Can leaf architecture improve crop biomass and yield in wheat?

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Abstract
It is proposed that an erect leaf-type might intercept more radiation, have greater radiation-use efficiency (RUE), and thus produce greater yields of wheat in the High Rainfall Zone (HRZ). A field experiment was undertaken in Cressy, Tasmania in 2016. Five of each erect and planophile lines, selected from the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population, were sown at three plant densities (100, 200 and 300 plants/m^2) with three replicates. Planophile lines intercepted more light and had a greater leaf-area index (LAI) and aboveground dry matter (DM) at anthesis than erect leaves, which translated into a higher normalised difference vegetative index (NDVI). At harvest, planophile lines were taller and had greater stem DM and aboveground DM, but grain yield was the same as for erect leaves. Planophile lines had greater ear DM at harvest at low plant densities. Plant density otherwise had limited impact on yield and components of yield. Although leaf erectness is potentially a trait that is easy to target in breeding programs, it appears that planophile leaves may be more adaptive in this cool temperate environment. Further experiments across different sites and seasons are required to improve our understanding of the potential for leaf architecture to contribute to yield in the HRZ.

Keywords
Erect leaves, planophile leaves, leaf angle, high rainfall zone.

Introduction
The High Rainfall Zone (HRZ) of Australia includes arable areas with rainfalls between 450 and 900 mm (Zhang et al. 2006). The potential yield of wheat in the HRZ ranges from 8 to 11 t/ha (Sylvester-Bradley et al. 2012), but is constrained by a range of abiotic stresses such as waterlogging, and subsoil constraints to root growth. Closing the yield gap requires appropriate management practices in combination with genetic material suited to the HRZ.

Plant breeding efforts traditionally targeted the low rainfall zone and as a result, there is less germplasm suited to the HRZ, although this is slowly changing through the introduction of long-season and winter wheat types. Increasing the harvest index (HI) has been a mainstay of closing the yield gap that started with the introduction of semi-dwarf wheats during the Green Revolution. Subsequently, a range of physiological traits such as improved water-use efficiency and deeper root systems (Fischer 2007; Aisawi et al. 2015) have also contributed to the adaption of wheat to environmental constraints.

Improved radiation-use efficiency (RUE) has similarly been associated with greater biomass at anthesis and hence grain yield in winter wheat (Foulkes et al. 2007; Fischer and Edmeades 2010). The morphological trait, leaf angle, has received relatively little attention in the literature as a potential mechanism to increase RUE in wheat. This trait is also easy to screen for in a plant-breeding program. Yunusa et al. (1993) reported differences in light interception between planophile and erect leaves in traditional and modern cultivars grown in Western Australia.

We hypothesise that erect leaves in HRZ environments may intercept more radiation, contain more N in the canopy, have greater RUE and thus produce greater yields. Here we test this hypothesis in a field experiment conducted in northern Tasmania with lines selected for erect or planophile leaf types at three plant densities.

Methods

Field experiments were conducted in northern Tasmania at the Burlington Road Trial Site (41°43′S, 147°06′E) sown on 31 May 2016. The experiment used the CSIRO wheat Multiparent Advanced Generation Inter Cross (MAGIC) population (Canvanagh et al. 2008). MAGIC lines were selected as either erectophile or planophile leaf habit. The experiment was a randomised complete block with 10 lines (five each of erectophile and planophile) with three target sowing densities (100, 200 and 300 plants/m^2) and three replicates. Plots were 1.2 m wide by 5 m long on raised beds. The row orientation was approximately northwest. Weeds, pests and disease were controlled throughout the experiment through frequent application of appropriate chemicals.

Plants were assessed for canopy erectness, light interception, normalised difference vegetation index (NDVI) and date of flowering (GS65) at weekly intervals from flag leaf emergence to flowering. Canopy erectness scores were determined from visual assessments on a scale 0 - 10, with zero being all leaves erect and 10 all completely drooped over. Light interception was measured using a light interception meter (Apogee Model MQ-301) above and below the canopy at a 45° angle across the rows between 1100 and 1400 h in full sun conditions. The percentage of light interception was then calculated. NDVI was measured with a GreenSeeker (Trimble). Date of GS65 was recorded when the anthers from mid spike were visible in 50% of main stems in the plot. Plants were cut at ground level from 0.3/m^2 quadrats seven days post flowering (GS65) and 0.6/m^2 quadrats at physiological maturity (GS87). Plant samples were divided into components (leaves, stems, ears and grains (at harvest)); the number of fertile tillers counted; green leaf area (at flowering) was determined using a planimeter (LiCor LI-3050C) and components dried at 60°C. Leaf area index (LAI), dry matter (DM) and yield were calculated as green leaf area or dry weight per unit ground area. The significance of main effects and interactions was analysed by ANOVA (Genstat 18, VSN International Ltd).

Results

The 2016 season in Tasmania was extremely wet, with the site receiving 960 mm of rainfall. Average air temperatures were similar to the long-term average (data not shown). Raised beds minimised the risk of waterlogging and the experimental plots achieved a plant density of 85, 168 and 256 plants/m^2, which was within 15% of the intended plant density of 100, 200 and 300 plants/m^2.

At flowering, plants with planophile leaves had greater NDVI, light interception, LAI and aboveground DM than erect leaves (Table 1). Both NDVI and light interception increased with planting density, although there was no difference in LAI or aboveground DM. The interaction between leaf type and plant density was not significant ($P > 0.05$).

At final harvest, plants with planophile leaves had greater stem DM, aboveground DM and were taller than plants with erect leaves. There was a trend for grain yield to be greater for plants with planophile leaves, although this was not significant ($P = 0.06$). Ear number increased with plant density, but there was no effect of plant density on stem DM, grain yield, aboveground DM or plant height. The HI was on average 0.41 across treatments (data not shown). There was a significant interaction between leaf type and plant density for ear DM, where plants with planophile leaves had heavier ears than erect leaves at the lowest plant density (Figure 1). There was no difference in ear DM at the higher plant densities. In a separate experiment using 72 MAGIC and breeding lines at the same site (data not shown), there was no relationship between leaf erectness and light interception at anthesis (GS65), aboveground DM or grain yield at harvest.

Table 1. Main effects of leaf type and plant density on normalised difference vegetation index (NDVI, 14 - 17 days pre GS65), light interception (LI, 7 - 10 days pre GS65), leaf area index (LAI), above-ground dry matter (AGDM, 7-10 days post GS65), yield and yield components at harvest.

	Anthesis				Harvest				
Main effect Leaf type	NDVI	LI (%)	LAI (m^2/m^2)	AGDM (g/m^2)	Ear number (m^{-2})	Stem DM (g/m^2)	Grain yield (g/m^2)	AGDM (g/m2)	Height (cm)
Erectophile	0.84	91.7	2.91	1317	532	518	655	1565	88.5
Planophile	0.86	95.6	3.81	1446	524	598	718	1707	95.4
$LSD_{0.05}$	0.01***	1.9***	0.42***	84**	ns	36***	ns***	106**	2.5***
Density									
85	0.84	91.0	3.33	1344	434	541	700	1628	92.0
168	0.86	94.1	3.49	1400	536	555	697	1646	91.7
256	0.86	95.9	3.26	1400	651	578	662	1636	92.1
$LSD_{0.05}$	0.10***	2.4***	ns	ns	40***	ns	ns	ns	ns

,* indicates statistical significance at P = 0.01 and 0.001, respectively. ns indicates not significant at P > 0.05.

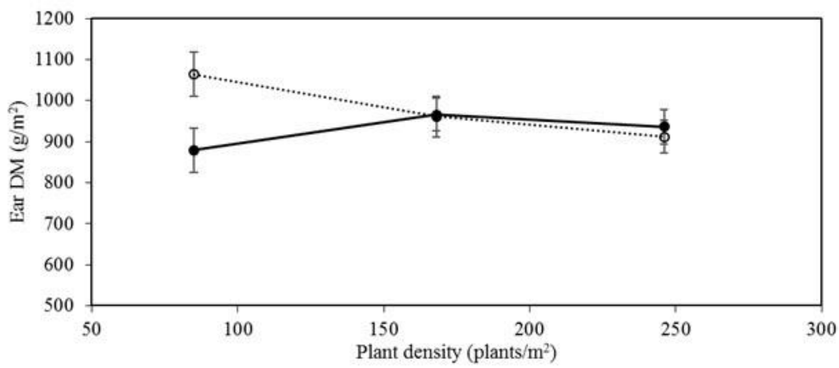

Figure 1. Effect of plant density and leaf type, erectophile (●) and planophile (○) on ear DM at harvest. Bars represents +/- SE.

Discussion

Grain yield of wheat in Tasmania is reported to have a potential of approximately 11 t/ha (Botwright Acuna et al. 2011). The MAGIC lines used in this experiment were not bred for this environment and while they attained approximately half of this potential yield, the number of ears/m^2 was similar to or exceeded the target for the HRZ (Sylvester-Bradley et al. 2012). The results indicate that this environment, depending on the seasonal conditions, may sustain somewhat more ears/m^2 with minimal impact on grain yield compared with other regions in the HRZ.

Contrary to the hypothesis, we have shown that a planophile leaf-type was an advantage in this environment compared with erect leaves in intercepting more light and leading to taller plants with greater aboveground and stem DM. Cultivars with planophile leaves were similarly shown to intercept more light in a field experiment undertaken in Western Australia (Yunusa et al. 1993). Further field experiments are required at other sites and seasons to confirm these results. Unpublished data from the co-authors in the 2016 season in Hamilton and Canberra suggests that erect leaves may provide improved RUE and grain yield, indicating that there may be significant genotype by environment interaction for leaf type that warrants further investigation.

Although leaf erectness is potentially a trait that is easy to target in breeding programs, it appears that planophile leaves may be more advantageous to improving light interception and biomass production in this cool temperate environment. Further experiments across different sites and seasons are required to improve our understanding of the potential for leaf architecture to contribute to yield in the HRZ.

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