Modelling impact of climate and soil interactions on yield benefit from early vigour of wheat

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Abstract
Early vigour, or faster early leaf area development, has been considered as an important trait for targeted breeding selection to increase dryland wheat yield such as in Australia. However, whether early vigour can increase yield across the whole Australian wheat belt and how soil type interacts with climate to impact on yield benefit of early vigour remain unknown. We present an analysis through combining field data and APSIM modelling to quantify impact of early vigour on wheat yield across contrasting climate and soil conditions (i.e. with different plant available water capacity (PAWC)). Simulated yield of wheat with the early vigour trait was on average 17%-29% higher compared to baseline wheat across all studied sites and soils. The results indicate a general positive yield benefits of early vigour, with higher benefit on larger soil PAWC.

Key Words
Triticum aestivum, establishment, genotype; environment, modelling, APSIM Next Generation

Introduction
Early vigour (i.e. faster leaf area development early in the season), a genetically complex trait (Moore and Rebetzke, 2015), has been considered an important trait for yield benefit of rainfed wheat in Australia. However, dryland wheat yield is a result of integration of seasonal climate conditions and water availability, with the latter also being influenced by plant available water holding capacity (PAWC) of the soil. It is therefore important to understand how soil by climate interactions impact on the yield benefit of early vigour.

The recent work of Zhao et al. (2019) presented a modelling framework in APSIM Next Generation (Holzworth et al., 2014; Brown et al., 2014) to quantify the impact of the major traits (e.g. rate of emergence, presence of coleoptile tiller, the leaf size profile, etc.) and genes (i.e. the dwarfing genes such as *Rht*1, *Rht*2, and *Rht8*) related to early vigour of wheat. They assessed the yield benefit of early vigour in wheat across 8 different sites with contrasting climate in Australia wheat belt, on a representative soil with a PAWC of 147 mm. In addition, their results on two other soils indicated that the yield benefit of early vigour in wheat can be significantly influenced by soil PAWC.

The objective of this research is to further extend the work of Zhao et al. (2019) to assess the impact of soil PAWC variations on the yield benefit of early vigour across climatic regions at representative sites in the Australian wheat belt.

Methods
We used the modelling framework developed by Zhao et al. (2019) in APSIM next generation to simulate the yield of a wheat with early vigour trait compared to a wheat without (i.e., baseline). Wheat cultivar 'Hartog' was used in the simulation for the baseline scenario, with cultivar parameters the same as the default parameters in APSIM. The high early vigour scenario was assumed for a wheat genotype to have maximum early leaf sizes that doubled those of wheat in the baseline scenario. For some high vigour wheat genotypes, the first leaf size was observed twice as big in area compared to normal vigour wheat genotypes (Zhao et al., 2019).

Eight sites were selected along a west-east (W-E) transect (Griffith, Yanco, Ardlethan, Temora Young) and a north-south (N-S) transect (Emerald, Narrabri, Young, Beulah). These sites cover the major climate types across the Australian wheat belt (Fig 1). Three soils were extracted from APSoil database (https://www.apsim.info/Products/APSoil.aspx) with PAWC of 95 mm, 147mm and 216 mm to a depth of 180 cm (Fig 2). Daily climatic data (rainfall, solar radiation, maximum and minimum temperatures) from 1957 to 2017 were extracted from the SILO Patched Point Dataset (Jeffrey et al., 2001; http://www.bom.gov.au/silo/).

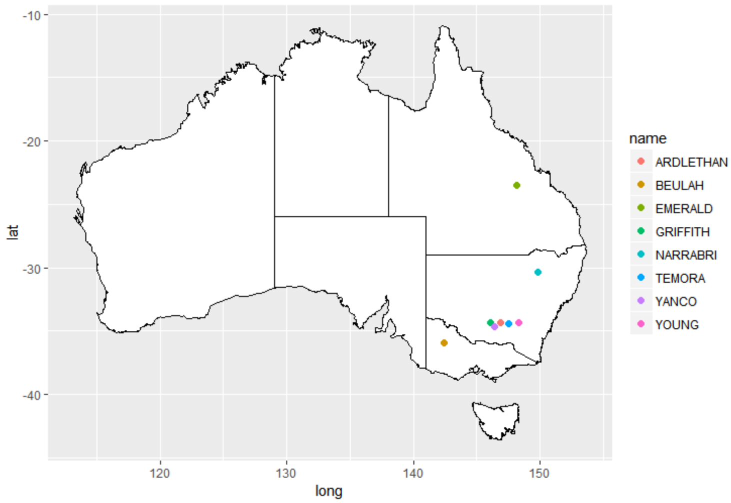

Figure 1. The spatial distribution of the eight study sites in Australia.

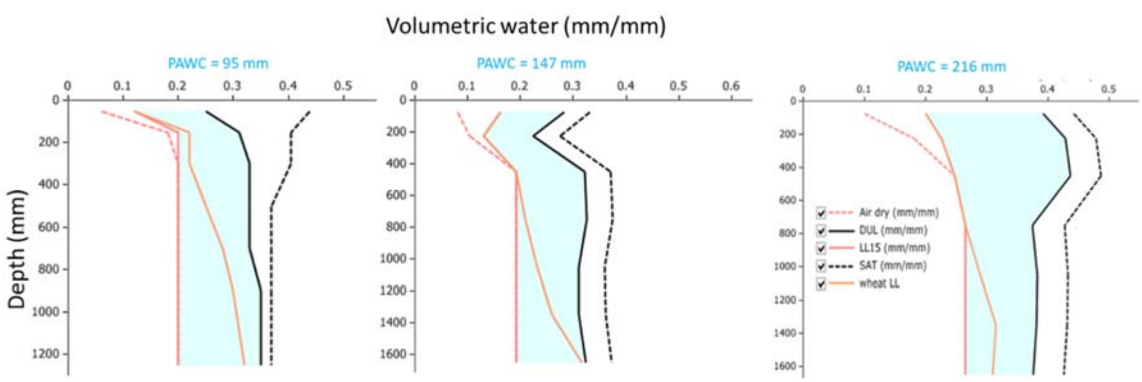

Figure 2. The three soil profiles used at the eight study sites in Australia. The shaded blue area indicated the plant available soil water capacity (PAWC).

Simulations were conducted for a continuous wheat-fallow cropping system at each of the 8 sites from 1957 to 2017. The wheat crop was sown every year within a sowing window from 1-May to 10- July if accumulated rainfall reached 25 mm within seven consecutive days and if there was more than 50 mm plant available water in the seed layer. Sowing depth was set to 30 mm with a plant population of 120/m^2 and row spacing of 250 mm. If these criteria were not met, the crop was sown on the last day of the window. Soil N in the simulations was maintained at levels non-limiting to plant growth.

Results

Generally, doubling the sizes of early leaves (i.e. the early vigour scenario) resulted in higher grain yield compared to baseline wheat at all 8 study sites (Fig 3). Along the W-E transect, the sites have similar uniform rainfall distribution during the year, early vigour led to more yield benefit at wetter than drier sites, particularly on soils with high PAWC (Fig 3, Griffith vs Temora). Along the N-S transect, rainfall pattern changes gradually from summer-dominant, to uniform and to winter-dominant rainfall, the yield benefit from early vigour increased from the north to south (Emerald vs Young and Beulah).

For early vigour wheat on a soil with PAWC of 95 mm, grain yield was simulated to be 4-22% greater across sites, with average increase in grain yield of 17% compared to baseline wheat. On soils with larger PAWC, early vigour led to more yield benefit, with average yield benefit of 22% on soil with PAWC of 147 mm and 29% on soil with PAWC of 216 mm compared to baseline wheat. For a given climate, soils with larger soil

PAWC can hold more water from rainfall for plant to use, likely better supporting the quicker growth with early vigour, and leading to subsequently higher yields.

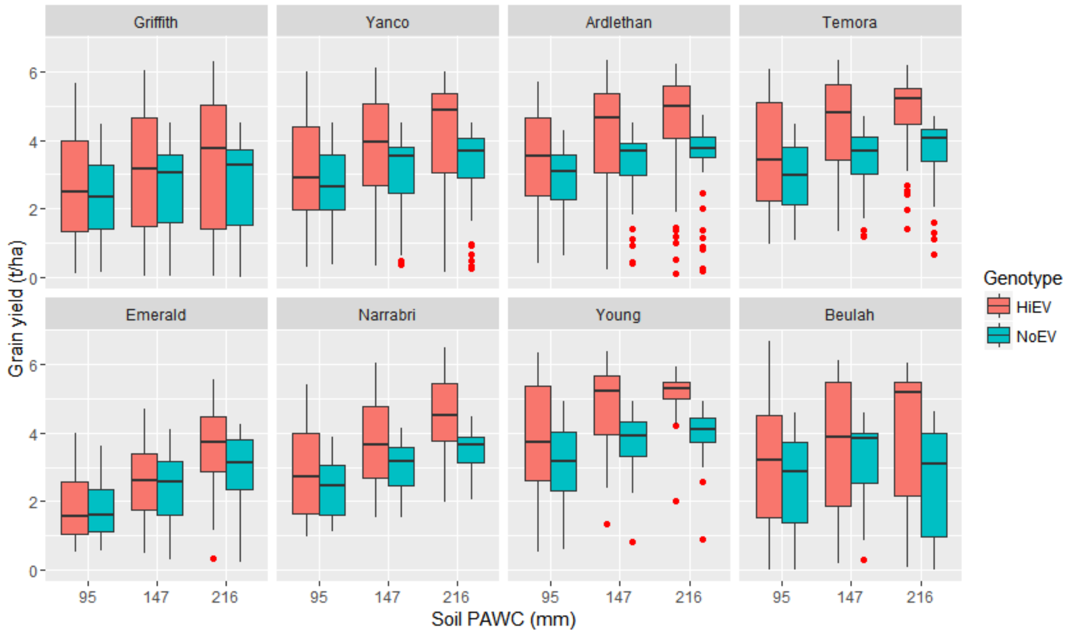

Figure 3. Impact of plant available water holding capacity (PAWC) on the average of simulated wheat yield (1957-2017) from the eight study sites for the baseline wheat (NoEv) and vigorous wheat (HiEV, doubled leaf sizes) in Australia.

Conclusion

Our simulation results indicate that early vigour trait led to yield benefit on all the three soils in eastern Australia. The yield benefit was simulated to be greater at wetter sites with uniform and winter-dominant rainfall on soils with higher water holding capacity.

Acknowledgements

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