differences between treatments before sowing in 2020.

The different stubble treatments might have affected soil moisture levels if the 2019–20 summer fallow had been drier. Instead, Breeza went from a below decile 1 rainfall in 2019 to above decile 9 rainfall in 2020. SMC was not depleted following the chickpea break crop, with SMC ranging from 29% to 34% across all depths and treatments at harvest (November 2020).

Conclusions

Growers need to be aware that Fp can vertically colonise the full length of standing cereal stubble in the field after harvest given sufficient fallow rainfall. In our experiment, the maximum detection of Fp within standing stubble at harvest in 2019 was between 10 cm and 20 cm. By the end of a six-month summer fallow, the maximum height of Fp recovery within standing stubble was equal to, or very close to, the cut height of the standing stubble at harvest in 2019 (>40 cm in tall stubble). Similar results were obtained at a second experiment site located near Narrabri, NSW.

Implementing lower harvest heights in cereal crops affected by fusarium crown rot (FCR)is a useful strategy to limit Fp colonisation in retained standing stubble during fallow and non-host periods, particularly if a wet summer is expected. This could help reduce inoculum build up within the standing stubble beyond the inoculum levels present at harvest. The spread of inoculum might be prevented during the harvest of short-stature crops such as chickpea, when inoculum is present above the chickpea harvest height.

Lower stubble height, along with inter-row sowing could be used together to help lower inoculum levels. This approach could still be used with stripper-fronts by stripping grain, then cutting stubble above colonisation height in a second pass to restrict vertical Fp colonisation. The cut fraction could be left between rows as mulch or baled, providing a better option than burning if there is extensive colonisation during a wet summer fallow. Further Fp vertical colonisation (i.e. above the levels present at harvest) is less likely over a dry summer, but there can still be extensive colonisation during the growing season, with inoculum persisting 2–4 years in intact stubble.

Modifying cereal harvest height for FCR management appears promising, with the experiment continuing in 2021 to determine the effect these stubble management practices have on FCR risk in subsequent bread wheat and durum wheat sowing.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both experiment cooperation and the support of the Grains Research and Development Corporation (GRDC) and the authors thank them for their continued support.

Ms Petronaitis thanks the GRDC and NSW DPI for co-funding her GAPP PhD scholarship (BLG211) and Dr David Backhouse and Dr Richard Flavel (UNE), Dr Steven Simpfendorfer (NSW DPI) and Dr Graham Brodie (UniMelb) for their PhD supervision. Rick Graham, Gururaj Kadkol and Kristy Hobson (NSW DPI) are thanked for providing materials for the experiment. Technical assistance provided by Chrystal Fensbo, Finn Fensbo, Jason McCulloch, Stephen Morphett, Michael Dal Santo, Jim Perfrement, Bailey Skewes, Alana Johnson, Scott Goodworth and Stuart Marshman (NSW DPI) is gratefully acknowledged.

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Growth of the fusarium crown rot pathogen in post harvest cereal stubble over a summer fallow, Narrabri 2019–20

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[3] Department of Agriculture and Fisheries (DAF), Leslie Research Facility, Toowoomba, QLD

Key findings

- The fusarium crown rot pathogen (*Fusarium pseudograminearum* (Fp)) can grow vertically to the height the cereal stubble was cut at harvest over a summer fallow, so will progress further in taller-length stubble (i.e., 32 cm or 45 cm above ground level i.e., harvest height).
- Pathogen growth was restricted at or after harvest by cutting the stubble shorter (i.e., 17 cm harvest height).
- Altering harvest height of cereal crops can affect stubble-borne pathogens dispersal such as Fp during the subsequent harvest of lower stature chickpea crops. Any implications this has on the disease risk for successive cereal crops within a rotation sequence is yet to be determined.
- Cereal stubble management treatments did not significantly affect soil moisture levels after a summer fallow or the following chickpea break crop performance in 2020 at Narrabri.

Introduction

The effects of fusarium crown rot (FCR), caused by the fungus *Fusarium pseudograminearum* (Fp), have increased in Australia over the past four decades. It associated with conservation-agriculture practice adoption such as cereal stubble retention. Despite the yield penalties associated with FCR, stubble retention is important for soil structure, moisture and fertility in the northern grains region (NGR) of NSW and southern Qld. Finding ways to limit the negative effects of disease whilst retaining cereal stubble is therefore essential.

Cropping practises are continually evolving, and new cropping trends could be reducing the efficacy of current disease management strategies. For example, adopting higher harvest heights (i.e., stripper fronts), light tillage (i.e., Kelly chaining) and rotations with shorter stature break crops (e.g., chickpea, *Cicer arietinum*) are becoming common in the NGR. The stripper front harvesting systems improve harvest efficiency by rapidly stripping plant heads at harvest, and increases retained stubble biomass (as standing stubble height is increased). It is unknown how such an increase in vertical cereal stubble height will affect Fp survival and/or growth.

Fusarium is capable of surviving in post harvest cereal stubble for ~three years and can also continue to colonise (i.e., grow) in post harvest cereal stubble by a process known as saprophytic colonisation. Additional stubble remaining from stripper front harvested cereal crops could increase Fp colonisation as there is more vertical stubble to colonise compared with the growth possible in stubble remaining from conventional or shorter harvest heights. Lowering or modifying an Fp-infected cereal crop harvest height could restrict standing cereal stubble colonisation, which could be beneficial for preventing further increases in Fp inoculum levels during fallow or non-host periods.

The effects of harvest height modification on Fp vertical colonisation over a summer fallow was investigated at Narrabri using a range of cereal harvest height and stubble management options in a two-year (durum–wheat–chickpea) rotation spanning the 2019–20 growing season. Soil moisture and chickpea yield under the different cereal stubble management treatments established in the 2019 season were measured during the 2020 season.

Site details

Location	Australian Cotton Research Institute, Narrabri, Latitude 30° 20' 28.84" S, Longitude 149° 59' 80.39" E.
Rainfall	In 2019, 195.7 mm of rainfall was recorded at the site, of which 75 mm fell in the growing season (Table 1). Supplementary irrigation was required for durum wheat establishment in 2019. The fallow rainfall (2019–20) was 323.4 mm. In 2020, 726 mm of rainfall was recorded at the site, of which 296.4 mm fell in the growing season. No irrigation was required in 2020.
Chickpea variety	PBA Seamer$^{(\phi)}$
Chickpea sowing date	27 May 2020.
Fertiliser	40 kg/ha Granulock Z®.
Sowing rate	Target 30 plants/m^2.
Insect management	Targeting *Helicoverpa* spp: Fastac Duo® 250 mL/ha (alpha cypermethrin 100 g/L) applied on 20 October.
Disease management	Seed treated with P-Pickel T® (1:5 water dilution applied at 1 L/100 kg seed).
Harvest date	9 November 2020.

Table 1 Rainfall (mm) for Narrabri during 2019 and 2020.

Season	2019 growing season							2019-20 fallow						2020 growing season						
Month	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall (month)	20.8	0.6	15.8	0.6	1.2	6.0	30.0	4.0	89.8	107.8	61.4	47.6	12.8	23.0	21.2	20.6	35.6	73.2	3.6	119.2
Rainfall (season)	75.0							323.4						296.4						
Rainfall (annual)	195.7								615.8											
Decile year*	< decile 1 (367)								> decile 9 (584.2)											
Long term average (annual)	584.2																			

* Decile values are for Narrabri Airport, NSW. Totals for each year and season are reported alongside the long-term average (with decile year indicators)

Treatment

Cereal stubble treatments (established 2019–20)

In 2019, cereal stubble from durum wheat, DBA Lillaroi$^{(\phi)}$ with extensive Fp colonisation was established via inoculation (2 gm–1 row of Fp-colonised grain inoculum). A range of cereal harvest heights (low, medium or high) and harvest trash (trash returned to plot or trash removed off plot) treatments were applied at harvest in 2019.

Stubble heights were measured after durum wheat harvest:

- low stubble averaging 17 cm.
- medium stubble averaging 32 cm.
- high stubble averaging 45 cm.

Before sowing in 2020, an additional stubble management treatment (Kelly chain) was applied to a selection of plots. This treatment was applied in combination with the harvest height treatments, to plots that had previously had cereal harvest trash retained.

Experiment design and statistical analysis

Design:

- Randomised block design, with three replicate blocks, in which
- cereal stubble management treatments (factorial combination of cereal harvest height and harvest trash, plus Kelly chain treatments) were randomly assigned to plots.

Analysis:

- The response variables, length of maximum colonisation and soil moisture content (SMC) percentage, were analysed across sampling times using a linear mixed model framework. Treatments, sampling time and their interaction were the fixed effects, while structural terms were fitted as the randoms.
- Response variables related to chickpea crop performance were also analysed.
- All models were fit using the ASReml-R package in the R statistical computing environment.

Results

Colonisation of cereal stubble by Fp over fallow (2019–20)

The maximum height the Fp colonised in the post harvest cereal stubble increased significantly over the 2019–20 fallow in the medium and tall stubble ($P < 0.001$, Figure 1). Maximum colonisation height increased significantly in medium (+15.2 cm) and tall (+21.4 cm) cereal stubble over the fallow (Figure 1).

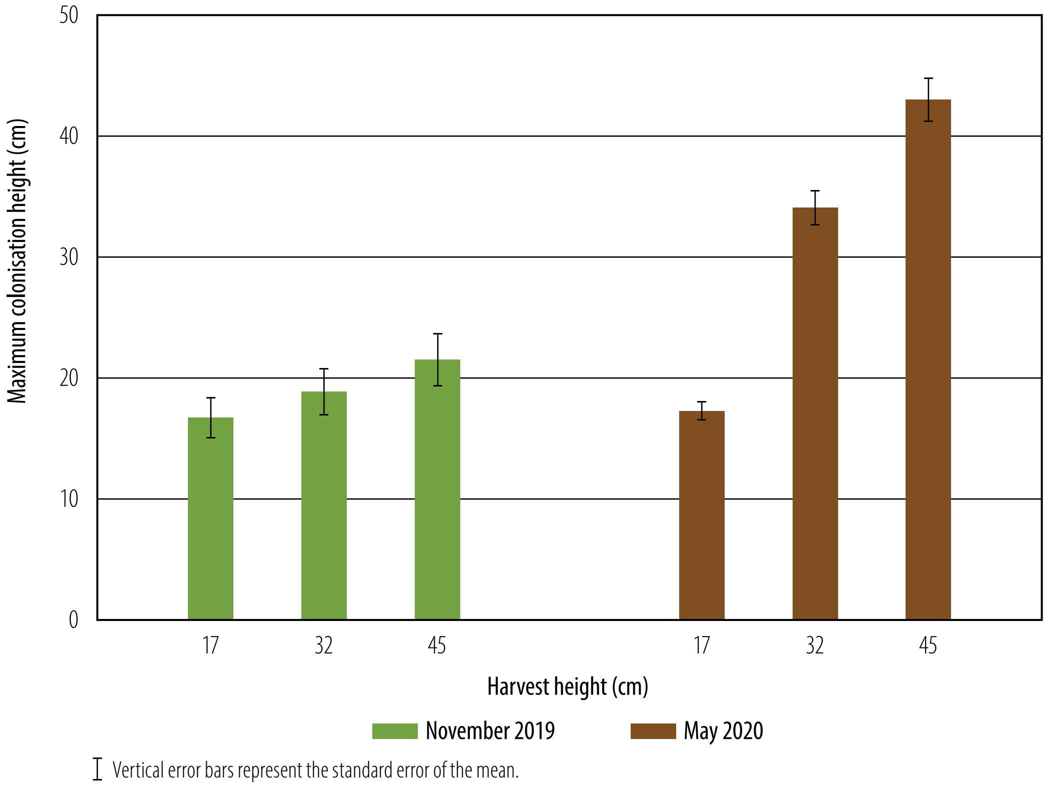


Figure 1 Maximum vertical colonisation (cm) of cereal stubble by *F. pseudograminearum* at the start (November 2019) and end (May 2020) of summer fallow in Narrabri.

Fuserium graminearum height did not change in the short cereal stubble because the fungus had already reached the cut height by harvest in 2019.

The high rainfall (323 mm; Table 1) over the summer was conducive to Fp saprophytic colonisation.

There was no effect of cereal harvest trash treatment (retained, removed or Kelly chained) on maximum colonisation at each time point (*P* >0.1).

These results demonstrate that Fp will continue to colonise to the cut cereal stubble height and suggests that lower cereal harvest heights might be effective at preventing Fp progression in infected standing stubble during the fallow period.

Chickpea establishment (2020)

Chickpea establishment ranged from 32 plants/m^2 to 39 plants/m^2. There was no significant effect from cereal stubble management treatments on establishment i.e., cereal stubble height (*P* = 0.18), harvest trash (retained, removed or Kelly chained) (*P* = 0.42) or stubble height and harvest trash (*P* = 0.61) (data not shown).

Chickpea grain yield (2020)

The cereal stubble management treatments applied in 2019–20 at Narrabri did not affect chickpea yield in the 2020 season i.e., standing cereal stubble height (harvest height) (*P* = 0.98), harvest trash treatment (trash retained, trash removed or Kelly chain) (*P* = 0.93) or a combination of harvest height and trash treatments (*P* = 0.46). Yields were uniform across the experiment, ranging from 2.1 t/ha to 2.2 t/ha.

Good fallow and in-season rainfall (Table 1) could have evened-out any influence that the differential cereal stubble heights and loads might have had on chickpea yield.

Height to lowest pod and crop height (2020)

There was no effect from cereal stubble management treatments applied in 2019–20 on lowest chickpea pod height in the 2020 season i.e., harvest height of standing stubble (*P* = 0.32), trash treatment (*P* = 0.72) or the combination of harvest height and trash treatments (*P* = 0.88).

The chickpea plants grown in shorter stubble were approximately 4 cm taller than plants in the medium and tall stubble treatments (*P* = 0.01, Figure 2). Additional heat or sunlight penetrating through the shorter cereal stubble during early establishment could have promoted chickpea growth, compared with medium or tall stubble. Cereal harvest trash treatments or the combination of stubble height and trash treatments did not affect chickpea canopy height (*P* = 0.72 and *P* = 0.88, respectively). Importantly, the increased canopy height in the short stubble treatments didn't appear to provide any flow-on benefits such as increased yield or improved height of lowest pods.

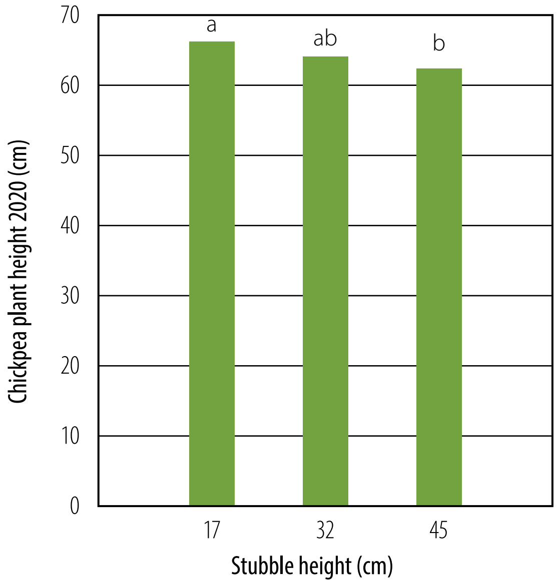
Soil moisture profiles (2019–20)

There were no significant differences in SMC resulting from cereal harvest height or trash treatments (or their interactions) when chickpea was sown in May 2020 (*P* >0.7). There appeared to be no detrimental effects from cereal stubble management treatments on SMC. The good rainfall at Narrabri over the 2019–20 fallow (Table 1) probably would have increased soil moisture over the fallow period and could have evened out the soil moisture at sowing in 2020.

The different stubble treatments might have affected SMC if the 2019–20 fallow had been drier. Instead, Narrabri went from a below decile 1 rainfall in 2019 to above decile 9 rainfall in 2020. Some interactions between SMC and cereal stubble treatments were approaching significance (*P* = 0.06) at chickpea harvest (in 2020) but no clear trends were evident (data not shown).

Conclusions

Growers need to be aware that Fp can vertically colonise the full length of standing cereal stubble in the field after harvest, given sufficient fallow rainfall. In our experiment, the maximum detection of Fp within standing stubble at harvest in 2019 was between 15 cm and 22 cm. By the end of a six-month summer fallow, the maximum Fp recovery height within standing stubble was equal to, or very close to, the cut height of the standing stubble at harvest in 2019 (> 40 cm in tall stubble). Similar results were obtained at a second experiment site located in Breeza, NSW.



Treatments with the same letter are not significantly different.

Figure 2 Height of chickpea plants i.e. canopy height (cm) at maturity appeared inversely correlated to the height of underlying cereal stubble at the Narrabri site.

Implementing lower harvest heights in cereal crops affected by FCR is a useful strategy to limit Fp colonisation in retained standing stubble during fallow and non-host periods, particularly if a wet summer is expected. This could help reduce inoculum build up within the standing stubble beyond the inoculum levels present at harvest. Inoculum spread might be prevented during the harvest of short-stature crops such as chickpea, when inoculum is present above the chickpea harvest height.

Lower stubble height, along with inter-row sowing, could together help lower inoculum levels. This approach could still be used with stripper fronts by stripping grain, then cutting stubble above colonisation height in a second pass to restrict vertical Fp colonisation. The cut fraction could be left between rows as mulch or baled, providing a better option than burning if extensive colonisation occurs during a wet summer fallow. Further vertical Fp colonisation (i.e., above the levels present at harvest) is less likely over a dry summer, but there can still be extensive colonisation during the growing season, with inoculum persisting for 2–4 years in intact stubble.

Modifying cereal harvest height for FCR management appears promising, with the experiment continuing in 2021 to determine the affect these stubble management practises have on FCR risk in a subsequent bread wheat and durum wheat sowing.

Acknowledgements

The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC and the authors thank them for their continued support. Ms Petronaitis thanks the GRDC and NSW DPI for co-funding her GAPP PhD scholarship (BLG211) and Dr David Backhouse and Dr Richard Flavel (UNE), Dr Steven Simpfendorfer (NSW DPI) and Dr Graham Brodie (UniMelb) for their PhD supervision. Rick Graham, Gururaj Kadkol and Kristy Hobson (NSW DPI) are thanked for providing materials for the experiment. Technical assistance provided by Chrystal Fensbo, Finn Fensbo, Jason McCulloch, Stephen Morphett, Michael Dal Santo, Jim Perfrement, Bailey Skewes, Alana Johnson, Scott Goodworth and Stuart Marshman (NSW DPI) is gratefully acknowledged.

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Optimising management strategies to reduce losses from fusarium crown rot in Australian Prime Hard and durum wheats

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Key findings

- Yield loss from Fusarium crown rot (FCR) across all entries averaged 15.1% (0.74 t/ha) under dryland conditions, but was only 6.4% (0.35 t/ha) when moisture stress was reduced during grain filling within the rainfall simulation treatment (supplementary irrigation).
- High residual soil nitrogen (N) levels, accumulated from mineralisation under extended drought conditions, limited N management interactions in 2020 at each site.
- Fusarium crown rot infection caused significant reductions in grain protein (GP) concentrations, between 0.3% and 0.6% units in some varieties, mainly under dryland conditions.
- The combined effect of FCR infection on reducing yield and grain protein led to reductions in grain N removal rates in all varieties of between 10% and 24% (14–30 kg N/ha) under dryland conditions and 4–10% (8–16 kg N/ha) under rainfall simulation.
- Variety selection is one of the key management strategies growers can use to maximise yield and grain quality in the presence of FCR infection.

Introduction

In northern NSW, bread and durum wheat provide the opportunity to produce a high quality, high protein grain (Australian Prime Hard (APH) or Australian Durum Wheat (ADR)), which attracts a price premium. However, this generally requires higher levels of N input to attain the 13–14% protein grade requirement. This relies on applying artificial N, commonly urea, and represents around 30–40% of input costs. Crop production in northern NSW is characterised by summer dominant rainfall and high water holding capacity vertosol soils, especially when moving from the higher rainfall in the eastern areas to drier areas in the west.

Growers that adopt conservation agriculture (CA) practices, such as no-till with stubble retention to optimise stored soil water, have revolutionised crop production and crop reliability, particularly in north-western NSW.

Unfortunately, there is always a compromise. With the adoption of CA, there has been an increased incidence of the stubble-borne pathogen *Fusarium pseudograminearum*, which causes FCR disease (Simpfendorfer et al. 2019). Fusarium crown rot is a basal infection in winter cereals that restricts water flow from the roots to the heads under moisture and/or temperature stress during grain-fill (Figure 1). This results in the formation of the distinctive 'whiteheads' that are associated with yield loss and reduced grain size, which in turn increases screening levels at harvest (Alahmad et al. 2018) (Figure 2). Increasing rates of N application (urea) at sowing can increase this incidence and the yield and quality losses associated with FCR (Simpfendorfer 2020).

Figure 1 Basal browning from FCR in Hellfire(l) wheat, 2021.

Consequently, producing APH and ADR wheat in northern NSW under dryland conditions has an inherently high risk given the level of climatic variability within and between seasons. This balance between risk versus reward is frustrating for growers when harvested grain fails to meet quality specifications in terms of low protein and high screenings (>5%).

Quantitative data on the percentage of grain receivals meeting APH or ADR in northern NSW is not freely available. National Variety Trial (NVT) analysis from 2014–2018 indicates only 25% are achieving APH and 49% ADR. This is supported by estimates from GrainCorp (pers. comm.). The majority of farmers are struggling to get the balance right as maximum yield might not necessarily equate to optimum nitrogen use efficiency (NUE), water-use efficiency (WUE) or profitability.

Research is required to optimise management of dryland durum/APH wheat crops to ensure maximum quality grain profitability under varying scenarios of:

- starting soil water
- variety choice
- risk of FCR
- nitrogen management
- yield potential (in-crop rainfall).

The project findings will underpin an improved matrix of decision support options (pre-crop and in-crop), to minimise the risk and maximise the profitability of producing premium APH and ADR wheat more reliably in northern NSW.

Figure 2 Whiteheads in wheat from fusarium crown rot; image by CSIRO.

Experiment design

Location

Three replicated field experiments were conducted in northern NSW in 2020; all sites had supplementary irrigation capacity to implement rainfall simulation treatments:

- Liverpool Plains Research Station, Breeza: Latitude 31°10’505”S, Longitude 150°25’296”E
- Australian Cotton Research Institute, Narrabri: Latitude 30°12’198”S, Longitude 149°35’589”E
- NSW DPI lease block, Piallamore: Latitude 31°10’1165”S, Longitude 151°03’351”E.

Treatments

- Fully factorial design, three replicates, blocked for in-crop simulated rainfall treatments, randomised design within blocks (288 plots/field site).
- Varieties:
    - three APH bread wheat varieties (LongReach Lancer$^{\Phi}$, LongReach Hellfire$^{\Phi}$ and Suntop$^{\Phi}$)
    - three durum varieties (DBA Lillaroi$^{\Phi}$, DBA Aurora$^{\Phi}$ and DBA Jandaroi$^{\Phi}$).
- Two levels of FCR infection:
    - nil
    - 1.5 g/m row of inoculum applied at sowing to create a moderate level of disease.
- Two target yield potentials:
    - decile 5 (D5) of 5.0 t/ha
    - decile 9 (D9) of 8.0 t/ha seasons.
- Two N application strategies: N budgeted application rates to achieve D5 or D9 yield potential:
    - 100% applied at sowing
    - split 50:50 between sowing and an in-crop application at GS39.
- Two rainfall scenarios:

  - in season rainfall
  - a simulated higher rainfall with 75 mm of supplementary irrigation at GS39 and GS61.

Measurements

A range of detailed measurements were collected at each site and each plot including:

- segmented soil water and nutrition testing (including N) at 0–30 cm, 30–60 cm, 60–90 cm and 90–120 cm depths at sowing and harvest
- plant emergence counts: 3–4 weeks after sowing
- soil water use: throughout the season using neutron probes (0–120 cm)
- agronomic evaluation: NUE, WUE, biomass accumulation/tiller and head number at physiological maturity, grain yield and harvest index
- pathology assessment: incidence and severity of FCR infection at harvest, based on visually rating the extent of browning in tiller bases and recovery of the causal fungus on laboratory media
- grain quality evaluation: screenings (<2.0 mm), grain protein concentration, 1000 grain weight, test weight, moisture and falling number
- grain N removal (kg/ha), calculated as yield × protein × 1.75.

Results

The predicted, wetter than average La Nina conditions throughout 2020 did not eventuate. Rainfall at Narrabri was 24% lower, Breeza 10% lower and Piallamore 21% lower than the long-term average (LTA) for these locations during the growing season (Table 1).

High residual N levels at the three sites (204 kgN/ha Narrabri, 129 kgN/ha Breeza and 196 kgN/ha Piallamore at 0–120 cm) limited the effect of the N management treatments in 2020, with no significant difference in yield or screening levels evident in the across site analysis. The N management strategy slightly increased grain protein levels from 14.9% in the D5 to 15.2% in the D9 treatment.

FCR infection had significant effects on grain yield, screenings, grain protein and grain N removal. This differed by variety and seasonal conditions (Table 2).

Rainfall simulation in 2020 (75 mm of supplementary irrigation at GS39 and GS61) established the benefit versus cost of varying production strategies if the predicted La Nina conditions had occurred compared with the lower, actual rainfall in winter and early spring (dryland) 2020, both in the presence and absence of FCR infection.

Table 1 Seasonal rainfall (mm) at experiment sites in 2020 and long-term average (LTA) (data from nearest BOM site).

Site	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Narrabri	43.6	218.4	114.8	52.6	18.0	27.4	38.0	26.0	28.6	108.8	2.0
LTA	72.8	59.9	50.6	34.5	38.7	39.3	38.2	32.0	32.9	48.4	51.0
Breeza	63.4	156.6	79.4	43.3	54.8	31.4	44.6	28.9	26.2	120.4	5.6
LTA	84.6	69.3	42.9	35.4	44.2	41.9	43.7	34.6	42.6	52.3	64.6
Piallamore	57.8	146.6	59.4	52.2	45.4	39.6	48.4	38.4	26.8	141.2	6.8
LTA	92.2	69.7	50.4	39.2	47.9	49.1	52.7	48.2	53.4	64.8	79.1

FCR infection effects on yield

- Yield loss from FCR was highest for the dryland treatment (averaged 18.9% at Narrabri, 18.4% at Piallamore and 8.3% at Breeza).
- The rainfall simulation treatment reduced the extent of yield loss from FCR, averaging 3.8% at Piallamore, 6.4% at Breeza and 7.6% at Narrabri.

All further data is discussed in the context of an across site analysis of the three field experiments conducted in 2020.

Yield loss was higher under dryland conditions, ranging from 6.8% (0.32 t/ha) in the APH bread wheat LongReach Hellfire$^{\phi}$ up to 21.8% (0.88 t/ha) for the durum DBA Jandaroi$^{\phi}$ (Table 2).

Yield loss was considerably reduced in the rainfall simulation treatment and ranged from not significant for DBA Aurora$^{\phi}$, up to 9.5% (0.41 t/ha) for the durum DBA Jandaroi$^{\phi}$ (Table 2).

Yield loss calculations can hide actual yield values. The rainfall simulation treatment provided a yield benefit of between 0.28 t/ha (DBA Jandaroi$^{\phi}$) to 1.51 t/ha (Suntop$^{\phi}$) over the dryland treatment in the absence of FCR infection. This benefit was even higher in the presence of FCR infection and ranged from 0.70 t/ha (DBA Lillaroi$^{\phi}$) up to 1.78 t/ha (DBA Aurora$^{\phi}$). LongReach Lancer$^{\phi}$ and Suntop$^{\phi}$ were 0.56 t/ha to 1.69 t/ha higher yielding than the other varieties in the presence of FCR infection under dryland conditions.

Under rainfall simulation, Suntop$^{\phi}$ remained the highest yielding variety in the presence of FCR infection providing a benefit of between 0.55 t/ha to 2.64 t/ha over the other varieties (Table 2).

Table 2 Effect of fusarium crown rot infection on yield, screenings, grain protein and grain nitrogen removal in durum and bread wheat varieties under two seasonal conditions (average three sites in northern NSW in 2020).

Season	Variety	Yield (t/ha)		Screening (%)		Protein (%)		Grain N removal (kg/ha)	
		Minus FCR	Plus FCR	Minus FCR	Plus FCR	Minus FCR	Plus FCR	Minus FCR	Plus FCR
Dryland	DBA Aurora	4.94	3.94	4.5	5.3	14.8	14.5	141	111
	DBA Lillaroi	4.49	3.89	3.1	3.7	16.6	16.0	142	119
	Jandaroi	4.06	3.18	2.1	3.7	16.8	16.3	130	100
	LongReach Hellfire	4.63	4.31	4.7	4.5	15.9	15.4	143	129
	LongReach Lancer	5.72	4.82	3.7	4.3	14.0	13.9	155	131
	Suntop	5.58	4.87	5.1	5.6	13.2	13.2	144	125
Rainfall simulation	DBA Aurora	5.84	5.72	3.7	4.0	15.1	14.7	173	165
	DBA Lillaroi	5.06	4.59	3.4	3.4	16.7	16.6	166	150
	Jandaroi	4.35	3.93	2.1	2.3	16.9	17.1	145	132
	LongReach Hellfire	5.32	5.07	3.9	4.1	15.6	15.2	166	153
	LongReach Lancer	6.37	6.02	3.6	3.7	13.9	13.8	176	166
	Suntop	7.08	6.57	3.7	3.9	12.6	12.6	177	165
l.s.d. ($P = 0.05$)		0.258		0.43		0.29		6.8	

Effects of FCR infection on grain quality

- Fusarium crown rot infection increased screening levels by 0.5 (Suntop$^{\phi}$) to 1.6% units (DBA Jandaroi$^{\phi}$) under dryland conditions, apart from LongReach Hellfire$^{\phi}$.
- Under simulated rainfall, FCR did not significantly increase screening levels in any of the varieties (Table 2).
- Only DBA Aurora$^{\phi}$ (+ FCR) and Suntop$^{\phi}$ (± FCR infection) had screening levels above the minimum receival standard of >5% under dryland conditions.
- Except for LongReach Hellfire$^{\phi}$, FCR infection increased screening levels in all entries by from 0.5 (Suntop$^{\phi}$) to 1.6% units (Jandaroi$^{\phi}$) under dryland conditions only (Table 2).
- Neither LongReach Lancer$^{\phi}$ and Suntop$^{\phi}$ had reduced grain protein under dryland conditions.
- In DBA Aurora$^{\phi}$ and LongReach Hellfire$^{\phi}$, fusarium crown rot infection reduced grain protein concentrations by 0.4% under simulated rainfall (Table 2).

Effects of FCR infection on grain N removal

- Fusarium crown rot infection reduced grain N removal in all varieties for dryland and simulated rainfall treatments.

- FCR infection significantly reduced grain N removal. In LongReach Hellfire$^{\phi}$, this was 10% (14 kg N/ha) and up to 24% (30 kg N/ha) in DBA Jandaroi$^{\phi}$ under dryland conditions (Table 2).
- The effect of FCR infection was reduced under simulated rainfall and ranged from 4% (8 kg N/ha) for DBA Aurora$^{\phi}$ up to 10% (16 N kg/ha) in DBA Lillaroi$^{\phi}$ (Table 2).

Conclusions

Although varietal selection is one of the key management strategies to maximise yield in the presence of FCR infection, it must not come at the cost of yield potential in the absence of this disease. LongReach Hellfire$^{\phi}$ for example, despite exhibiting the lowest yield loss from FCR infection (6.8%) under dryland conditions was still 0.51 t/ha to 0.56 t/ha lower yielding than LongReach Lancer$^{\phi}$ and Suntop$^{\phi}$ respectively. Similarly, although Suntop$^{\phi}$ was generally the highest yielding APH variety, LongReach Lancer$^{\phi}$ had superior grain quality with lower screenings and higher grain protein concentrations. Our results also underlined the susceptibility of durum varieties in the presence of FCR, particularly under dryland conditions.

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Fusarium crown rot seed fungicides: independent field evaluation, 2018–2020

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Key findings

- Current fungicide seed treatments registered for the suppression of Fusarium crown rot (FCR) inconsistently reduce the extent of yield loss from this disease.
- Victrato® had consistent and stronger activity than other seed treatments on limiting yield loss from FCR.
- Under high FCR infection levels significant yield loss may still occur with the use of Victrato® in drier seasons.
- Fungicide seed treatments, including Victrato®, should not be considered standalone control options for FCR but can be used as an additional tool within existing integrated disease management strategies for FCR.

Introduction

Fusarium crown rot (FCR), caused predominantly by the fungal pathogen *Fusarium pseudograminearum* (Fp), is a major constraint to winter cereal production across Australia. A range of integrated management strategies including crop rotation, varietal selection, inter-row sowing, sowing time, stubble and fallow management are required to minimise losses.

A number of fungicide seed treatments have been registered to suppress FCR in recent years with a further product, Victrato® from Syngenta, available to Australian growers before sowing in 2024.

Although chemical companies conduct their own widespread field evaluation across Australia, growers and their advisers value independent evaluation of the potential relative fit of these fungicide seed treatments within integrated management strategies for FCR.

Evaluation parameters

- A total of 11 replicated plot experiments (generally 2 × 10 m with minimum of three replicates).
- Randomised complete block design.
- The winter cereal crop and number of varieties differed between experiments with wheat (W), barley (B) and/or durum (D) evaluated in each experiment (Table 1).
- Inoculated versus uninoculated treatments with inoculated plots infected by Fp inoculum grown on sterilised wheat grain (2.0 g/m of row at sowing). This ensures high (>80%) FCR infection in inoculated plots with uninoculated plots only exposed to any background levels of Fp inoculum naturally present. This allows for comparison between yield effects of the various fungicides when FCR is present or absent.
- Fungicide seed treatments were applied in 1 kg to 3 kg batches using a small seed treating unit to ensure good even coverage of seed.
- Yield loss from this disease is measured as the difference between inoculated and uninoculated treatments.

Locations

- Eleven sites: NSW from 2018–2020 (Table 1).
- Two sites: WA, Merredin and Wongan Hills, 2018.
- One site: Vic, Horsham, 2018 only (Table 1).

Treatments (6)

- Nil
- Vibrance® (difenoconazole + metalaxyl-M + sedaxane at 360 mL/100 kg seed)
- Rancona® Dimension (ipconazole + metalaxyl at 320 mL/100 kg seed)
- EverGol® Energy (prothioconazole + metalaxyl + penflufen at 260 mL/100 kg seed)
- Victrato® (Tymirium® technology based on cyclobutrifluram at 40 g and/or 80 g active ingredient/100 kg seed).

Figure 1 Fusarium crown rot infection. Left hand plant affected, right hand plant unaffected.

Results

Averaged across all cereal entries

Low in-crop rainfall between March and September reduced the yield potential at each site in each season and increased the extent of FCR yield loss. This was highlighted in the nil seed treatments where yield loss ranged from 11–48% in 2018, 14–20% in 2019 and 11–37 % in 2020 (Table 1).

- Vibrance® and Rancona® Dimension significantly reduced the yield loss from FCR in six of 14 experiments.

- EverGol® Energy reduced FCR yield loss in eight of 14 field experiments (Table 1).
- Victrato® significantly reduced yield loss from FCR in 10 of 10 experiments at the 40 gai rate and 14 of 14 field experiments at the 80 gai rate. Yield loss reduction was also generally stronger with this product compared with the other fungicide seed treatments, and better at the 80 gai than 40 gai rate.
- Significant yield loss still occurred with Victrato® (9–26 %) at the drier sites. The dry conditions increased the yield loss from FCR (>35% in nil seed treatment). However, the 80 gai rate at these disease-conducive sites at least halved the yield loss compared with the nil seed treatment.
- Yield losses from FCR were lower at the wetter sites (<26%). Victrato® reduced this yield loss to <6%, with increased yields at some sites due the effects from reduced background levels of FCR infection.
- Moisture stress during grain filling is known to exacerbate yield loss from FCR and favour Fp growth within the base of infected plants. Dry soil conditions throughout the season at the seeding depth is likely to have restricted the fungicide actives from moving off the seed coat and into surrounding soil. Consequently, uptake of the fungicide active by root systems would be restricted. This would reduce fungicide movement into the sub-crown internode, crown and tiller bases where FCR infection is concentrated. It is currently not clear whether reduced efficacy under drier conditions could be related to one or both of these factors.

Table 1 Effect of various fungicide seed treatments on yield loss (%) associated with Fusarium crown rot infection in 14 replicated inoculated versus uninoculated field experiments: 2018–2020.

Year	**Location**	**Crop**[A]	**Rainfall**[B] **(mm)**	**Yield**[C] **(t/ha)**	**%Yield loss from Fusarium crown rot**[D]					
					Nil	**Vibrance®**	**Rancona® Dimension**	**EverGol® Energy**	**Victrato® 40 gai**[E]	**Victrato® 80 gai**[E]
2018	Merriwagga, NSW	2W	63	1.44	44	nd[F]	nd	32	25	18
	Mallowa, NSW	2W	73	1.73	48	nd	nd	nd	26	24
	Gilgandra, NSW	2W	93	2.14	42	35	27	28	16	9
	Merredin, WA	2W	182	2.66	35	nd	nd	nd	23	13
	Horsham, Vic	2W	185	2.56	21	nd	nd	nd	+2I	+5
	Wongan Hills, WA	2W	291	3.27	11	nd	nd	nd	1	0
2019	Gulargambone, NSW	W/B	141	3.12	20	2	5	9	–G	+2
	Narrabri, NSW	W/B	200[H]	4.01	14	10	9	7	–G	6
2020	Boomi, NSW	3W/D	202	4.91	37	nd	28	nd	24	18
	Gurley, NSW	W/B	234	6.50	13	nd	nd	nd	–G	1
	Rowena, NSW	W/B	247	6.21	12	7	nd	4	–G	2
	Trangie, NSW	3W/D	412	4.13	26	20	23	19	4	2
	Gilgandra, NSW	3W/D	420	4.07	12	6	7	7	3	0
	Armatree, NSW	3W/D	425	4.37	11	nd	nd	7	3	+1

[A] Winter crop type variety numbers where W = wheat variety, B = barley variety and D = durum variety.

[B] In-crop rainfall from March to September. Critical time for fungicide uptake off seed and expression of FCR.

[C] Yield in uninoculated treatment (average of varieties) with nil seed treatment.

[D] Average percentage yield loss from FCR for each seed treatment (averaged across varieties) compared with the uninoculated/nil seed treatment.

[E] gai =grams of active ingredient.

[F] nd = no difference, % yield loss from FCR with fungicide seed treatment not significantly different from the nil seed treatment. Values only presented when reduction in % yield loss from FCR is significantly lower than the nil seed treatment.

[G] 40 gai treatment not included at these sites.

[H] Two irrigations, at GS30 and GS39 of 40 mm and 30 mm respectively, due to drought conditions.

[I] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced the effects from both the added FCR inoculum as well as natural background levels of fusarium present at that site.

Comparative effects on durum versus bread wheat

Durum wheat is known to have increased FCR susceptibility compared with many wheat and barley varieties. The increased FCR prevalence in farming systems, aided by the adoption of conservation cropping practices including retaining cereal stubble, means durum has been removed from rotations due to this risk. The durum variety DBA Lillaroi$^{\phi}$ was compared with three bread wheat varieties at four sites in 2020 (Table 2).

Table 2 Effect of Victrato® seed treatment at two rates on yield loss (%) from Fusarium crown rot in three bread wheat (W) and one durum (D) variety at three sites in 2020.

	Average yield loss from Fusarium crown rot (%)^{AB}											
Site:	**Boomi 2020**			**Trangie 2020**			**Gilgandra 2020**			**Armatree 2020**		
Treatment:	**Nil^{C}**	**Victrato®**		**Nil**	**Victrato®**		**Nil**	**Victrato®**		**Nil**	**Victrato®**	
Variety		**40 gai**	**80 gai**		**40 gai**	**80 gai**		**40 gai**	**80 gai**		**40 gai**	**80 gai**
Lancer (W)	29	23	20	30	10	8	13	2	0	9	4	+7
Mitch (W)	39	18	11	13	+2	+5	9	2	1	5	0	0
Trojan (W)	34	22	18	20	4	2	12	1	0	14	2	2
Lillaroi (D)	48	32	24	45	11	6	16	5	+2	14	6	+2

[A] Average percentage yield loss from FCR for each seed treatment compared with the uninoculated/nil seed treatment for that variety.

[B] Results with a plus in front of them show that the treatment yielded higher than the uninoculated nil treatment (i.e. the treatment reduced affects from both the added FCR inoculum as well as natural background levels of Fusarium present at that site.

[C] Nil = no seed treatment.

FCR with nil seed treatment caused a generally higher yield loss in the durum (14–48%), compared with the three bread wheat varieties (5–39%).

The bread wheat Mitch$^{\phi}$ tended to have reduced yield loss from FCR compared with the other entries, apart from at the Boomi site (Table 2).

Yield loss from FCR was reduced with Victrato® in both the bread wheat and durum varieties. Even at the drier, higher, loss site at Boomi in 2020, the 80 gai rate halved the extent of yield loss in the durum variety Lillaroi$^{\phi}$, with better efficacy in the other three sites.

Conclusions

Current fungicide seed treatments registered for suppressing FCR can inconsistently reduce yield loss extent from this disease. Victrato® appears to have more consistent and stronger ability to limit FCR yield loss.

In the absence of fungicide seed treatments, average yield loss from FCR infection across the 14 sites over three seasons was 24.7%. The 80 gai rate of Victrato® significantly reduced yield loss from FCR to an average of 6.1% across the 14 field experiments. Under high infection levels as created with artificial inoculation in these experiments, there can be significant yield loss (up to 24% measured), particularly in drier seasons.

Dry soil conditions around seeding depth throughout a season might reduce the uptake of fungicides applied to the seed coat. Drier seasons also exacerbate FCR expression, which would place additional pressure on fungicide seed treatments. However, even under these conditions Victrato® at the 80 gai rate still at least halved the level of yield loss from FCR.

Fungicide seed treatments, including Victrato®, should not be considered standalone control options for FCR. Rather, they should be used as an additional tool within existing integrated disease management strategies for FCR.

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Fungicide resistance in wheat powdery mildew in NSW and northern Victoria, 2020

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Key findings

- The wheat powdery mildew (WPM) pathogen has a very high risk of developing fungicide resistance.
- Resistance to Group 11 (quinone outside inhibitors, QoI) fungicides has been detected across most of the southern growing region (Tasmania, Victoria and South Australia) and was detected in parts of NSW in 2020.
- Widespread plant resistance or reduced sensitivity to Group 3 demethylation inhibitors (DMIs) is considered an extremely high risk with a DMI 'gateway' mutation detected at very high frequencies across NSW and northern Victoria in 2020.
- Careful use and rotation of available fungicide actives will help control the spread of resistance in WPM.
- Agronomic practices that minimise disease pressure, reduce the need to apply fungicides.
- Good management will help protect the long-term efficacy of current fungicides.

Introduction

A key challenge in the 2020 winter cropping season across much of New South Wales and northern Victoria were WPM levels, caused by *Blumeria graminis* f. sp. *tritici* (Bgt), High mineralised soil nitrogen (N) levels following 2–3 years of drought resulted in thick canopies and high leaf nitrate levels, favouring WPM infection. Infections progressed into the wheat heads late in the season in some regions (Figure 1).

A range of bread wheat and durum varieties were infected, especially Scepter$^{\Phi}$ and Vixen$^{\Phi}$ (Table 1), which are susceptible (S) to very susceptible (VS) to WPM and widely grown across the affected regions. Wheat powdery mildew occurs predominantly in high-value, irrigated cropping regions, which create ideal conditions for disease development. However, the disease was also prevalent in a number of dryland crops in the wet 2020 season.

Concerns around fungicide management arose with control being less than desirable. Contributing factors included:

- potential reduction in fungicide sensitivity and/or resistance in the pathogen
- application timing – i.e., too much time between stripe rust fungicide timings to cope with the quicker cycle time and rapid infection for WPM
- adequate spray coverage, especially of heads, which are a horizontal target.

Many crops had 2–4 in-crop fungicide applications during the season, yet WPM continued to progress. *Bgt* has a remarkable ability to adapt to fungicide treatments, which makes this pathogen a high risk for fungicide resistance to develop.

In response, a collaboration with the Centre for Crop Disease Management (CCDM) based at Curtin University in WA and NSW DPI was established to collect and analyse WPM samples for levels of fungicide resistance.

Figure 1 Powdery mildew in a wheat head. Photo courtesy Chris Toohey.

Table 1 Location of 19 wheat powdery mildew samples collected across NSW in 2020 and frequency of DMI (triazole) gateway and QoI (strobilurin) mutations.

Location	State	Variety	DMI F136	QoI A143
Katamatite	NE Vic	Scepter$^{\phi}$	100%	90%
Katamatite	NE Vic	Scepter$^{\phi}$	100%	90%
Cobram	NE Vic	Scepter$^{\phi}$	100%	46%
Cobram	NE Vic	Scepter$^{\phi}$	100%	28%
Balldale	SE NSW	Scepter$^{\phi}$	100%	98%
Walbundrie	SE NSW	Scepter$^{\phi}$	100%	5%
Rennie	SE NSW	Suntop$^{\phi}$	85%	27%
Rennie	SE NSW	Scepter$^{\phi}$	85%	20%
Deniliquin	SW NSW	Scepter$^{\phi}$	99%	35%
Deniliquin	SW NSW	Scepter$^{\phi}$	99%	20%
Deniliquin	SW NSW	Scepter$^{\phi}$	83%	20%
Jerilderie	SE NSW	Scepter$^{\phi}$	100%	37%
Hillston	SW NSW	DBA Vittaroi$^{\phi}$	96%	21%
Hillston	SW NSW	Vixen$^{\phi}$	94%	3%
Hillston	SW NSW	Vixen$^{\phi}$	85%	6%
Yenda	SW NSW	LongReach Cobra$^{\phi}$	100%	44%
Yenda	SW NSW	Vixen$^{\phi}$	100%	12%
Edgeroi	NE NSW	DBA Lillaroi$^{\phi}$	82%	29%
Wee Waa	NW NSW	DBA Bindaroi$^{\phi}$	62%	51%

Wheat powdery mildew is favoured by susceptible wheat varieties growing in mild and humid weather (15–22 °C, relative humidity >70%), with a dense crop canopy, high N levels, good soil moisture profiles and extended periods of damp, humid conditions under the canopy. *Bgt* survives on wheat stubble and volunteer wheat plants (Figure 2). Wind can spread spores to crops over moderate distances (kilometres). The pathogen is crop specific and only infects wheat, not barley or other grain crops. These crops can also get powdery mildew, but caused by different species of the pathogen.

Figure 2 Powdery mildew on a wheat leaf.

Location

Agronomists from across NSW and northern Victoria submitted infected wheat samples.

Survey design

Collaborating agronomists collected plants infected with WPM and sent them to Tamworth for processing. This was to help ensure viability in transit when sent to CCDM in WA for molecular analysis of frequency of mutations for DMI (F136 gateway mutation, Group 3, triazoles) and QoI (A143 mutation, Group 11, strobilurins) resistance within the WPM population in each sample.

Active ingredients that are examples of Group 3, DMI triazoles include: tebuconazole, propiconazole and flutriafol.

Active ingredients that are examples of Group 11, strobilurins include: azoxystrobin and pyraclostrobin.

CCDM analysed 19 viable WPM samples (Table 1) collected from across NSW and northern Victoria. The sample distribution was:

- north-eastern Victoria (4)
- south-eastern NSW (5)
- south-western NSW (8)
- north-eastern NSW (1)
- north-western NSW (1).

The F136 mutation, also known as a gateway mutation, has been previously associated with reduced sensitivity to some DMI (Group 3, triazole) fungicides. This mutation is normally found together with other mutations that are ultimately responsible for the resistant phenotype observed to cause various fungal pathogens in the field.

Once the frequency of the F136 and other mutations in a WPM pathogen population reach moderate levels, then reduced sensitivity to DMI fungicides is possible under field conditions.

Very high frequencies can cause resistance to fungicides and spray failure under field conditions with some DMIs.

The F136 gateway mutation itself does not necessarily mean field failure. It is however an initial warning that issues with continued DMI fungicide use exist. Field efficacy of DMI fungicides in the presence of this gateway mutation can vary considerably with individual DMI actives, depending on what other mutations exist once this gateway mutation occurs within a WPM population.

Further laboratory and glasshouse testing is continuing with CCDM to determine the relative sensitivity of these WPM populations to various DMI actives.

Results

- All 19 NSW and Victorian WPM samples had an F136 frequency of between 62–100% (Table 1).
- The high frequency of DMI resistance across NSW and Victoria was surprising, but not unexpected given the lack of WPM control in these crops in 2020.
- A lower frequency of the QoI A143 mutation was detected, ranging from 51–98% (Table 1). The presence of this mutation in the WPM pathogen population is associated with complete resistance to Group 11 strobilurin fungicides (e.g. azoxystrobin). At frequencies above 50%, it can become ineffective under field conditions. This is alarming, as four of the WPM pathogen populations appear to have dual resistance to DMI (Group 3) and QoI (Group 11) modes of action (MOA).
- The strobilurins are known to rapidly succumb to fungicide resistance, which is why they are always mixed with another MOA fungicide group (usually DMIs, Group 3). The high frequency of DMI F136 in the NSW and Victorian WPM pathogen populations is likely to be increasing the rate of selection for QoI resistance.
- A concerning aspect in relationship to the QoI A143 resistance gene, is that it confers cross resistance to all fungicides within the Group 11 mode of action group (strobilurins).

Management implications for growers

Planning of fungicide rotations needs to consider all fungal pathogens that could be present in the crop, otherwise the fungicide treatment for one pathogen might select for resistance in another. For example, while there is little evidence of fungicide resistance developing in rust populations globally, growing S–VS rust varieties means the only control option is fungicides. This can potentially have off-target selection pressure on the development of other fungal pathogens such as *Bgt*, which is very prone to fungicide resistance development.

Careful fungicide use will minimise the risk of fungicide resistance developing in WPM in Australia and help ensure fungicides longevity.

Advice to NSW and Victorian wheat growers includes:

- **avoid using Group 11** fungicides in areas where resistance to QoIs has been reported
- **minimise using Group 3** fungicides that are known to have compromised resistance
- **monitor Group 3** fungicides closely, especially where the gateway mutation has been detected
- **rotate Group 3** fungicide actives within and across seasons. Do not use the same Group 3 product twice in succession
- **avoid** more than three applications of fungicides containing a **Group 3** active in a season
- **Group 11** fungicides should be used as a preventative, rather than for curative control, and should be rotated with effective **Group 3** products with no known resistance
- **avoid** applying **Group 7** and **Group 11** products more than once each growing season, either alone or in mixtures. This includes in-furrow or seed treatments, as well as subsequent foliar sprays. Combined seed and in-furrow treatments count as one application.

Growers and agronomists who suspect DMI reduced sensitivity or resistance should contact the CCDM's Fungicide Resistance Group at frg@curtin.edu.au. Alternatively, contact a local plant pathologist or fungicide resistance expert to discuss the situation. A list of contacts and further information on fungicide resistance and its management is on the AFREN website (https://afren.com.au/).

Conclusions

NSW and Victorian growers need to be aware that issues with WPM fungicide resistance already exist, which could result in reduced fungicide sensitivity or potentially spray failures with DMI (triazoles) and QoI (strobilurin) fungicides.

CCDM is continuing to test the level of reduced sensitivity to different DMI actives in these WPM pathogen populations, which will be communicated to growers and their advisers.

Fungicide resistance is a real issue and needs to be managed using an integrated approach. This will help limit further resistance development within WPM pathogen populations and in other at-risk fungal pathogens (e.g., net blotches in barley, and yellow spot or septoria tritici blotch in wheat).

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