Optimising flowering time, phase duration, HI and yield of milling wheat in different rainfall zones of southern Australia

James Hunt[1], Neil Fettell[2], Jon Midwood[3], Paul Breust[4], Renick Peries [5] Jaikirat S Gill[6] and Annieka Paridaen[3]

[1] CSIRO Sustainable Agriculture National Research Flagship, PO Box 1600 Canberra ACT 2601 Email james.hunt@csiro.au
[2] University of New England, PO Box 300 Condobolin NSW 2877 Email neil.fettell@une.edu.au
[3]Southern Farming Systems, 23 High Street Inverleigh VIC 3321 Email jmidwood@sfs.org.au, aparidaen@sfs.org.au
[4]FarmLink research, PO Box 240 Junee NSW 2663 Email paul@farmlink.com.au
[5]DPI- Farm Services Victoria, PO Box 103 Geelong VIC 3220 Email renick.peries@dpi.vic.gov.au
[6] Department of Agricultural Sciences - Latrobe University, Bundoora VIC 3086 Email Jaikirat.Singh@latrobe.edu.au

Abstract
Early sown, slow maturing wheat varieties have a theoretical yield advantage over fast maturing varieties sown later as they capture more resources and have a longer yield formation phase. However, this advantage is often not expressed, as the early dry matter production of slow varieties sown early can be excessive, and leads to low harvest index (HI) and lodging, which reduces yields to levels achieved by fast varieties sown later.

This study aims to see whether the theoretical potential yield advantage of early sown, slow varieties could be expressed in high (Lake Bolac, Victoria), medium (Temora, NSW) and low (Condobolin, NSW) rainfall environments and under different management intended to increase HI and reduce lodging. Four commercially available and locally adapted spring milling wheat varieties of varying maturity were sown at different dates such that they flowered on the same optimal date for each location. Regionally relevant management treatments were applied; very low plant densities (Temora, Condobolin, Lake Bolac), plant growth regulators (Lake Bolac, Temora) and sub-soil manuring (Lake Bolac).

At Temora and Condobolin, low plant densities increased harvest index and yield in slow varieties sown early, but decreased total dry matter production and yield for faster varieties sown later. At Temora, the very slow maturing variety Eaglehawk sown early (15 April) and at low plant populations out-yielded (6.3 t/ha) mid (Gregory 9 May, 5.4 t/ha) and fast varieties sown later (Lincoln 19 May, 5.5 t/ha). At Condobolin, slow maturing varieties sown early produced more dry matter, but drought stress in late winter/spring reduced seed-set and HI such that yields were equivalent. At Lake Bolac, the slow variety Bolac sown early (27 April) out-yielded (7.0 t/ha) the mid-fast variety Lincoln sown on 20 May (6.0 t/ha).

In medium and high rainfall environments there is significant potential for productivity increases by increasing the area of slow maturing varieties sown early beyond that currently practiced, and adapting management to increase harvest index. In low rainfall environments, productivity increases from early sowing of slow maturing varieties are still possible, but are likely to result from a greater proportion of planted crop area flowering at an optimal time.

Key Words
Wheat maturity, time of sowing, harvest index, canopy management

Introduction
In south-eastern Australia, autumn rain has declined in frequency and magnitude (Pook *et al.* 2009; Verdon-Kidd and Kiem 2009) while farm sowing programs have increased in size. Contemporary sowing programs often exceed the available sowing opportunities, and extreme weather during spring has made achieving timely flowering of cereal crops increasingly critical to yield and farm profitability. Earlier sowing increases the frequency of planting opportunities, and allows more crop to be sown and flower on time. However, earlier planting of currently popular mid-fast varieties comes with increased frost risk, which is prohibitive in many locations. Frost risk can be managed by planting slow maturing varieties when sowing early, and early sown, slow maturing wheat varieties have a theoretical yield advantage over fast maturing varieties sown later as they capture more resources and have a longer yield formation phase. However, this advantage is often not expressed, as the early dry matter production of slow varieties sown early can be excessive, and leads to low harvest index (HI) and lodging, which reduces yields to levels achieved by fast varieties sown later (Stapper and Fischer 1990; Riffkin *et al.* 2003). This study aimed to evaluate whether the theoretical yield advantage of early sown, slow maturing varieties could be expressed in high, medium and low rainfall environments and under different management intended to increase HI and reduce lodging.

Methods

Pre-experimental modelling

APSIM N-wheat (Keating *et al.* 2003) simulations 1890-2009 with a multiplier on yield for frost and heat damage (after Farre *et al.* 2010) was used to identify optimal flowering windows at three different locations with contrasting climates (Lake Bolac Vic – high rainfall, Temora NSW – medium rainfall and Condobolin NSW – low rainfall) across the grain belt of south eastern Australia.

Field experiments

In each location, commercially available and locally adapted spring milling wheat varieties of varying maturity were sown at different dates such that they flowered on the same optimal date identified by APSIM. Maturity groups were classified as 'very slow' (Forrest⏀ at Lake Bolac and EGA Eaglehawk⏀ at Temora and Condobolin), 'slow' (Bolac⏀ at all sites), 'mid' (Derrimut⏀ at Lake Bolac and EGA Gregory⏀ at Temora and Condobolin), 'fast' (Lincoln⏀ at all sites) and 'very fast' (Axe⏀ at Condobolin only). Regionally relevant management treatments intended to increase HI were applied in a factorial design and included very low plant densities (Temora, Condobolin, Lake Bolac), plant growth regulators (PGRs - Lake Bolac, Temora) and sub-soil manuring (Lake Bolac). All experiments were conducted as a complete randomised block design and analysed using ANOVA in Genstat 13.

Results

Pre-experimental modelling

Using mean grain yield from APSIM, optimal flowering dates in each environment were 23 October at Lake Bolac, 28 September at Temora and 16 September at Condobolin (Figure 1).

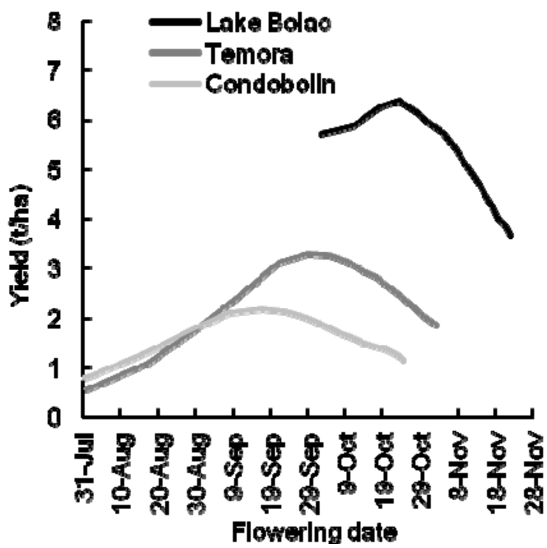

Figure 1. Mean flowering date (Z65) and yield at each location from 120 year (1890-2009) APSIM simulation with a multiplier applied to yield for heat and frost.

Sowing date of the different maturity classes required to achieve optimal flowering date was consistent across environments. Optimal sowing date for the very slow maturity group was 15 April with optimal sowing dates for subsequent groups being progressively ten days afterward (slow – 25 April, mid – 5 May, fast – 15 May, very fast 25 May). Experimental sowing dates deviated from these somewhat, but flowering of the different maturity classes largely coincided at all locations (Table 1).

Table 1. Experimental sowing and anthesis dates (Z65 – 50% of ears flowered) for the different maturity groups at each location.

	Lake Bolac		Temora		Condobolin	
Maturity group	**Sowing date**	**Anthesis date**	**Sowing date**	**Anthesis date**	**Sowing date**	**Anthesis date**
Very slow	15 April	19 October	15 April	2 October	15 April	15 September
Slow	27 April	16 October	27 April	3 October	27 April	13 September
Mid	6 May	14 October	9 May	5 October	5 May	13 September
Fast	20 May	20 October	19 May	4 October	16 May	16 September
Very fast	-	-	-	-	25 May	20 September

Field experiments
At Lake Bolac, annual rye-grass resistant to herbicide groups A & B overran the first time of sowing and all low plant density treatments and these have been excluded from analysis. Sub-soil manuring increased average yield from 5.2 t/ha to 6.2 t/ha and grain protein from 11.3% to 12.0% due to increased nitrogen availability, despite all treatments being top-dressed with 184 kg/ha N as urea. Because yields in the ripped treatment were limited by N availability, they have also been excluded from analysis. The slow variety Bolac$^{(l)}$ sown on 27 April yielded 7.0 t/ha, the mid variety Derrimut$^{(l)}$ sown on 6 May yielded 6.6 t/ha and the fast variety Lincoln$^{(l)}$ sown on 20 May yielded 6.0 t/ha (P=0.006, LSD(P=0.05) = 0.6 t/ha).

At Temora there was a very large yield advantage from sowing a very slow variety early (EGA Eaglehawk$^{(l)}$ 15 April) and adjusting seeding rate to improve HI (6.3 t/ha) compared with sowing mid and mid-fast varieties in their optimal window (EGA Gregory$^{(l)}$ 9 May 5.4 t/ha, Lincoln$^{(l)}$ 19 May 5.5 t/ha – Table 2). There was a yield reduction in mid and mid-fast varieties sown at low densities and there was no effect of PGRs on yield. The yield benefit of the slow varieties may be an under-estimate of the value of early sowing at this site. Seed bed moisture was optimal for sowing on 15 April following 16 mm of rain on 10 April, but was becoming marginal on 27 April and by 9 and 19 May irrigation (8 mm applied into press-wheel furrows with drippers) was required to establish the crop. Therefore in a dry-land farm situation where irrigation was not possible, the early sown slow varieties would have had an even greater yield advantage over the later sown faster varieties as the rain that allowed them to emerge did not fall until 25 May.

Table 2. Grain yield and harvest index of four wheat varieties of different maturity sown at two plant densities at Temora in 2011 to flower on the same date.

	Grain yield (t/ha)		Harvest index (%)	
Variety & sow date	**40 plants/m²**	**100 plants/m²**	**40 plants/m²**	**100 plants/m²**
EGA Eaglehawk$^{(l)}$ (15 April)	6.3	6.0	0.41	0.39
Bolac$^{(l)}$ (27 April)	5.9	5.7	0.42	0.39
EGA Gregory$^{(l)}$ (9 May)	5.0	5.4	0.44	0.43
Lincoln$^{(l)}$ (19 May)	4.8	5.5	0.44	0.44
P-value	0.009		0.018	
LSD (p=0.05)	0.5		0.01	

Yield at Temora and Lake Bolac was strongly related to growth during stem elongation (Figure 2). In high-yielding locations, yield is determined by grain number (particularly grains per ear) and this is a function of crop growth during stem elongation (Sadras *et al.* 2012). Sowing slower maturing varieties early (particularly photoperiod sensitive types such as Forrest$^{(l)}$ and EGA Eaglehawk$^{(l)}$) extends their stem elongation phase relative to fast varieties sown later (Figure 3) resulting in higher grain number and yield potential.

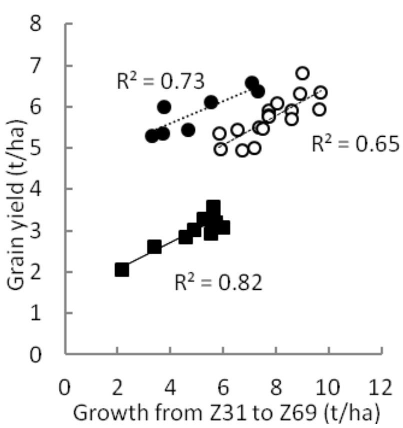

Figure 2. The relationship between growth during stem elongation and grain yield at Lake Bolac (●), Temora (○) and Condobolin (■) in 2011.

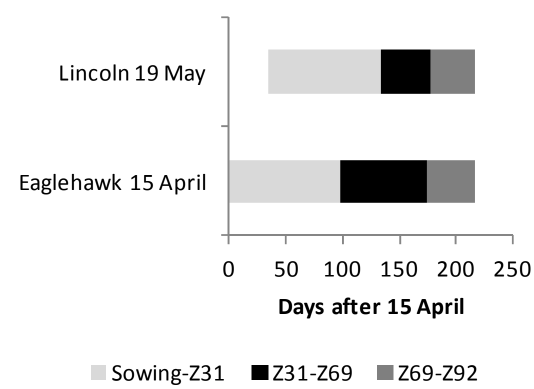

Figure 3. Phase durations for EGA Eaglehawk sown 15 April and Lincoln sown 19 May at Temora in 2011.

At Condobolin, dry conditions in late winter reduced grain set in the earliest sowings and similar yields were obtained from sowing dates ranging from 15 April until 16 May. The higher biomass from sowing earlier was offset by a lower HI (Table 3), even at a low plant density. While there was an increase in HI and yield at low plant densities for long season varieties sown early (EGA Eaglehawk⁽ᴰ, Bolac⁽ᴰ), there was a yield penalty at low plant densities for short season varieties sown later (Lincoln⁽ᴰ, Axe⁽ᴰ).

Table 3. Grain yield and harvest index of five wheat varieties of different maturity sown at two plant densities at Condobolin in 2011 to flower on the same date.

	Grain yield (t/ha)		Harvest index (%)	
Variety & sow date	**30 plants/m²**	**90 plants/m²**	**30 plants/m²**	**90 plants/m²**
EGA Eaglehawk⁽ᴰ (15 April)	3.4	3.1	0.37	0.32
Bolac⁽ᴰ (27 April)	3.3	2.9	0.38	0.35
EGA Gregory⁽ᴰ (5 May)	3.6	3.2	0.44	0.39
Lincoln⁽ᴰ (16 May)	2.8	3.0	0.46	0.45
Axe⁽ᴰ (25 May)	2.1	2.6	0.45	0.44
P-value	0.029		0.027	
LSD (p=0.05)	0.4		0.02	

Conclusion

Earlier sowing of slow maturing wheat varieties has potential to increase dry-land wheat production in southern Australia in the face of declining autumn rainfall and sowing opportunities. In higher yielding locations and seasons, early sown slow maturing varieties were found to have a yield benefit over later sown faster varieties due to increased grain number, particularly if managed to increase HI. In lower yielding environments there may be no yield benefit, but there is no evidence of a yield reduction, and whole-farm wheat yield should increase as a greater proportion of crop will flower at an optimal time. More research is required to optimise agronomy of early sown slow varieties, and overcome current limitations to sowing early e.g. herbicide resistant grass weeds.

Acknowledgements

This research was funded through the GRDC Water-Use Efficiency Initiative and the DAFF and GRDC funded National Adaptation and Mitigation Initiative.

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Proceedings of the 16th ASA Conference, 14-18 October 2012, Armidale, Australia. Web site www.agronomy.org.au