Do long season wheat cultivars maximise yield potential under irrigation in subtropical Australia?

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Abstract
Irrigated wheat producers in QLD and northern NSW have for the last decade been advised to grow quicker maturing cultivars with high levels of lodging resistance. The recent identification of lodging resistant long-season cultivars has prompted this study to examine whether lodging resistant long-season cultivars possess higher yield potential than quicker maturing cultivars. A key component of the study methodology involved the comparison of long season cultivars (sown early) with quick maturing cultivars (sown later), such that they flowered at the same time. Results showed that early-sown longer season cultivars generally yielded more than the late sown, quick maturing cultivars, but this was not observed consistently across all environments. The yield advantage was predominantly expressed at environments that experienced hot and dry conditions during grain filling where irrigation supply may not have matched crop demand.

Keywords
Wheat phenology, time of sowing, irrigation, lodging.

Introduction
One of the management techniques being promoted to improve wheat yields in temperate rainfed production systems of Australia is the use of longer season cultivars sown early in the sowing window (e.g. Coventry et al. 1993; Hunt et al. 2015). Early sowing of long season genotypes is considered more likely to increase grain yield when lodging is prevented (Stapper and Fischer 1990), and when used in years with sufficient stored soil water and early seasonal rainfall (van Rees et al. 2014). And although Hunt et al. (2015) did not observe yield benefits in early season genotypes in subtropical Australia, their subtropical environments experienced low rainfall, and may not have had enough inherent yield potential to show the yield advantage often associated with early sown wheat.

Unfortunately in irrigated wheat production systems of Queensland and northern NSW, the longer season cultivars favoured in rainfed production systems have yielded poorly in comparison to quicker maturing cultivars due to their increased lodging susceptibility (Peake et al. 2014; Peake et al. 2016). This has constrained irrigated wheat production in the region to the use of a small number of quick maturing cultivars with high levels of lodging resistance, capping yield potential at 8 - 9 t/ha (Peake et al. 2014). Nevertheless, recent identification of more lodging resistant long season germplasm (Peake et al. 2015) has stimulated further interest in whether longer season germplasm could provide increased yield potential for irrigated producers in subtropical Australia. This study aims to determine whether newly released longer season cultivars with improved lodging resistance can provide increased yield potential in comparison to quick-maturing cultivars, in irrigated production systems of Queensland and northern NSW.

Methods
A key aspect of the methodology was the consideration of synchronised flowering time. The comparison of cultivars with different phenology is best conducted by ensuring cultivars flower at the same time (Peake et al. 2015; 2016), due to the importance of climatic conditions at anthesis in determining grain yield. This comparison is logically achieved by sowing longer-season cultivars on an early sowing date, and quick maturing cultivars on a later sowing date, such that they subsequently flower together during the window considered to achieve the best balance between avoiding both frost and high temperatures during grain filling. However, the variation experienced in phenological response for specific cultivars between locations and seasons prevented comparison of the same long-season and quick maturing cultivars at each environment, while also achieving synchronised flowering.

We therefore conducted yield comparisons between cultivars that flowered during a common flowering period at each environment, meaning that the cultivars included in the analysis varied between environments. The common flowering period was defined as the period bordered by the earliest flowering date of any cultivar sown on the late sowing date, and the latest flowering date of any cultivar sown on the early sowing date. Cultivars flowering within this window were then used in two alternative yield comparisons termed (1) ‘average cultivar performance’ and (2) ‘optimum cultivar performance’. ‘Average cultivar performance’ was the mean yield of cultivars flowering in the crossover flowering period defined for the environment, for a given sowing date (early or late). ‘Optimum cultivar performance’ was determined by comparing the highest yielding cultivars for each sowing date from the crossover flowering period. The cultivars included in the study were those identified as having moderate to high levels of lodging resistance (i.e. MR-MS or better) and consistently high yields in initial irrigated screening experiments (Peake et al. 2014; 2015). The cultivars were Sentinel, Mitch, Lancer, Cobra, Trojan, Suntop, Crusader, Merinda, Livingston, Kennedy, Dart, Bellaroi, and Caparoi. Sowing dates for each trial are listed in Table 1a.

Experimental design

Experiments were conducted at four locations representing different climatic regions over three growing seasons (2014-2016). Plots at Narrabri, Emerald and Gatton were sown to a standard plot configuration of 2 m wide x 7 m long and were trimmed to 5 m length at harvest. Longer, narrower plots were sown at Spring Ridge 1.4 m wide by 12 m and trimmed to 10 m at harvest. All experiments were irrigated to minimise water stress and each environment had over 500 mm of water available during the growing season through a combination of stored soil water at sowing, rainfall and irrigation. Pests and diseases were successfully controlled using a range of agrochemicals as preferred by the local co-operators, with the exception of a powdery mildew outbreak during late grain filling at Narrabri in 2014. The trials were arranged as randomised complete block designs with latinising so the same treatment combinations of agronomic regimes by cultivar do not occur in the same row or column. Plots were grown using recommended best practice for irrigated wheat production in QLD and NNSW, where N requirement over and above soil N was applied in-season in order to minimise lodging risk. More than 270 kg/ha of soil + fertiliser N was supplied to all experiments such that N was considered non-limiting. Plant growth regulators (chlormequat chloride + trinexapac ethyl) were also applied according to label rates in a mixture at GS30-31. Grain yield is reported at 12% moisture. Lodging was calculated as average grainfill lodging as described by Peake et al. (2016).

Statistical analysis

A combined trial analysis was conducted using linear mixed models with individual trial designs and separate residual variances fitted for each trial. The site by year combinations were collapsed into a single factor called ‘environments’. The fixed effects were environment * (sowing date/cultivar) and due to the nature of cultivars did not form a full factorial combination. These fixed effects were partitioned in follow up analyses to test the cases where flowering occurred in a common window for the early and late sowing date treatments (or maximum yielding cultivars flowering in a common window), and also to explore the environment by sowing date effects within the two agronomic regimes separately. The use of different cultivars for the early and late sowing dates confounds sowing date with the cultivars used to represent them and a different selection of cultivars could therefore give a different result. Emerald 2015 was eliminated from all analyses as optimum sowing dates were not achieved in the field and no common flowering period between sowing dates achieved. Several environments (Narrabri 2015, Spring Ridge 2015 and Spring Ridge 2016) were eliminated from the analysis of average grainfill lodging due to low levels of lodging with a large number of zero values meaning analysis of these environments was problematic. Narrabri 2014 and 2015 were eliminated from the analysis of flowering day of year (DOY) as replicated flowering data was not collected at this location. The statistical package ASReml (version 3.0) within ‘R’ (Butler et al. 2009) was used to conduct the analyses. The least significant difference tests (LSD’s) were used to do pair-wise comparisons of treatments for significant terms, with the level of significance set at 5% for all comparisons.

Results and Discussion

A key method of the study was the use of alternative sowing dates to match cultivar phenology and create a crossover flowering period common for cultivars sown on both sowing dates. Results from the ‘average cultivar performance’ analysis showed that this objective was achieved successfully, with only 0-2 days difference achieved in flowering date between the early and late sown cultivar groups (Table 1b). Individual cultivars identified in the optimum cultivar performance analysis also flowered at similar times, with only one comparison having a flowering difference of more than 7 days (Table 1c).

Table 1. (a) Sowing dates for the 'early' and 'late' sown trials, (b) comparison of anthesis date for early and late sown cultivar groups from the analysis of 'average cultivar performance, (c) cultivars identified in the 'optimum cultivar performance' analysis for the 'early' and 'late' sowing dates, and a breakdown of the highest yielding cultivars for the quality classification groups (d) Australian Prime Hard (APH) and (e) non-APH.

	2014			2015		2016	
	Emerald	Narrabri	Spring Ridge	Narrabri	Spring Ridge	Gatton	Spring Ridge
	(a) Sowing date for the 'early' and 'late' sown trials at each environment						
Early	13-May	15-May	19-May	25-May	18-May	17-May	19-May
Late	30-May	30-May	11-June	9-June	9-June	25-May	14-June
	(b) Flowering difference between sowing date groups from the 'average cultivar performance' analysis (Fig. 1a)						
F.Diff	2	0.4#	0.1	-0.8#	1	0.6	2
	(c) Optimum cultivars and flowering difference between them from the 'optimum cultivar performance' analysis (Fig. 1b)						
Early	**Mitch**	**Cobra**	Mitch	**Cobra**	**Cobra**	**Mitch**	Trojan
Late	Suntop	Livingston	**Trojan**	Cobra	Cobra	Kennedy	**Cobra**
F.Diff	3	-1	-0.7	8	6*	5*	2*
	(d) Highest yielding APH cultivars						
Early	Kennedy 6.40	Lancer 6.04	Lancer 8.11	Lancer 8.30	Suntop 8.42	Lancer 6.00	Lancer 7.97
Late	Suntop 6.31	Crusader 8.28	Wallup 8.86	Suntop 6.66	Wallup 7.32	Kennedy 7.26	Suntop 7.59
F.Diff	9*	0	-2	8	6	-0.3	4*
	(e) Highest yielding non-APH cultivars						
Early	**Mitch 6.85**	**Cobra 8.51**	Mitch 8.67	**Cobra 8.65**	**Cobra 9.54**	**Mitch 8.31**	Trojan 8.48
Late	Livingston 6.01	Livingston 8.44	**Trojan 9.62**	Cobra 7.07	Cobra 8.08	Livingston 6.60	**Cobra 8.73**
F.Diff	-2*	-1	-0.7	7	-6*	-1*	**2***
LSD_{Yield}	0.79	1.30	0.35	0.82	0.27	0.61	0.28

***** Indicates significantly different flowering dates between cultivars. F.Diff **-** the difference in flowering date between the early and late sowing date (negative data indicates the later sowing date flowered earlier). Shading indicates that the cultivar yield was not significantly different to the optimum cultivar yield within the relevant environment. **Bold type** indicates the highest yielding cultivar within a single environment.
#Narrabri 2014 and 2015 were not statistically analysed for flowering date as only one replicate was assessed for this variable.

Results of the average cultivar performance analysis showed that the longer season cultivars were significantly higher yielding than the quicker maturing cultivars at five of the seven environments (Figure 1a), with the largest yield differences of 1.4 and 1.2 t/ha observed at Narrabri and Spring Ridge in 2015. However, the longer season cultivars had significantly decreased yield compared to the quicker maturing cultivars at Narrabri and Spring Ridge in 2014 (by 0.8 and 0.4 t/ha respectively). The optimum cultivar performance analysis (Figure 1b) gave slightly different results, with the 'optimum' early sown cultivar significantly higher yielding at just three environments (Narrabri and Spring Ridge in 2015, and Gatton in 2016), and the late sown cultivar significantly higher yielding at one environment (Spring Ridge 2014).

The yield advantage of early season cultivars at Narrabri and Spring Ridge in 2015 were associated with a hot and dry grain filling period during which irrigation supply may not have matched crop demand. This may have elicited an adaptive response from the longer season cultivars, such as the deeper root systems produced by longer duration crops (Thorup-Kristensen et al. 2009). The reversal of this yield advantage at the same sites in 2014 when the late season cultivar group had higher yield may have been associated with the higher levels of lodging observed at these sites, with the quick maturing cultivar group having significantly less lodging at Narrabri in 2014, and numerically (but not significantly) less lodging at Spring Ridge 2014. The results therefore indicate that the use of longer season cultivars sown early did not convey a yield advantage in all environments compared to the use of quicker maturing cultivars sown later, when comparisons were made between cultivars flowering in similar climatic conditions. However, the early-sown, longer season cultivars did have increased yield on more occasions than the late-sown quick maturing cultivars. Further research is necessary to confirm the physiological basis of these trends, and could help identify beneficial traits of interest to wheat breeding programs. The highest yielding cultivar at each environment was a non-APH cultivar (Table 1c, d, e), although an APH cultivar was not significantly lower in yield to the 'optimum' cultivar at four of the environments. However at the southernmost environment

(Spring Ridge), APH cultivars were significantly lower yielding than the highest yielding non-APH cultivars in all years, suggesting APH cultivars do not possess the same yield potential at this location as Cobra and Trojan, which were bred for environments in southern Australia.

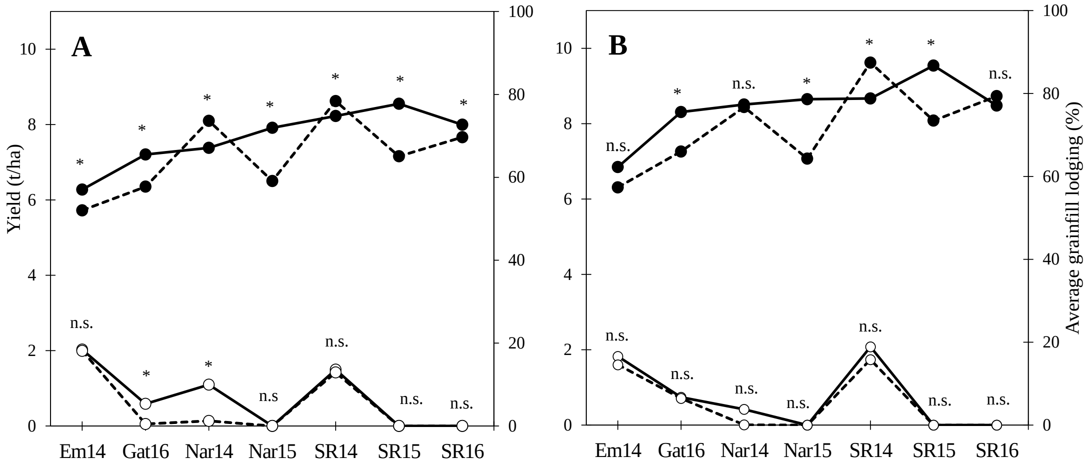

Figure 1. Yield (●) and grainfill lodging (○) for the early (——) and late (— — —) sown treatments from the analyses of (A) average and (B) optimum cultivar performance at Emerald (Em), Gatton (Gat), Narrabri (Nar) and Spring Ridge (SR) during 2014-16. Pairwise comparisons are marked as * (significantly different at p<0.05) or 'n.s.' (not significantly different).

Conclusion

Results of the study showed that for cultivars flowering within the common flowering window, longer season cultivars sown early tended to have higher yields than the late sown, quick maturing cultivars, but this was not observed consistently across all environments. In particular the early-sown long season cultivars did express a yield advantage at environments when extremely hot and dry conditions were experienced during grain filling and irrigation supply may not have matched crop demand. At the southernmost environment studied, APH cultivars did not possess the same yield potential as the highest yielding cultivars sourced from southern Australia. Further work is underway to use simulation analysis for environmental characterisation in order to better assess the resource limitations inherent at each environment.

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