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Use of a managed stress environment in breeding cotton for a variable rainfall environment

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ABSTRACT

Australian rainfed cotton is grown in regions with highly variable rainfall, with in-crop rainfall ranging from 100 mm to 800 mm. The CSIRO cotton breeding program conducts rainfed germplasm evaluations at its core research site, as well as a number of regional locations. As a direct result of our variable rainfall environment, yields < 550 kg ha^{-1} are observed in 20% of years. Historically, these low yielding seasons result in variable experimental data with an increased risk of experimental failure as a non-significant result. Therefore, the aim of this research was twofold. Firstly, to develop and evaluate a managed stress environment (MSE) protocol where 'rainfed' germplasm evaluations are irrigated when yield is expected to fall below the minimum threshold for our target breeding environment (550 kg ha^{-1}). Secondly, to assess the reliability of germplasm performance under rainfed conditions and limited water situations, clarifying whether germplasm selected under very dry rainfed conditions has the ability to produce high lint yield in seasons with higher than average rainfall. It was hypothesised that applying one furrow irrigation in very dry seasons will reduce within experiment variability and increase experimental yields to better reflect our breeding target environment. As irrigation timing will impact its efficacy, the OZCOT simulation model for cotton crop management was used to determine the most effective irrigation date with respect to soil water content and crop growth stage. The simulation, conducted with weather data from a 151 year period, concluded that yields > 550 kg ha^{-1} were not achieved in 27 seasons (18%). These 27 seasons underwent further simulations to determine the most suitable soil water content and crop growth stage where yield was increased with a single irrigation. It was determined that an irrigation should be applied to a 'rainfed' experiment if plant available water (PAW) reached approximately 40% by peak flowering (100-110 DAS). Paired rainfed and MSE experiments with 21 genotypes were established in 2013/14, 2014/15 and 2015/16 to provide field validation of the developed protocol. Genotype performance was assessed in terms of lint yield and fibre quality. Results show that in dry seasons (2013/14) irrigating the 'rainfed' treatment was necessary to reduce within experiment variability and increase yields above 550 kg ha^{-1}. However, once rainfed yield levels increase due to greater in-crop rainfall (2014/15 and 2015/16), irrigation was no longer necessary. This was further supported by the result that genotype yield ranking differed between rainfed and MSE treatments. Genotype changes in fibre quality between treatments were small. It was concluded that a MSE, designed to produce experimental data better matched to our breeding target environment as well as reducing the risk of experimental failure, would be a worthwhile addition to rainfed evaluations conducted in variable rainfall environments.

1. Introduction

Australian rainfed cotton production occurs in warm regions with intermittent and highly variable rainfall throughout the growing season. Not only is the rainfall variable, it is also skewed such that a smaller proportion of seasons have favourable rainfall patterns (Fig. 1). This environmental variability significantly impacts the area of rainfed cotton production, as well as crop yields (Fig. 2). Rainfed cotton production relies on the use of stored soil moisture as well as in-season rainfall, so production is targeted to long-season regions where soils

Abbreviations: ACRI, Australian Cotton Research Institute; Avg., average; CSIRO, Commonwealth Scientific and Industrial Research Organisation; CV, coefficient of variation; ET_O, grass reference crop evapotranspiration; DAS, days after sowing; GxE, genotype-by-environment interaction; HVI, High Volume Instrument; MSE, managed stress environment; NAM, neutron attenuation metre; PAW, plant available water; T_a, air temperature; T_{max}, maximum air temperature; v.r., variance ratio

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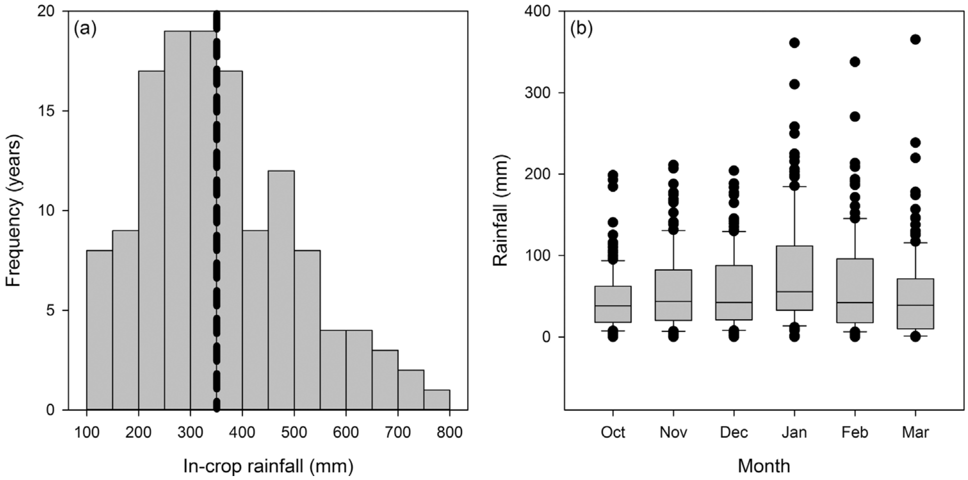

Fig. 1. (a) Frequency distribution of in-crop rainfall (October to March), where the dashed line represents the mean rainfall; and (b) box plot highlighting monthly variation in rainfall measured between 1885 and 2015 at Wee Waa (15 km west of ACRI). Data sourced from Aust. BOM (2015).

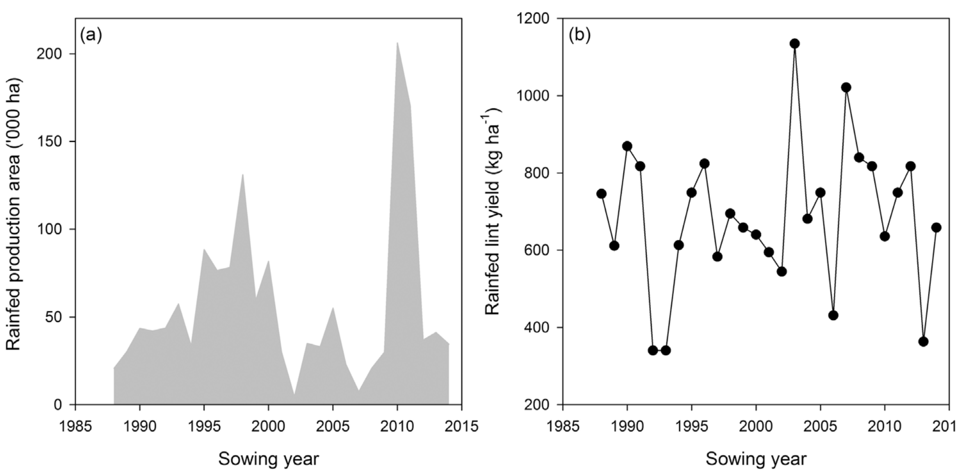

Fig. 2. In-crop rainfall variability alters: (a) the production area of Australian rainfed cotton, and; (b) the average industry wide rainfed lint yield. Data compiled from Australian Cotton Yearbooks (Dowling, 2015).

have high water holding capacity (principally Vertosols) and in-season rainfall is more reliable. However, often long-season areas are those regions with increased rainfall variability. Agronomic management practices can reduce the risk associated with this variable in-crop rainfall. 'Skip-row' sowing configurations that decrease plant population can increase the soil water availability to individual plants (Bange et al., 2005). Sowing dates are varied according to soil water availability (Hearn, 1995; Bange et al., 2005). Modest nitrogen inputs, to control early season growth, and the use of limited/no-tillage and stubble retention, to increase the capture and storage of soil water, are employed (Bange et al., 2002). Finally, later-maturing cultivars with phenological plasticity, and the okra leaf trait, have been shown to provide benefit in this target environment (Stiller et al., 2004).

As a direct result of the variable rainfall environment, rainfed cotton crops are not sown every season. Thus, the proportion of the Australian cotton industry that rainfed cotton represents is dynamic; between 5 and 25%, where sowing decisions are influenced by cotton prices, availability of stored soil moisture and long-range rainfall predictions (Ford and Forrester, 2002). The average lint yield for Australian rainfed cotton systems is approximately 800 kg ha^{-1}, however yield potential can range from less than 300 to over 2000 kg ha^{-1}, primarily depending on seasonal rainfall patterns (Ford and Forrester, 2002). Although it is important for rainfed crops to produce yield in seasons with limited in-season rainfall, rainfed cotton producers tend to only sow crops in more favourable seasons. Furthermore, most profit is made in seasons with higher than average in-crop rainfall. Therefore, in this target environment it may arguably be more important for a genotype to perform under water-limited, but not extreme drought, conditions.

The CSIRO rainfed cotton breeding program conducts paired irrigated and rainfed germplasm evaluations at its core research site at the Australian Cotton Research Institute (ACRI). Additional data are collected from up to five alternative rainfed and 15 irrigated locations on commercial farms across Australian cotton production regions. An important aspect of the CSIRO rainfed breeding program is that although targeted parental selection for rainfed cultivar development occurs, only intermediate and advanced material is assessed under rainfed conditions, where early generation material is only evaluated under irrigated conditions. This ensures that yield potential is a consideration in the selection of material, as well as yield performance and reliability under water-limited conditions. The ability to conduct off-site evaluations is limited by the seasonal conditions and willingness of collaborators to sow a rainfed crop.

It is widely established that an increase in water availability will decrease variability and increase crop yields. Furthermore, under water limited conditions the genetic potential of a genotype may not be expressed, which may limit the ability to resolve statistical genotype differences. This has been observed in the CSIRO rainfed Advanced Line Trials in the period between 1995 and 2014 (Fig. 3a). This effect can be highlighted by the observation that statistical variation as a percentage of the experiment mean rises significantly when rainfed yield is less than 550 kg ha^{-1} (Fig. 3b). In the period between 1995 and 2014, 20% of seasons at ACRI resulted in rainfed yields < 550 kg ha^{-1}. Historically, these years result in variable experimental data and increased risk of experiment failure. Therefore, rainfed germplasm evaluated in these seasons may not confidently provide information for selection and progression of candidate lines through the rainfed breeding program.