Management of early sown wheat: Evaluation of G x E x M interactions to increase harvest index and yield of early sown wheat

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Abstract

Early sown slow developing wheats offer increased biomass accumulation, grain number and thus potential grain yield. However, the greater vegetative growth of early sown crops can result in low harvest index (HI). We evaluated management strategies to improve HI in three early sown winter wheat cultivars using four experiments conducted across south eastern Australia. Strategies included low stand densities (30-50 plants/m²), defoliation, and deferred application of nitrogen fertiliser. We found low stand densities had a small positive effect on HI and grain yield. Defoliation tended to increase HI and but also reduce yield (depending on cultivar) due to reduced biomass which negated much of the increase in HI. Deferring nitrogen had a variable effect depending on starting soil N and timing of in-season rain to allow crop uptake of top-dressed N. The management factors studied here have some potential for improvement of HI but responses were variable and with small effect sizes. We conclude that genetic improvement is required to raise HI and yield in early sown wheat.

Key Words

Winter wheat, grazing, seeding rate, nitrogen

Introduction

Wheat production in Australia is dominated by fast-developing spring cultivars that when sown in late-autumn will flower at an optimal time in early-spring. Recent research has demonstrated that water limited potential yield can be increased by sowing winter or slow-developing spring wheats earlier than currently practised such that they flower at the optimal time but have a longer vegetative phase duration (Hunt *et al.* 2019). Sowing earlier with slow developing cultivars can increase biomass accumulation, grain number and thus potential yield. However, results from studies in SE Australia have demonstrated that long phase duration yields have been only equivalent to those of faster developing cultivars sown on time (Hunt *et al*. 2019, in these conference proceedings) from a similar flowering time. Gomez-Macpherson and Richards (1995) found in their experiments and in reviewed experiments of others (Batten and Khan 1987; Connor *et al.* 1992) that the grain yields of slow developing cultivars were equivalent to faster developing cultivars sown later due to low harvest index (HI) in early sown cultivars.

Harvest index (HI) is the ratio of grain to total shoot dry matter and can be used as a measure of reproductive efficiency. It is a trait determined by interactions between genotype (G), environment (E) and crop management (M). Historic yield gains due to breeding have largely been achieved by increasing HI implying strong genetic control. Environmental factors are likewise important, and include seasonal pattern of water supply (Passioura 1977; Fischer 1979) and extreme temperatures during crop reproductive development.

There are two likely explanations for reduced HI in early sown slow developing cultivars. A longer vegetative phase means that a greater proportion of water supply is used prior to anthesis in comparison to faster cultivars sown later. in glasshouse experiments, the ratio of pre- and post-anthesis water use has been demonstrated to be strongly related to HI (Passioura 1977). The second explanation is that increased plant height and more leaves lead to competition for carbohydrates between the developing spike and elongating stem of early sown crops (Gomez-Macpherson and Richards 1995). Agronomic management strategies such as plant stand density, timing of nitrogen application, and crop defoliation can be used to alter early dry matter accumulation, seasonal pattern of water-use and carbohydrate partitioning in order to improve HI. Here, we evaluate the effect of these strategies to improve HI and grain yield in early sown crops.

Methods

Two field sites were chosen for evaluation of management strategies for early sown winter wheat representative of the major medium-low rainfall environments in which wheat is grown in SE Australia (Table

1), experiments were completed in both 2017 and 2018. At each site three winter cultivars Longsword (fast winter), Kittyhawk (mid winter), and DS Bennett (mid-slow winter) were planted in mid-April which is optimal for winter cultivars. Management factors applied included; 1) two nitrogen timings (seedbed N and deferred N) ensuring either adequate N supply at sowing or deferred until early stem elongation; 2) two defoliation treatments to simulate grazing (control and defoliation) applied by mechanical mower twice during tillering before Z30; 3) two plant stand density treatments (low and high) targeting 50 and 150 plants/m^2 respectively. Management factors were applied to each cultivar in a factorial fully randomised complete block experiment which equating to eight management combinations per cultivar per site with four replications. At all sites if the seedbed was too dry to allow emergence, plots were irrigated with ~10 mm of water, applied using pressure compensating drip-lines placed in seeding furrows, to germinate seed and allow emergence.
Harvest index (HI), dry matter (DM), and grain yield (GY) were measured from quadrat cuts (0.46 m^2) taken at crop maturity and analysed individually using mixed linear models or across environments using ANOVA with site year, cultivar, nitrogen, defoliation, and plant density as factors/fixed effects and block structure as random effects.

Table 1 Location of field experiments, average annual rainfall, summer fallow (Nov-Mar) and growing season rainfall (Apr-Oct)

Site	Station number & years of record	Mean annual rainfall (mm)	2016-2017 Nov-Mar rainfall (mm)	2017 Apr-Oct rainfall (mm)	2017-2018 Nov-Mar rainfall (mm)	2018 Apr-Oct rainfall (mm)
1. Yarrawonga VIC	81124 (1994-2018)	469	140	276	161	135
2. Loxton SA	24013 (1896-2018)	261	120	135	83	92

Results & discussion

There was significant variation in HI, DM, and GY across experiments. The largest effect size was generally due to environment (Table 1 and Figure 1a). Higher HI were achieved at Loxton compared to Yarrawonga in both seasons due to a greater severity of frost and sterility at Yarrawonga. There was a strong positive relationship HI and GY at Yarrawonga in 2018 (R^2=0.86), likely due to the severe stem and flowering frost events that significantly impacted grain number and thus yield. At other sites under moderate temperature stress HI was not correlated with GY. This means a higher HI did not always result in higher grain yield. The strong relationship with DM and GY within treatments of similar harvest index at Yarrawonga in 2017 (R^2=0.71), and Loxton 2017 and 2018 (R^2=0.79suggest that total biomass can be improved along with maintenance of a high harvest index using G x M strategies (figure 1b) to improve crop yield.

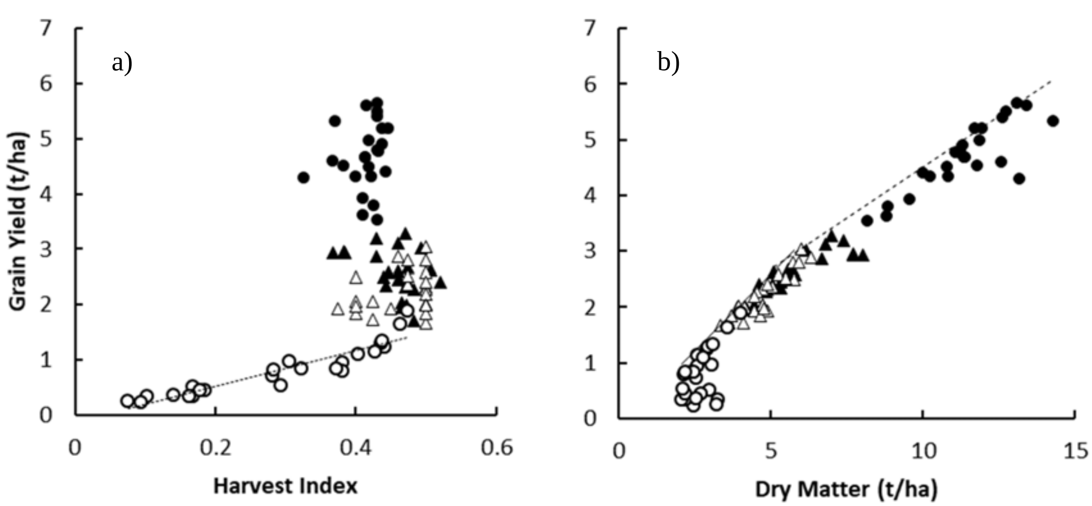

Figure 1. Relationships between harvest index (a), dry matter (b) and grain yield at Yarrawonga 2017 (●), Yarrawonga 2018 (○), Loxton 2017 (▲), and Loxton 2018 (∆).

Table 2. Analysis of variance output for significant management factors influencing HI, DM, and GY. (<0.001= *, <0.01 = **, <0.05 = *)**

Management Factor#	HI	DM t/ha	GY t/ha
Environment	***	***	***
Cultivar	***	ns	**
Defoliation	***	***	**
N timing	***	ns	ns
Stand density	ns	***	***
Cultivar x environment	***	**	***
Environment x N timing	***	*	ns
Environment x stand density	**	***	***
Environment x cultivar x defoliation	***	**	*

#all other management factors and combinations were not significant

All management factors interacted with environment (Table 2). Outside of environment, cultivar, and defoliation there was little interaction between seed rate and nitrogen timing. Defoliation was the most reliable management strategy to increase HI but responses were still variable and depended on cultivar and environment. In 7 out of 12 cultivar x environment combinations, defoliation increased HI but this response translated to a yield increase in only Longsword (0.5 t/ha) and Kittyhawk (0.4 t/ha) at one site (Yarrawonga in 2018) due to a delay in crop development reducing stem frost damage. Yield remained similar to undefoliated controls at 5 out of 12 situations, and decreased yield in 5 situations. Decreased yield responses to defoliation were generally explained by a reduction in total crop biomass. Longsword was the most responsive cultivar to defoliation (increased HI at all sites) whereas DS Bennett was the least responsive (increased HI at Yarrawonga in 2018 only).

Genotypic differences in HI were stable and consistent across sites. DS Bennett tended to have higher HI than both Kittyhawk and Longsword. However, this came with a trade-off in biomass and sometimes yield, and DS Bennett almost always had a lower biomass meaning yields between cultivars were often similar (Figure 1 and Table 3) at high and low HI. The improved biomass and grain number potential (data not presented) of cultivars like Longsword pave the way for genetic progress on improving traits strongly correlated to improved HI such as floret sterility, fruiting efficiency and biomass partitioning. When management strategies such as simulated grazing (defoliation) were effective in increasing HI this came at a trade-off in crop biomass similar to the responses observed between DS Bennett and Longsword.

Table 3. Mean harvest index (HI), dry matter (t/ha), and grain yield (t/ha) of winter cultivars and the management effect size when defoliated. Different letters within a site indicate significant differences and ns indicates no significant effect of management.

		Control trait means			Management Effect (defoliation)		
Environment	Genotype	HI	DM (t/ha)	GY (t/ha)	HI	DM (t/ha)	GY (t/ha)
Loxton 2017							
	DS Bennett	0.46a	5.8b	2.7b	ns	-1.0	-0.4
	Kittyhawk	0.43b	6.9a	3.0a	+0.07	-2.5	-0.8
	Longsword	0.41c	7.0a	2.8a	+0.12	-1.8	ns
Loxton 2018							
	DS Bennett	0.50a	4.4b	2.2b	ns	ns	ns
	Kittyhawk	0.42c	4.5b	1.9c	-0.02	ns	ns
	Longsword	0.47b	5.7a	2.6a	+0.03	ns	ns
Yarrawonga 2017							
	DS Bennett	0.42a	12.0b	5.1a	ns	-0.7	-0.3
	Kittyhawk	0.41a	12.2b	5.1a	ns	-2.1	-0.8
	Longsword	0.36b	13.0a	4.7b	+0.07	-3.3	-0.5
Yarrawonga 2018							
	DS Bennett	0.38a	3.3a	1.3a	+0.04	ns	ns
	Kittyhawk	0.11c	3.0a	0.3b	+0.18	ns	+0.4
	Longsword	0.17b	2.4b	0.4b	+0.20	ns	+0.5

The effect of stand density and nitrogen timing on HI depended on environment (
Table 4). Plant density was generally an ineffective strategy with a significant effect on HI at only 1 out of the 4 site years. HI was improved by 0.03 with a lower stand density at Loxton in 2017 which translated to a small increase in GY of 0.3 t/ha. At Yarrawonga in 2017, the yield response to lower densities was due to increased DM of 1.4 t/ha and not HI. These results are significant for management as it suggests targeting 50 plants/m² is sufficient to allow maximum yields to be achieved but is not a reliable strategy to increase HI.

Deferring N until stem elongation increased HI by 0.04 at Loxton in 2017 and by 0.01 at Yarrawonga in 2017 and 0.07 in 2018, however this came with a trade-off in biomass at Loxton resulting in a small yield penalty (
Table 4). At Yarrawonga a small improvement in HI did not improve yield in 2017 but a 0.07 increase in HI in 2018 resulted in a 0.3 t/ha yield increase. Except for Yarrawonga in 2017, lack of spring rainfall may have reduced the crop's ability to take up top-dressed N.

Table 4. Management effect of deferring N until Z30 and lower plant density on mean harvest index (HI), dry matter (t/ha), and grain yield (t/ha) across all winter cultivars. ns indicates no significant effect of management.

	Effect of deferring N until Z30			Effect of lower plant density		
	HI	DM (t/ha)	GY (t/ha)	HI	DM (t/ha)	GY (t/ha)
Loxton 2017	+0.04	-0.7	-0.1	+0.03	ns	+0.3
Loxton 2018	ns	ns	ns	ns	ns	ns
Yarrawonga 2017	+0.01	ns	ns	ns	+1.4	+0.8
Yarrawonga 2018	+0.07	ns	+0.3	ns	ns	ns

Conclusion

The management factors presented here have shown limited scope to improve HI and yield in early sown crops. Defoliation had the most reliable effect on HI but also tended to reduce biomass which negated much of the increase in HI. Responses to stand density and nitrogen timing were variable and with small effect sizes. Given the limited effect of management strategies found here, we propose that genetic improvement is the most promising avenue for increasing HI and yield in early sown wheat, and postulate that this could be achieved more rapidly through early generation screening for partitioning traits such as HI and fruiting efficiency in slow developing genotypes.

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