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Screening chickpea for adaptation to water stress: Associations between yield and crop growth rate

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ABSTRACT

Robust associations between yield and crop growth rate in a species-specific critical developmental window have been demonstrated in many crops. In this study we focus on genotype-driven variation in crop growth rate and its association with chickpea yield under drought. We measured crop growth rate using Normalised Difference Vegetative Index (NDVI) in 20 diverse chickpea lines, after calibration of NDVI against biomass accounting for morphological differences between Kabuli and Desi types. Crops were grown in eight environments resulting from the combination of seasons, sowing dates and water supply, returning a yield range from 152 to 366 $\mathrm{g\,m^{-2}}$. For both sources of variation – environment and genotype – yield correlated with crop growth rate in the window 300 °Cd before flowering to 200 °Cd after flowering. In the range of crop growth rate from 0.07 to 0.91 $\mathrm{g\,m^{-2}\,{}^{\circ}Cd^{-1}}$, the relationship was linear with zero intercept, as with other indeterminate grain legumes. Genotype-driven associations between yield and crop growth rate were stronger under water stress than under favourable conditions. Despite this general trend, lines were identified with high crop growth rate in both favourable and stress conditions. We demonstrate that calibrated NDVI is a rapid, inexpensive screening tool to capture a physiologically meaningful link between yield and crop growth rate in chickpea.

1. Introduction

Chickpea is one of the most important pulse crops grown in over 50 countries with an aggregated annual production of 14 million tonnes in 2014 (Jumrani and Bhatia, 2014; FAO, 2015). It is an important source of affordable protein, which is being increasingly recognised for its health benefits, and contributes nitrogen fixation in rotations with cereals (Venn and Mann, 2004; Duc et al., 2014; Arnoldi et al., 2015; Rubiales and Mikic, 2015). However, chickpea yield remains unstable and unreliable and in many countries averages less than 1 $\mathrm{t\,ha^{-1}}$ mainly as a result of abiotic and biotic stress (FAO, 2015; Rubiales et al., 2015; Rubiales and Mikic, 2015).

Yield is associated with crop growth rate in a species-specific critical window in maize, wheat, canola, sunflower, pea and soybean (Tollenaar et al., 1992; Andrade et al., 2002, 2005; Guilioni et al., 2003; Sadras et al., 2012b; Zhang and Flottmann, 2016). Crop growth rate integrates environmental and genotypic sources of variation, and is thus a trait often used in modelling and with potential applications in breeding (Wiegand and Richardson, 1990). Guilioni et al. (2003) for example, found a single linear relationship between yield and crop growth rate of field pea regardless of stress type (drought or heat), while Echarte et al. (2004) demonstrated that growth rate in a critical period was useful in quantifying yield differences in maize hybrids grown in contrasting environments.

Both the timing of the critical period and the models describing the relationship between yield and crop growth rate differ among species. The most critical period is before flowering in small grain cereals, and after flowering in pulses (Sadras and Dreccer, 2015); Fig. 1c outlines the critical period of chickpea. Indeterminate soybean has a linear relationship with zero intercept, canola also has a linear relationship with undefined intercept, while determinate maize and sunflower are non-linear (hyperbolic) with a non-zero intercept indicating a minimum crop growth rate for reproduction (Egli and Yu, 1991; Egli, 1993; Vega et al., 2001a; Guilioni et al., 2003; Andrade et al., 2005; Zhang and Flottmann, 2016). Linear (Guilioni et al., 2003) and non-linear relationships (Sadras et al., 2013) have been reported for field pea. The shape of the model is important because a linear relationship indicates a tight coupling between vegetative and reproductive growth, whereas non-linearity indicates decoupling. The decoupling can be morphological as in maize and sunflower where strong apical dominance constrains seed set under high availability of resources, or physio-

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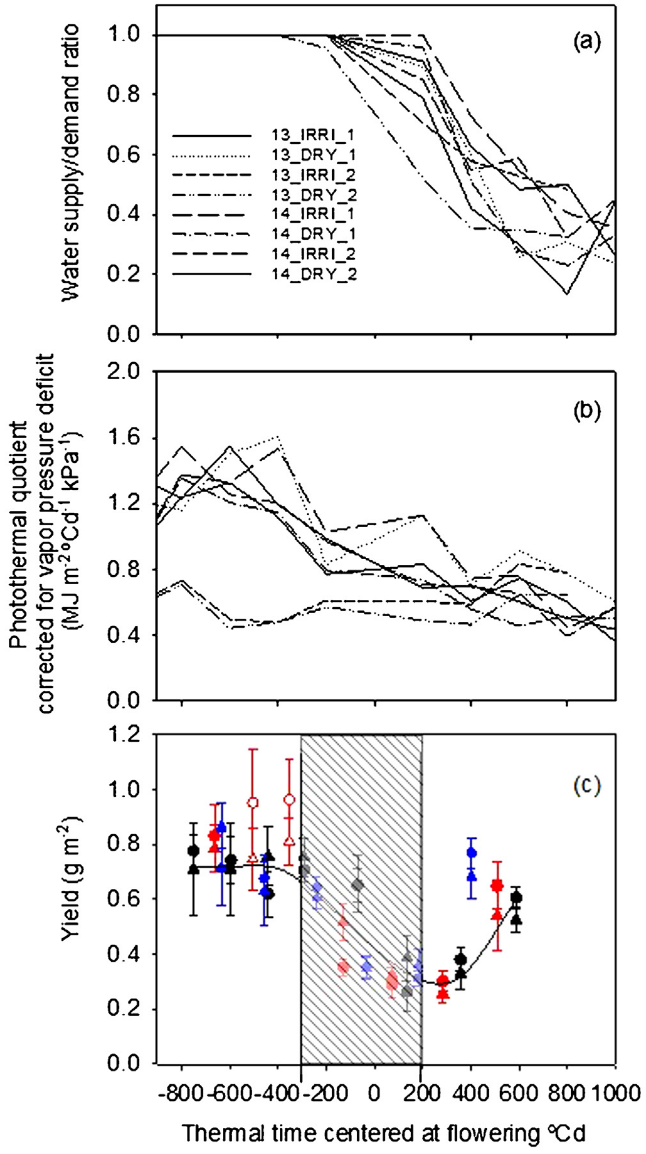

Fig. 1. Seasonal patterns of (a) water stress index (1 indicates no stress while 0 indicates maximum stress) and (b) photothermal quotient corrected for vapour pressure deficit in eight environments. As a reference, (c) shows the critical period for yield determination (adapted from Lake and Sadras (2014)) where the shaded area represents the time when we measured crop growth rate. Key to environments: Year_Water Regime_sowing time; for example 13_IRRI_1 indicates 2013, irrigated, 1st sowing.

logical as speculated for field pea (Andrade et al., 2005; Sadras et al., 2013).

Crop growth rate can be derived from destructive measurements of biomass (Tollenaar et al., 1992; Andrade et al., 1999; Guilioni et al., 2003; Zhang and Flottmann, 2016) or with morphometric measurements based on allometric relationships (Vega et al., 2001b). Both methods are time consuming. A non-destructive option is spectral reflectance, which can provide high throughput alternatives (Ma et al., 1996, 2001; Sadras et al., 2013). There has been limited work in grain legumes which have a more challenging architecture as illustrated by Sadras et al. (2013) who used Normalised Difference Vegetative Index (NDVI) to measure crop growth rate in field pea where separate calibrations were required for different morphological types (semi-leafless and conventional leaf types).

Few studies investigated the association between yield and crop growth in chickpea. Krishnamurthy et al. (1999) and Ramamoorthy et al. (2016) reported relationships between crop growth rate and yield in chickpea but their growth rates were derived from harvest biomass and duration of growth; this is in reality a primary measure of maturity biomass and does not allow for specific insights into the relationship between yield and crop growth rate in physiologically meaningful periods. There is scarce information in chickpea about the association of yield and crop growth rate within physiologically meaningful critical periods (Lake and Sadras, 2014), the nature of the association (linear/non-linear) or the consistency of the relationship for different varieties and environments. This research aims to test the association between growth rate within the critical period and yield in a collection of chickpea lines grown in an environmental range from nearly yield potential to agronomically meaningful water stress (Passioura, 1996, 2007).

2. Materials and methods

The experimental details have been presented in Sadras et al. (2016) who also reported yield and phenology. In this section we summarise general methods, and provide detail on the approach to measure crop growth rate and its association with yield.

2.1. Plant material and experimental design

Fifteen Desi and five Kabuli chickpea lines (Table 1) that represent a broad range in agronomic adaptation, yield, morphology and phenology were evaluated. Crops were grown at Roseworthy (34°52′S, 138°69′E) in South Australia; eight environments resulted from a combination of two seasons (2013 and 2014), two sowing dates and two water regimes.

The first sowing date was 7th June 2013 and 10th June 2014 and the second was 9th July 2013 and 15th July 2014. Late-sown crops were expected to have lower yields caused by elevated temperatures and lower photothermal quotient (Fig. 1b) (Sadras and Dreccer, 2015).

The two water regimes were either sprinkler irrigated or rainout shelter canopy for the first sowing date (installed on the 3rd August in 2013 and 23rd July in 2014) and sprinkler irrigated and rainfed for the late sowing (from here on we will refer to the rainfed and rainout shelter environments as “dry”). Irrigation was applied to match evaporative demand and begun 41–76 days after sowing. Water regimes were intended to provide conditions suitable for high yield, and water deficit around the critical period for yield determination (Fig. 1a and c).

Treatments were laid out in a split-split-plot design of three replicates with sowing date as main plot, water regime as secondary plot, and varieties randomised within each plot. Plot size was 7.25 m^2, comprised of six rows (spaced 24 cm) of five meters length. For further details of crop management see Sadras et al. (2016).

2.2. Measurements

2.2.1. Phenology

We scored phenology weekly to establish time to: 50% of plants in each plot reaching flowering, pod emergence (developing pods of 2–4 mm in length), end of flowering and maturity (yellowing pods) (Berger et al., 2004; Lake and Sadras, 2014). Flowering duration was calculated as the time between 50% flowering and the end of flowering. We used a thermal time scale to express phenology, calculated from daily mean temperature and base temperature of 0 °C (Berger et al., 2006).