Assessment of canopy growth and development for three wheat cultivars under different water and nitrogen regimes

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Abstract
Traits related to water productivity in dryland cropping interact in multiple ways to influence final grain yield. Crop modelling can be a useful tool to address the challenge of determining how to best combine region-specific traits and develop management adaptation for specific cultivars. The Agricultural Production Systems sIMulator (APSIM) model has been developed and widely-used for diverse applications in scientific research and decision support. However, the model requires further development to accurately simulate important candidate traits associated with water productivity. To better capture differences among genotypes, APSIM needs improvement related to the modelling of canopy development as a driver of water use. Field experiments were conducted in 2015 to assess variation and covariation in traits related to water productivity, e.g. early vigour, tillering, leaf area development, water soluble carbohydrate (WSC) accumulation and transpiration efficiency. Contrasting genotypes for these traits were grown under a range of water and nitrogen regimes. Data were collected through field observation, destructive sampling and high-throughput technologies. Extensive phenotyping was used to explore patterns in canopy development and canopy structure and their impact on productivity, with particular focus on variation occurring during the vegetative stage. An improved wheat model is being developed using the Plant Model Framework in the next generation prototype of APSIM. Experiments described above, as well as previously collected datasets, are being used to develop new algorithms. The new model will be used to assess wheat traits related to water productivity across the Australian wheatbelt.

Keywords
APSIM, crop model, high throughput phenotyping, water productivity.

Introduction
Crop models can be utilised to understand how to best combine traits for target environments and assist breeding of new cultivars (Hammer et al. 2014; Chenu et al. 2017). The Agricultural Production Systems sIMulator (APSIM) model has been developed and widely-used for diverse applications in decision support for crop management, whole-farm analysis and policy development (Holzworth et al. 2014). However, the model requires further development to be able to simulate different candidate traits related to water productivity, including early vigor, tillering, canopy development, water soluble carbohydrate content and transpiration efficiency. Developing new algorithms for this purpose requires a better understanding of the intrinsic mechanisms affecting these traits under different environments and management as well as the interactions between these traits.

The aim of this study was to quantify the growth and development of canopies, especially during the vegetative stage, in contrasting wheat genotypes and environments. Field experiments were conducted over two years using contrasting cultivars under a range of water and nitrogen availability regimes and sowing dates. These experiments will be used at a later stage for APSIM algorithm development. The results from 2015 of three key genotypes sown at the normal date are discussed here.

Methods
Wheat experiments were conducted in 2015 and 2016 at the University of Queensland Gatton Campus experimental station (27.50°S, 153.01°E). Contrasting canopies were established using two irrigation treatments (irrigation and rain-fed), two nitrogen treatments (high and low), two sowing dates (normal and late in 2015, normal in 2016) and eight cultivars. The experimental field was 54 m wide and 161 m long, and split into four blocks and 621 plots. Plots contained seven rows and were 2 m wide and 7 m long. The four

treatments refer to the four irrigation and nitrogen treatments (i.e. 'RLN' for rain-fed and low nitrogen, 'RHN' for rain-fed and high nitrogen, 'ILN' for irrigation and low nitrogen, and 'IHN' for irrigation and high nitrogen). Fertiliser was applied at sowing with 205 kg ha^{-1} for high nitrogen and 50 kg ha^{-1} for low nitrogen (Urea, 46% N) after measuring the pre-planting soil nitrogen being *ca* 32.3 kg ha^{-1} (at 0 to 0.6 m depth), averaged for samples across the field about one month prior to sowing. Each treatment was split into two sub-blocks for the two sowing treatments in 2015. The normal sowing dates was 21 May in both years and 22 June for the late sowing in 2015 only. Eight cultivars were selected to represent contrasting water productivity traits (i.e. maturity, early vigour, tiller number, transpiration efficiency, water soluble carbohydrate and protein content) with three replicates. In each sub-block, all treatments were randomised by the R package DiGGer. The plant density was *ca* 150 plant m^{-2}. The results from 2015 of three key genotypes (medium-maturity cultivars 'Hartog' and 'Suntop', and late-maturing cultivar 'Gregory') sown at the normal date are discussed here.

Intensive measurements related to wheat phenology, canopy development, and biomass partitioning were taken from sowing to maturity. Development was scored using Zadoks scores (Zadoks et al. 1974) once or twice a week depending on growth stage. The Haun index of the main stem and total stem number was assessed weekly on four tagged plants until heading. Quadrats of 1 × 1 m size were harvested at two week intervals to determine the leaf area index and biomass partitioning (dry weights of green leaves, dead leaves, stems and heads, if applicable

Results

Stem numbers per plant increased linearly until growth stage DC31, where they plateaued at a maximum value, before gradually decreasing while tillers senesced up to flowering (Figure 1). Segmented linear functions were fitted to changes in stem numbers. Significant differences were observed in the stem number among genotypes and management regimes, in particular in the duration of tiller production. Treatments with irrigation and high nitrogen had the highest stem number per plants. 'Gregory' had the highest stem numbers in all treatments except RHN.

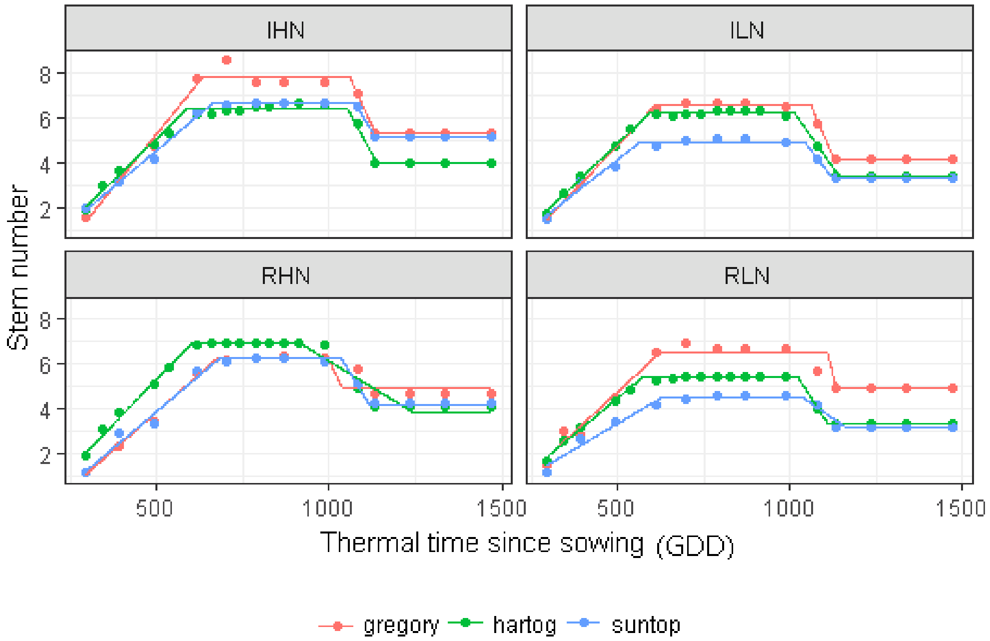

Figure 1. Change over thermal time (GDD, base temperature = 0°C) in stem number per plant for cultivars 'Suntop', 'Hartog' and 'Gregory' for two irrigation treatments (irrigation (I) and rain-fed (R)) and two nitrogen treatments (low (LN) and high (HN) nitrogen). Four segmented linear equations where fitted to the data to show the dynamic changes in stem numbers.

Genotypic differences in biomass production and partitioning was observed among cultivars but these differences were much smaller than variation among irrigation and nitrogen treatments (Figure 2). The IHN treatment had the highest biomass. The relatively small variations observed between treatments of irrigation and rain-fed were due to relatively high rainfall during the growing season in 2015.

Other phenotypic data, obtained from other equipment, were collected in the field experiment including ground coverage, NDVI and light interception but are not presented here. Further analysis is being conducted with all collected datasets to explore the intrinsic mechanisms of canopy development and growth, and to develop new algorithms to develop the wheat model in next generation of APSIM.

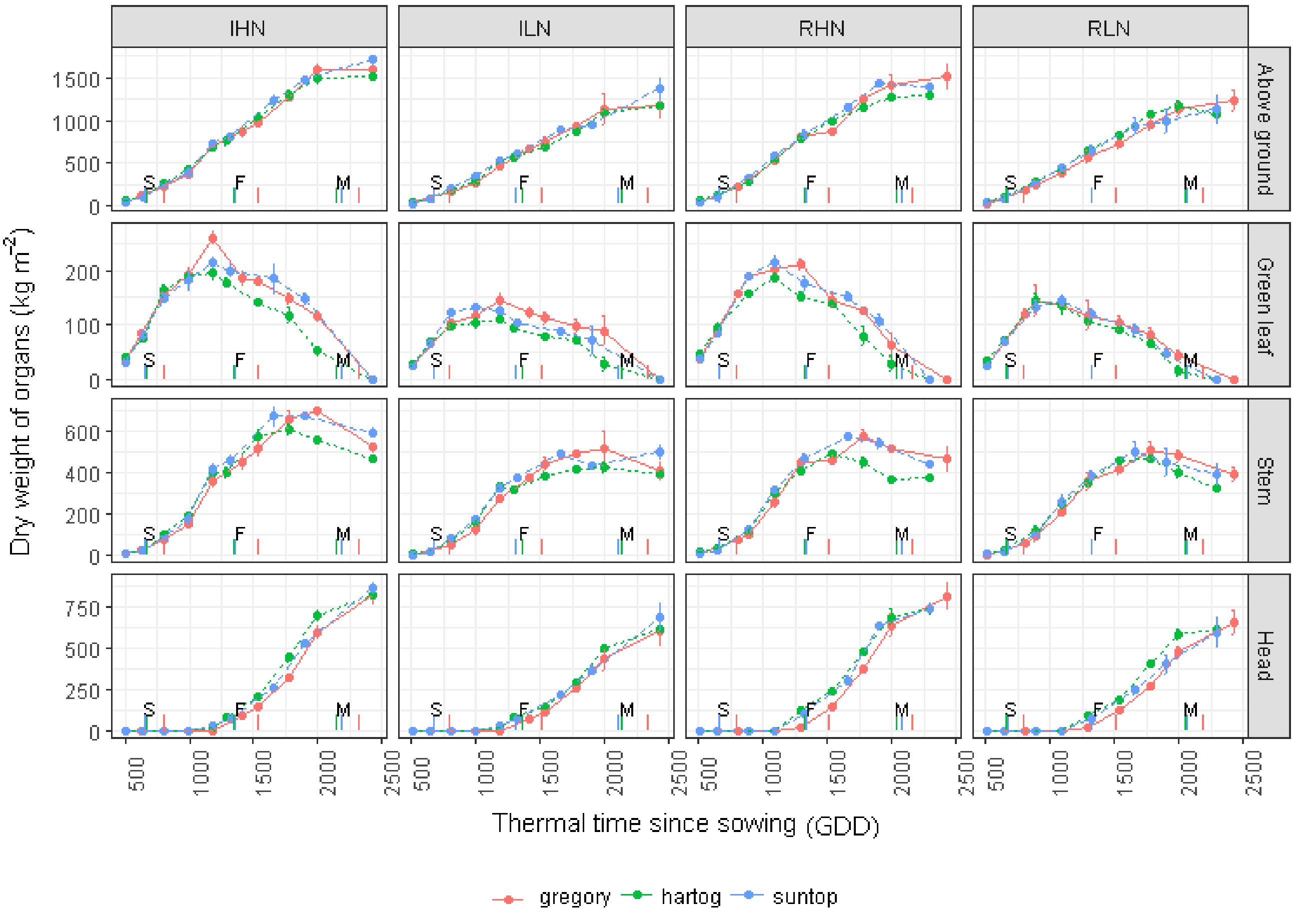

Figure 2. Change over thermal time (GDD, base temperature = 0°C) of the dry weight for different organs (above ground, green leaf, stem and head) . The field experiments included three cultivars ('Suntop', 'Hartog' and 'Gregory'), two irrigation treatments (irrigation (I) and rain-fed (R)), two nitrogen treatments (low (LN) and high (HN) nitrogen). The vertical bars at the bottom are the major growth stages (i.e. S for DC31, F for flowering and M for maturity). The error bars are standard errors of three replicates.

Conclusion

Wheat experiments were conducted in the field over two years to assess genotypic variation in traits related to water productivity. Multiple technologies were used in the field experiment to collect phenotypes and monitor wheat growth and developments. Fusing datasets from all resources provided the opportunity to explore the interaction of genotype, environment and management in detail. Analysis of all collected data is leading to the development of an improved wheat model using the Plant Model framework (Brown et al. 2014) in the next generation APSIM (Holzworth et al. 2014). The new model will be used to assess wheat traits related to water productivity across the Australian wheatbelt.

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