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Canopy development and grain yield of dryland wheat is modified by strategic nitrogen supply and stubble management

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ABSTRACT

Yield in dryland wheat could be improved through a better understanding of crop responses to no-till (NT), stubble retention and nitrogen (N). Field experiments were established at Roseworthy and Karoonda in South Australia to evaluate wheat crop responses to contrasting tillage systems, different amounts of stubble and N timing. Canopy development regulated grain yield. No-till crops produced more biomass compared with conventional tillage while large amounts of stubble (5 t ha^{-1}) reduced biomass at harvest compared with both moderate amounts of stubble (2.5 t ha^{-1}) and bare ground. The application of N at sowing produced large vegetative biomass compared with delayed N supply. However, delayed N supply allowed more rapid accumulation of biomass between stem elongation and flowering, the critical period for yield determination in wheat. Crop growth rate during this period positively correlated with grain number ($R = 0.44$) but negatively with tiller numbers ($R = 0.66$). Grain yield declined with the retention of more than moderate amounts of stubble, irrespective of whether the stubble was applied as mulch or left standing; similarly, additional stubble did not improve water conservation benefits. Results demonstrate that the strategic supply of N under stubble retention can increase crop growth rate during the critical period between stem elongation and flowering.

1. Introduction

Sustainable dryland cropping typically involves no-till (NT), stubble retention and effective nitrogen (N) fertilization. However, the mechanisms operating among tillage systems, stubble amounts and N fertilization are only partially understood. Limitations arise from a poor understanding of how these management practices impact crop developmental rates to improve yield potential. This limitation is compounded by challenges in matching water use patterns with N availability and crop demand for N. Uncertainties on the optimal amount of stubble to retain and its orientation (mulch or standing stubble), as well as post-harvest handling challenges of stubble limit tillage and stubble management options.

Tillage and stubble retention affect soil water and N economies, the fundamental constraints in dryland cropping systems. Together with stubble retention, NT conserves soil through reduced runoff, erosion, evaporation and increased infiltration (Alvarez and Steinbach, 2009; Kirkegaard, 1995). Yield gain from increased water availability depends on many factors, such as crop growth rate, and N use patterns (Sadras and Lemaire, 2014). In wheat, crop growth rate between stem elongation and flowering affects grain number, radiation use efficiency and N uptake (Andrade et al., 2005; Miralles and Slafer, 2007; Slafer et al., 2015). Little is documented on the mechanisms that impact crop growth rate and yield in NT and stubble retention systems.

Wheat and maize crops grown under NT and stubble retention had slow initial growth rates compared with those under conventionally tilled soils (Verhulst et al., 2011). However, the slow growth rates were compensated in later stages, which led to higher grain yield. The authors attributed the slow start and the subsequent compensation at late stages to the synchronization of N availability with crop demand for N, compared with an initial flush of N in tilled soils. Nonetheless, from a physiological point of view, the shift in biomass indicates changes in crop growth rate during the reproductive phase. Nitrogen deficiency will impact differently at different growth stages during crop growth (Ravier et al., 2017). Therefore, low initial N, when plant available water is high, are poorly matched but may lead to high yield if some

Abbreviations: CT, conventional tillage; NT, no-till; N1, sowing application of 100 kg N ha^{-1}; N2, 100 kg N ha^{-1} timed as 25% at sowing, 50% at tillering and 25% at awn emergence; N3, 100 kg N ha^{-1} subdivided as 50% at tillering and 50% at awn emergence (N3); S0, zero stubble retention; S1, low stubble; S2, moderate stubble; S3, high stubble; CGR, crop growth rate; RUE, radiation use efficiency; WUE, water use efficiency

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water is conserved for later growth. Water limitations during the yield determination window reduce N recovery, potentially reducing leaf area, photosynthetic activity and grain number (Slafer et al., 2015). Studies evaluating management practices only use end-of-season yield components (Brennan et al., 2014; Singh et al., 2015) but provide little information about the physiological mechanisms regulating crop growth and yield.

Rainfall uncertainties make N fertilization a risky venture in drylands, which leads to large gaps between actual and water-limited potential yield (Sadras et al., 2016). Water-limited yield potential is the maximum yield achievable under rainfed conditions if soil water capture and storage are maximised and nutrient constraints are eliminated (van Ittersum et al., 2013). Improved moisture regimes under NT and stubble retention provide opportunities for better N management, particularly with late N applications (Riar and Coventry, 2013). N applications at sowing minimise the risks of N fertilization in drylands (Sadras et al., 2016) but lead to potential trade-off in the build-up of large vegetative biomass that squanders valuable soil moisture before the reproductive and grain-filling phases (van Herwaarden et al., 1998; Zhou et al., 2017). In addition, wheat crops require small amounts of N in the initial stages while applications at sowing inefficiently convert biomass to yield (Hooper et al., 2015; Zhou et al., 2017) and predisposes N to leaching losses (Alley et al., 1996). Timing the N supply is one mechanism used to manage biomass to better match rainfall patterns and balance water use, both before and after flowering (Zhou et al., 2017). Late applications of N provide better N recovery for increased grain yield quality (Coventry et al., 2011). In Australia, management of stubble in NT systems can require the removal of excess stubble by burning or feeding livestock to minimise physical impairment to seeding operations and crop establishment (Flower et al., 2017; Rochecouste and Crabtree, 2014; Scott et al., 2013). Recent findings are inconsistent; some report yield increase as stubble amounts increase (Scott et al., 2013; Yunusa et al., 1994) but others show a negative relationship (Flower et al., 2017). The increased yield is attributed to conservation of water and nutrients while losses are ascribed to reduced plant numbers due to physical obstruction by stubble, and diseases and pests (Scott et al., 2013); yet the minimum amount of stubble required to off-set losses and maximise benefits is not known (Kirkegaard et al., 2014). The quality and amount of stubble is important, as high amounts of cereal stubble have larger negative effects compared with legume or brassica materials (Flower et al., 2017), presumably due to lower C:N ratio in the latter types. However, cereal stubble is dominant, and understanding the critical quantities of stubble to retain could provide a theoretical basis for the minimal amount to retain and post-harvest handling techniques (Kirkegaard et al., 2014). These amounts are likely to be independent of the cropping environment and system.

In view of the identified limitations, this study examined crop growth and water use on wheat yield as affected by tillage, stubble and N timing in contrasting environments. We hypothesised that, (i) the effects of management practices on yield are mediated by changes in crop growth rate between stem elongation and flowering, (ii) yield response to tillage and stubble is N dependent, and (iii) the critical amount of stubble at which grain yield is maximised in dryland wheat is independent of cropping environment. In NT systems, an optimal amount of stubble in combination with better N timing could reduce wheat yield gaps in winter-rainfall Australian environments.

2. Materials and methods

2.1. Sites

Field experiments combining tillage systems, different amounts of stubble application and N timing were conducted in 2013 through 2015 in two contrasting dryland wheat growing Mediterranean-type environments in South Australia. The sites had a history of commercial production, with rotation of cereals, canola and crop legumes under continuous NT and use of direct drill sowing equipment while stubble was typically reduced by grazing livestock. Experiments were conducted in 2013 through 2015 at Roseworthy farm of the University of Adelaide (34.52 °S, 138.68 °E, 63 m altitude) and in 2013 and 2014 at Karoonda (35.04 °S, 140·05 °E, 75 m altitude).

Roseworthy has 463 mm average annual rainfall, with 315 mm in the growing season between April and October. The site has mean maximum temperature of 22.5 °C and mean minimum temperature of 10.0 °C during this cropping season. Soil is red-brown earth and classified as sodic, supracalcic, red chromosol with a firm sandy loam surface in the A horizon (Isbell, 2002). Soil tests before sowing at 0–20 cm depth returned a pH of 6.6 in $CaCl_2$, EC of 244 µS cm^{-1}, 0.07% by weight total N (Kjedahl method) and 1.41% by weight organic carbon (Walkley-Black chromic acid wet oxidation method). At 20–40 cm depth, the soil had a pH of 6.7, 252 µS cm^{-1} EC, 0.05% total N by weight and 1.21% organic carbon by weight.

Karoonda is located in the Murray Mallee with lower rainfall than Roseworthy. Annual rainfall at this site is 310 mm, and approximately 70% falls between April and October cropping season. Mean maximum temperature at this site is 24.0 °C whereas the mean minimum temperature is 9.0 °C. Karoonda soils are sandy with a shallow profile of approximately 60 cm on rock. At 0–20 cm depth, pH was 6.6, 163 µS cm^{-1} EC, 0.02% by weight total N and 0.63% by weight organic carbon (C). At 20–40 cm depth the soil has a pH of 7.2, an EC of 629 µS cm^{-1}, 0.01% total N by weight and 1.07% C by weight.

2.2. Treatments and experiment design

At Roseworthy, two tillage systems (conventional tillage, CT, and no-till, NT), four rates of stubble (zero, low, moderate and high) and three N timings. The N timing represented normal (single sowing application), low yield (early application) and high yield (late application) based on the results of Hooper et al. (2015). N timing treatments were, (i) sowing application of 100 kg N ha^{-1} (N1), (ii) 100 kg N ha^{-1} split as 25% at sowing, 50% at tillering and 25% at awn emergence (N2), and (iii) 100 kg N ha^{-1} divided as 50% at tillering and 50% at awn emergence (N3). The experimental design was a split-split plot arrangement in a randomized complete block design with three replications. Tillage system was assigned to the main plots, residue amount formed the sub-plots, while N timing made the sub-sub-plots.

In Karoonda, two tillage systems (CT and NT) and four rates of stubble (zero, low, moderate and high stubble) were evaluated under uniform application of 100 kg N ha^{-1} at sowing. The experiment design was a split plot arrangement in a randomized complete block design with four replications. Tillage system was assigned to the main plots and stubble amounts were assigned to the sub-plots. In both sites, main plots were 48 m long and 6.5 m wide, sub-plots were 48 m long and 1.5 m wide while sub-sub plots measured as 12 m by 1.5 m. Six rows were sown per plot with as 0.25 m spacing.

2.3. Experiment management

In both sites, crops of wheat (*Triticum aestivum* L.), Justica CL Plus, a variety well-adapted to Australian conditions were grown. Crops were sown on 29th May 2013, 10th June 2014 and 24th June 2015 at Roseworthy while at Karoonda crops were sown on 28th May in both 2013 and 2014. At the beginning in 2013, crops were sown into surface applied stubble mulch. After sowing, mulch was applied manually at zero stubble (0 t ha^{-1}), low stubble (0.5 t ha^{-1}), medium stubble (2.5 t ha^{-1}) and high stubble (5 t ha^{-1}). In 2014 and 2015, crops were sown into standing stubble treatment. After harvesting the previous stubble was retained after cutting to different heights and the cut material was removed. Stubble was cut at ground level for zero stubble, 15 cm from the ground level for low stubble, 25 cm for moderate stubble and 35 cm for high stubble. A canvas bag was secured at the rear of the straw walker of the harvester to collect the cut stubble. Conventional tillage