Deep soil water-use determines the yield benefit of long cycle wheat

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Abstract

The yield advantage of early sown slow developing (long cycle) wheat cultivars over fast developing cultivars sown later (short cycle) is variable. This variable response is likely due to environmental factors, but the precise set of conditions that confers an advantage to long cycle treatments is not known. We compared short and long cycle wheat cultivar x time of sowing combinations over four seasons in Temora, NSW. Two seasons (2011, 2012) had over 400 mm of summer fallow (December-April) rain which filled the soil profile to depth, and two seasons had summer fallow rain that was less than the site average of 208 mm (2015, 2016). Rainfall 30 days prior to the start of flowering (approximating the critical period for yield determination) in each year was 8, 6, 14, 190 mm respectively. We observed that there was only a yield benefit in long cycle treatments in seasons where there was soil water stored at depth, and there was little rain during the critical period for yield determination in wheat, forcing greater reliance on stored soil water for crop growth (2011, 2012). In these seasons the higher yield of long cycle treatments could be attributed to greater soil water extraction from deep in the profile (<1.0 m), and consequently greater dry-matter production, grain number and grain yield. In the other seasons, lower evaporation and higher biomass accumulation in long cycle treatments traded off against inferior harvest index such that yields were equivalent to short cycle treatments.

Key words

Sumer fallow rainfall, crop water use, harvest index, evaporation

Introduction

In southern Australia, fast developing spring wheat crops are established following the hot, dry summer fallow period on rains that fall in late autumn (April-May), and grow through the cool winter months to flower at an optimal time in early spring during which collective damage from drought, frost and heat are minimised (Flohr *et al.* 2017). Under this system of relatively short crop life cycles, Hochman *et al.* (2017) reported a 27% decline in water limited yield potential over the period 1990-2015 which was attributed to reduced rainfall and rising temperatures. By exploiting a much wider sowing window and thus longer growing season, Hunt *et al.* (2019) propose that earlier sowing with slower developing cultivars (long cycle) can increase Australian national wheat yields by 0.54 t/ha under current climate conditions.

Early sowing systems are facilitated by management that improves capture and storage of summer fallow rain (summer fallow weed control, stubble retention and no-till farming) to allow early germination, and slow developing wheat cultivars in which progress through the crop's life cycle is impeded by a photoperiod or vernalisation requirement (Kirkegaard *et al.* 2014). However, field experiments conducted over many decades have shown that the yield advantage of long cycle treatments is variable (Gomez-Macpherson and Richards 1995; Penrose and Martin 1997; Hunt 2017; Peake *et al.* 2018). Hunt (2017) hypothesised that long cycle treatments only have a yield advantage in seasons when the soil profile fills to depth and their potentially deeper root growth becomes advantageous (Lilley and Kirkegaard 2016). In partial support of this hypothesis, Peake *et al.* (2018) found that under irrigated sub-tropical conditions long cycle treatments only had a yield advantage at sites where sub-optimal irrigation timing led to crops being drought stressed in spring, however the hypothesis has not been formally tested under rain-fed conditions. Thus the aim of this study was to investigate the relationship between deep soil water extraction and crop yield differences between long and short cycle crops in a rain-fed environment.

Method

Field experiments

Field experiments were conducted in four seasons (2011, 2012, 2015, 2016) at Temora, NSW. Each experiment had four sowing dates spaced at 10 day intervals commencing in mid-April and ending in mid-

May, but only data for the treatments that flowered concurrently and within the optimal flowering period for Temora (25 September – 10 October) are shown (Table 1). Sowing date is defined as the calendar date at which seeds become imbibed and begin the process of germination. This could be the date on which they are planted into a moist seed bed, or the date on which they received rainfall/irrigation after being sown into a dry seed bed. Each experiment had four cultivars that were selected as being highest yielding milling spring wheat cultivars for four development types (fast, mid, slow and very slow) based on yield performance in National Variety Trials for south eastern NSW. In 2015 and 2016 a fast spring (Sunstate) and very slow spring (W16A) near-isogenic pair (Hunt *et al.* 2019) were included in experiments. Chemical fertilisers and pesticides were applied such that nutrient limitations, weeds, pests or diseases did not limit yield.

Table 1. Target and actual sowing dates (SD) and flowering dates (FD) in 2011, 2012, 2015 and 2016.

Cultivar	Development type	Cycle length	2011		2012		2015		2016	
			SD	FD	SD	FD	SD	FD	SD	FD
EGA Eaglehawk	Very slow	Long	15-Apr	2-Oct	18-Apr	14-Oct	17-Apr	10-Oct	15-Apr	16-Oct
W16A	Very slow	Long					17-Apr	13-Oct	15-Apr	22-Oct
Bolac	Slow	Long	27-Apr	3-Oct	26-Apr	11-Oct	27-Apr	5-Oct	27-Apr	2-Oct
EGA Gregory	Mid	Short	9-May	5-Oct	8-May	13-Oct	27-Apr	6-Oct	6-May	2-Oct
Lincoln/ Condo	Fast	Short	19-May	4-Oct	17-May	13-Oct	15-May	7-Oct	15-May	2-Oct
Sunstate	Fast	Short					7-May	10-Oct	15-May	6-Oct

Measurements

Day of flowering was recorded as the date when 50% of the spikes in each plot had visible anthers. In 2011 and 2016, dry matter at maturity, dry grain yield and harvest index (HI) were determined by cutting all plants in two 0.78 x 1.2 m quadrats per plot (4 middle rows) and mechanically threshing. In 2012 and 2015, grain yield was determined by mechanically harvesting the four middle rows of each plot. All dry matter (DM) and grain yields are reported at oven-dry moisture content. Experiments were split-plot (whole plot = time of sowing, sub-plot = cultivar) with four replicates, and either randomised complete block or row: column designs.

In 2011 and 2012 daily photosynthetically active radiation (PAR) interception was estimated using regular readings of NDVI recorded using a GreenSeeker® (Trimble Inc., Sunnyvale CA) up to head emergence based on an existing relationship developed for wheat at Temora (PAR = 1.60*NDVI - 0.39, R^2 = 0.92). In 2015 and 2016 canopy light interception PAR was recorded around solar noon using a ceptometer (AccuPAR LP-80; Pullman, WA, USA) at 4 positions per plot at the time of Z39 and Z70 DM sampling. Values of daily fractional PAR interception were obtained by interpolation between readings of interception (Monteith 1972). Daily estimates of PAR interception were used to estimate daily soil evaporation (Es) based on FAO56Eo values of potential evapotranspiration and days since last rain fall (d) after the method used by Siddique *et al.* (1990) where Es = Eo*(1/d). Daily estimates of Es were summed from the day on which initial neutron moisture meter (NMM) soil water measurements were made (early April) to maturity to estimate seasonal soil evaporation. Seasonal transpiration was calculated as seasonal crop water use (soil water measured early April – soil water at maturity + intervening rainfall) as estimated by NMM minus Es, and this was used to calculate transpiration efficiency (TE) for dry matter. In 2015 and 2016 these are calculated for the NILs only as NMM tubes were only installed in these treatments. In each year, a two-sample t-test (Genstat 19) was used to test for significant differences between pooled means of long and short cycle treatments. Within each block of each year, long cycle and short cycle treatment yields were used to calculate the yield benefit of long cycle treatments over short cycle treatments, which were plotted against the soil water extraction from between 1.0-1.6 m depth for each block.

Results

Neutron moisture meter measurements made on 7 April, 3 April, 14 April and 15 April in each growing season respectively determined average initial PAW across the site to be 104 mm, 91 mm, 28 mm and 27 mm. December-April rainfall in 2011, 2012, 2015 and 2016 was 442, 395, 206 and 113 mm (long term average 208 mm), and growing season rainfall (April-October) was 200, 169, 279 and 588 mm (long term average 312 mm) respectively. Rainfall 30 days prior to the start of the optimal flowering period (25 September to 10 October as per Flohr *et al.* 2017) in each year was 8, 6, 14, 190 mm respectively.

In all seasons long cycle treatments produced more dry matter than short cycle treatments (Table 2). In 2011 and 2012 the increase in dry matter was converted into yield, such that yield of long cycle treatments was greater than short cycle treatments. The greater accumulation of dry matter was driven by greater soil water extraction from depth (data not shown) leading to greater water use (Table 2). Greater water extraction from depth was allowed by deeper root growth from longer duration of growth (see Kirkegaard *et al.* 2015 for root measurements from these experiments in 2012). Long cycle treatments also lost less water to evaporation (Table 2). For example, in 2012 EGA Eaglehawk was able to extract 21 mm more water than Lincoln, and lost 10 mm less to evaporation. In 2011 and 2012 greater growth during the reproductive phase drove greater weight of spikes, grain number (data not shown) and thus grain yield. Long cycle treatments had lower evaporation in 2015 and 2016 and grew more dry matter. However, without access to extra stored soil water, it was not enough to overcome lower HI, so yields were not significantly different from short cycle treatments sown later (Table 2). There was a positive linear relationship between the yield benefit of long cycle treatments and soil water used below 1 m (Figure 1). Grain yield of long cycle treatments increased at a rate of 3.5 g.m^{-2}.mm (or 35 kg.ha^{-2}.mm) of stored soil water.

Table 2. Mean values for long and short cycle treatments grown in Temora, for dry-matter at maturity, grain yield, harvest index, crop water use, estimated evaporation and transpiration efficiency for dry matter at maturity in each growing season. Shaded cells indicate that long and short cycle treatments are significantly different at the 95% confidence level.

	Maturity dry matter (g m^{-2})		Grain yield (g m^{-2})		Harvest Index		Crop water use (mm)		Estimated evaporation (mm)		TE maturity dry matter (g m^{-2} mm^{-1})	
Year	**Long**	**Short**	**Long**	**Short**	**Long**	**Short**	**Long**	**Short**	**Long**	**Short**	**Long**	**Short**
2011	1286	1079	528	457	0.41	0.43	329	319	78	96	5.2	4.9
2012	1078	887	483	403	0.44	0.45	332	321	59	66	4.1	3.7
2015	1353	1300	405	438	0.30	0.34	374	356	80	91	4.5	4.4
2016	1874	1610	583	628	0.31	0.40	599	593	84	97	3.7	3.2

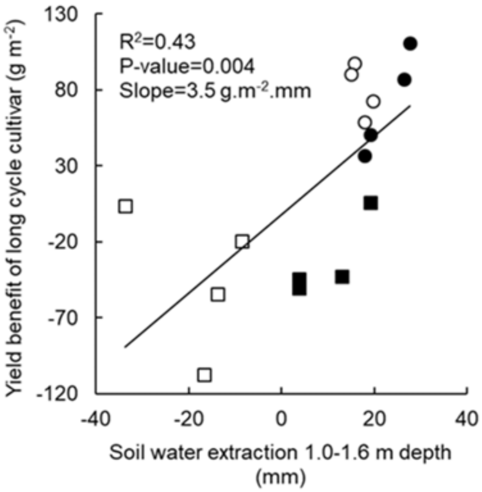

Figure 1. Yield benefit of long cycle cultivars (Eaglehawk, Bolac, W16A) over short cycle cultivars (Gregory, Lincoln, Condo, Sunstate) in 2011 (●), 2012 (○), 2015 (■) and 2016 (□) and soil water extracted from 1.0-1.6 m depth by the long cycle treatment. Each symbol represents individual replicates. P-value and R^2 value relates to the regression fitted to the data.

Discussion

Requisite conditions for a yield benefit in long cycle treatments were a) the presence of deep soil water and b) low rainfall during the critical period for yield determination in wheat. This forced greater reliance on deep soil water for crop growth, and long cycle treatments were able to access more of this due to longer duration of root growth. In seasons where no soil water was available at depth (2015) or sufficient rain fell during the critical period to meet crop demand (2016), reduced evaporation in long cycle treatments was not sufficient to overcome lower HI associated with long cycle cultivars. Our results support the findings reported by Peake *et al.* (2018), who found that long cycle treatments had the greatest yield advantage in environments where post-anthesis water stress was severe. The efficiency in converting soil water stored below 1 m to grain yield reported in this study (35 kg/ha.mm) is in close agreement to the marginal water-use efficiency for deep soil water reported by Lilley and Kirkegaard (2007) of 30–36 kg/ha.mm and Angus and van Herwaarden (2001) of 33 kg/ha.mm.

Conclusion

Results of this study show that long cycle treatments only have a yield advantage over short cycle treatments in seasons where the soil profile is filled, and where little rain falls during the critical period for yield determination. Without accessing extra deep water, long cycle treatments still had greater biomass due to reduced evaporation, but also had lower HI compared to short cycle treatments sown later and yields were equivalent.

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