Drought experienced by Australian wheat: current and future trends

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Abstract

Drought frequently limits Australian wheat production and the expected future increase in extreme temperatures and rainfall variability will further challenge productivity. A modelling approach captured plant x environment x management interactions to simulate drought patterns experienced by wheat crops for representative locations and managements across the wheatbelt. Simulations were performed for 123 years of ‘current’ climate (1889-2011) and four future climatic scenarios for 2030, accounting for predicted shifts in sowing dates and soil water content at sowing.

Across the wheatbelt, four main drought-environment types have been identified for the ‘current’ climates, ranging from stress-free/light-stress to severe stress with terminal drought. The frequency of occurrence of these environment types greatly varied across seasons and locations, and these variations tended to accentuate in future climate. Frequency of the most-severe (terminal) drought type was predicted to increase by 10 to 77% on average across the wheatbelt for the studied future climatic scenarios, with some high spatial variability between regions. While the *Wet & Low emission* scenario had no substantial impact on drought frequency in most regions, the *Dry & High emission* scenario more than doubled severe-drought frequency in several regions and substantially impacted the others (>25% increase). Further study is needed to assess alternative options (genotype and management) to reduce future drought impact, in particular for the *Dry & High emission* scenario.

Keywords

Water deficit, environment characterisation, mega-environment, climate change, modelling, APSIM.

Introduction

While growth in population and urban/industrial water demands are increasingly limiting water supply for agricultural production, improving crop yield remains a key strategy globally to meet projected demand (Borlaug and Dowswell, 2005). Recent trends in increased extreme temperature and rainfall events are forecast to amplify with climate change (e.g. IPCC, 2007; Battisti and Naylor, 2009; Coumou and Rahmstorf, 2012).

The Australian wheatbelt is characterised by large variation in inter-annual rainfalls (e.g. Williams *et al.*, 2002; Potgieter *et al.*, 2002) and by soils ranging from shallow sands to deep clays. Extending the modelling approach applied by Chenu *et al.* (2011), this paper aims to analyse the drought patterns that wheat crops experience in Australia in current and future climatic scenarios.

Materials and Methods

The APSIM crop model (e.g. Keating *et al.*, 2003) was used to simulate crop drought pattern for the quick/medium maturity variety ‘Hartog’ across the Australian wheatbelt over 122 years. To represent the Australian wheat cropping system, the major production areas (West, South, South-East, East) were divided into 22 regions (Fig. 1) and 60 locations, each representing between 130 000 and 230 000 hectares of planted wheat (averaged data from 1975-2000, 2005 and 2006; source: Australian Bureau of Statistics). The simulations used weather records for 1889-2010 (SILO Patched Point Dataset; Jeffrey *et al.*, 2001; http://www.longpaddock.qld.gov.au/silo/) and for four future climatic scenarios for 2030. Future climates had been generated for a wet and dry scenarios (Global Climate Models (GCM) ECHAM5 and GFDL-21, respectively) and a high and low CO_2 emission scenarios (A1FI and A2, respectively; IPCC, 2007). They had been calculated by QCCCE based on historical data (baseline from 1889 to 2010), using Consistent Climate Scenarios projections (Version 1.1).

For each climatic scenario and each location, an assessment of the sowing window and soil water content at sowing was performed. The sowing windows were determined as periods that resulted in flowering time occurring during low-risk periods of extreme temperatures (less than 10% chance of frost (Tmin < 0°C) and less than 30% chance of heat (Tmax > 35°C); Zheng *et al.*, 2012). Five representative sowing dates and soil water contents at sowing were calculated for each site and each climatic scenario, based on preliminary simulations beginning 1-Nov with a fallow (Fig. 2). Those initial conditions were used to simulate the

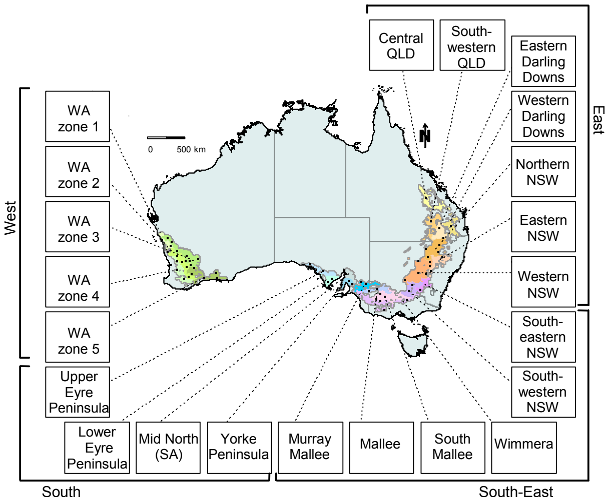

Fig. 1 The 22 regions (coloured and named in each box) and 60 sites (dots) used in the simulations to represent four cropping areas ('West', 'South', 'South-East' and 'East') of the Australian wheatbelt. Figure adapted from Chenu *et al.* (submitted).

drought pattern for the current and each of the future climatic scenarios.

The daily drought pattern was calculated for each crop based on a water-deficit index ("water supply/demand ratio") which indicates the degree to which the soil water extractable by the roots ("water supply") is able to match the potential transpiration ("water demand"). For each environment (site x year x sowing date x initial soil water x climatic scenario), this daily index was centred around flowering and averaged over 100°Cd from emergence to 450°Cd after flowering. In a previous study (Chenu *et al.*, submitted), four main drought-environment types (Fig. 2) were identified across the wheatbelt (using a similar methodology applied for sowing windows defined based on local practices). Simulations of the present study were classified based on which environment type they were the most similar to, i.e. based on the minimum sum of squared differences for the considered water-deficit pattern compared to the water-deficit pattern of the environment types. Analyses were done with R (R Dev. Core Team, 2011).

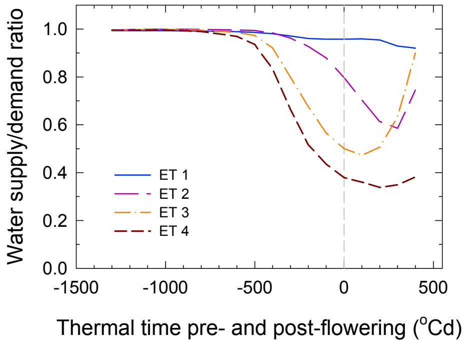

Fig. 2 Simulated water-stress index for four environment types identified across the Australian wheatbelt for the period 1889-2011. The stress index corresponds to the ratio of soil water supply to crop water demand and is represented as a function of cumulative thermal time relative to flowering, from crop emergence to 450°Cd after flowering. Figure adapted from Chenu *et al.* (submitted).

Results and discussion

Four main drought-environment types were identified by Chenu et al. (submitted) across the wheatbelt (Fig. 2): stress-free or light-stressed environments (ET1), mild water shortages during grain filling that were relieved by maturity (ET2), more severe water stresses that occurred during the vegetative stage and relieved during mid-grain filling (ET3), and water deficits from early stage onwards, with severe stresses throughout the grain filling period (ET4). The frequency of these environment types varied spatially (Fig. 4) and over time (data not shown), with a tendency for higher frequency of severe stresses during the last decade.

By 2030, the average temperature during the crop cycle is expected to increase compared to the baseline by 0.3°C (*Wet & Low emission* scenario) to 0.8°C (*Dry & High emission*) across the wheatbelt, with some substantial variations across regions (Fig. 3). Cumulative rainfall during the crop cycle is forecast to decrease by 14 mm (*Wet & Low emission* scenario) to 52 mm (*Dry & High emission*) on average, which corresponds to a 7 to 25% reduction in within-season rainfall, respectively. The change in climatic conditions led to a shift in sowing and flowering windows (Fig. 3; Wang *et al.*, 1992; Madgwick *et al.*, 2011; Zheng *et al.*, 2012), with e.g. the median sowing date occurring 4 days earlier on average across the wheatbelt for the *Dry & High emission* scenario. While a high spatial variability was observed in the shift in sowing and flowering windows (Fig. 3), this shift is expected to further increase over time with the effect of climate change (data not shown). Zheng *et al.* (2012) forecast early sowing to be shifted up to 1 to 2 month(s) earlier by 2050 in

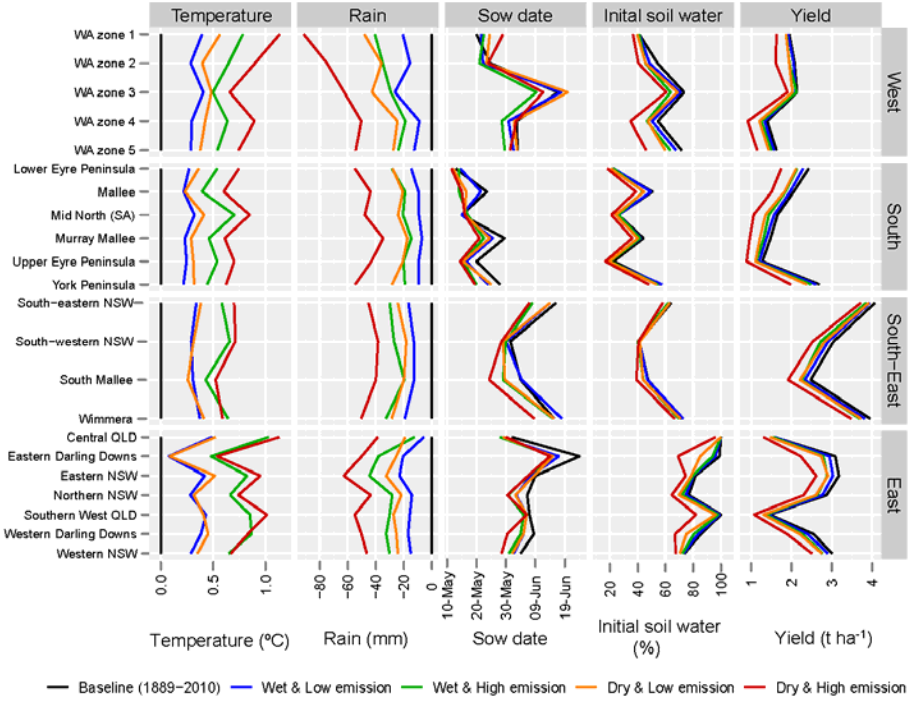

Fig. 3 Effect of four climatic scenarios for 2030, compared to the baseline data (1889-2010) on (i-ii) change on average temperature and cumulative rainfall during the cropping season, (iii) median sowing date and (iv) the median level of initial soil water at sowing, and (v) simulated yield. Data averaged for multiple locations in each of 22 regions of the Australian wheatbelt (Fig. 1).

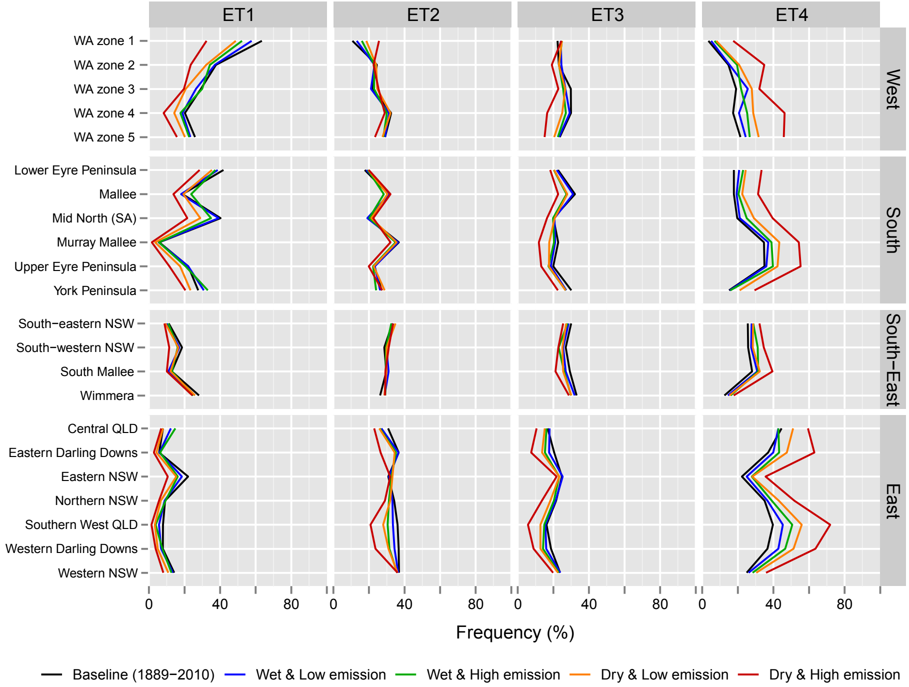

Fig. 4 Effect of four climatic scenarios for 2030, compared to the baseline data (1889-2010) on the frequency of four main drought environment types identified for current climate (presented in Fig. 2). Data from simulations in multiple locations for each of 22 regions of the Australian wheatbelt (Fig. 1).

locations like Merredin, for a medium and short-season variety, respectively. Soil water content at sowing was also forecast to decrease, with a maximum impact in *WA zones 4 and 5* for the *Dry & High emission* scenario (>35% reduction in median soil water content; Fig. 3).

In future climates, the predicted change in initial and seasonal conditions indicate an increase in occurrence of severe ET4 stresses (Fig. 2 and 4), with no substantial change or reduced occurrence of the other environment types. Across the wheatbelt, ET4 frequency increased by 10, 21, 33 and 77 % on average for the *Wet & Low emission*, *Wet & High emission*, *Dry & Low emission and Dry & High emission* scenarios, respectively. Hence, the ET4 frequency for these scenarios was predicted to reach an average of 25, 28, 30 and 41% of occurrence, respectively, across the Australian production area. Across regions, the rise in ET4 frequency varied from a 25% (*South-eastern NSW* region) to a 2-fold (*Mid North (SA)* and *WA zones 1-2-4-5*) increase for the most pessimistic scenario (*Dry & High emission*).

The simulations predicted a substantial decrease in yield, especially for the *Dry & High emission* scenario. Note that the effect of CO_2 was not integrated here, nor were heat-shock impacts considered. Improving current crop models to simulate effects of extreme climates on crop production is urgently required as part of a strategy to adapt to future climate (e.g. Howden *et al.*, 2007; Moriondo *et al.*, 2011).

Conclusion

Impact of future climates on drought occurrence greatly varied depending on the scenario considered. Although the optimistic *Wet & Low emission* scenario results in only a 10% increase in most-severe stresses by 2030, a much greater proportion of these stresses was forecast for all regions under the *Dry & High emission* scenario (77% increase on average; 41% of occurrence). Recent climatic observations show that we are currently tracking toward a high CO_2 emission scenario (A1FI; Le Quere *et al.*, 2009). Both scenarios studied with a high emission forecast (i.e. wet and dry options) had a substantial impact on severe drought occurrence (28 and 77% increase on average, respectively).

While sowing dates have been adapted to the future temperature trends in this study, extending the approach to a broad range of genotypes and managements would allow the assessment of different options to best adapt to future climatic scenarios, and in particular the likely high emission scenarios. In terms of crop improvement, it is becoming urgent to begin the adaptation of varieties to the future, as breeding cycle takes 5 to 20 years (Chapman *et al.*, 2012).

Acknowledgment

We thank Dr. Steve Crimp for advice on selecting future climate scenarios, QCCCE (http://www.climatechange.qld.gov.au/whatsbeingdone/queensland/centreofexcellence/) for providing scenarios, and Dr. Bangyou Zheng for the future sowing windows. This research was partly funded by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF GMS-0335), who also funded the research to generate the consistent climate scenarios.

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