Effect of climate variability on Australian dryland cotton yield

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Abstract

The area under dryland cotton has recently increased in Australia due to cotton providing a profitable summer rotational option. Dryland cotton is affected by climate variability, particularly extreme temperature and rainfall, which influences crop growth, development and yield. The goal of this study was to explore the influence of rainfall and extreme heat variability on yield during the cotton growing season in four important Australian dryland cotton growing regions, focussing on the summer months which coincide with critical cotton reproductive stages. Across these regions, inter-seasonal yield was found to be highly variable with coefficient of variation ranging from 33 – 49%. This yield variability can translate into large fluctuations in profits. Dryland cotton grown in soils with higher plant available soil water storage capacity and in combination with higher growing season and summer rainfall led to highest average yield (3.66 bales/ha at Dalby). The number of extreme heat events (maximum temperature ≥ 35°C) reduced yield at all sites ($p < 0.05$) with average reductions between 0.51 - 1.65 cotton bales/ha. Notable year-to-year variability was present and significant relationship to rainfall could be found across the sites. However the relationship between cotton yield and rainfall is weak ($R^2 = 0.06 – 0.48$). This highlights a need to better characterise the relationship between rainfall events and timing in relation to phenology rather than to seasonal means.

Keywords

APSIM, Summer rainfall, Cotton bales, Extreme heat.

Introduction

Australian cotton is worth about $3 billion annually to the economy, and is dependent on summer climatic conditions. It is typically grown in 400-700 mm summer rainfall zones of Queensland and NSW (Cotton Australia 2017). Cotton has a strong tap root system (Wrona et al. 1999) and this enables the plant to access soil water and nutrients deeper in the soil profile that may be unavailable to other crops. Dryland cotton has expanded recently due to good potential profits (CSD 2015). Research at Moree has shown that dryland cotton in a commercial farm can be up to 58% more profitable than sorghum in a summer cropping rotation (CSD 2015). Higher profits are directly related to marked improvements in the dryland production system including higher gross margin per hectare (CSD 2015). In 2016, dryland cotton area was about 96,074 ha; yield over the five years (2009-2014) was about 4.09 cotton bales/ha, with a range of 0.5 to 7.5 bales/ha depending on region (Drylandcotton 2017).

The optimum dryland cotton sowing time is from mid-October to mid-November in most dryland areas and harvest is during the drier autumn (CSD 2015). Stored soil moisture at sowing time, and rainfall and temperature during the cotton growing season and reproductive stages of cotton, are the critical agronomic factors influencing final yield. Extreme temperatures (daily maximum temperature in excess of 35°C) can also influence cotton yield. Research has indicated that pollen tube growth in the styles is strongly inhibited by temperature above 35°C, and cotton yield decreases because of the effect of high temperature during square development (Song et al. 2015). In Australian cotton growing regions, research by Bange (2007) also shows that temperatures greater than 35°C can reduce photosynthesis and increase respiration; both collectively reduce the amount of assimilates available for growth, and in turn reduce cotton yield. Investigating the potential impact of climate variability on dryland cotton was the primary aim of this work, which modelled the effect on yield of climate (rainfall, mean temperature and extreme heat days) across four dryland cotton regions in Australia.

Methods

Four dryland cotton sites, three sites in Queensland (Biloela, Emerald, Dalby) and one site in NSW (Moree) were selected for analysis (Table 1). Sites historical daily climate data from 1889–2016 was obtained from SILO-patched point dataset (www.longpaddock.qld.gov.au/silo/ppd/index). The Agricultural Production Systems Simulator (APSIM)-Ozcot cotton model was used to generate realistic dryland cotton yields at each location, (Holzworth et al. 2014). The APSIM-Ozcot model has been shown to adequately simulate cotton systems at the four sites analysed here along with other locations (Williams et al. 2015; Yang et al. 2014).

Soil characteristics, as obtained from APSoil (https://www.apsim.info/Products/APSoil.aspx), were variable across the sites. For instance, plant available soil water storage capacity (PAWC) was 197, 287, 285 and 238 mm for Biloela, Emerald, Dalby and Moree, respectively. Simulated cotton yields were found to be representative of the four sites, corroborated by discussions with local cotton experts (J Montgomery pers. comm.) and published results (Roth et al. 2013; Cotton Australia 2017).

Site-by-site summary statistics (mean and coefficient of variation) were generated for yield and for rainfall, temperature and number of extreme heat days (maximum temperature ≥ 35°C) for October through February (OF), representing the growing season, and for December, January and February (DJF), representing critical plant growth phases for cotton and growing season (GS) rainfall, that is rainfall from simulated planting date to harvest. Regression analysis was used to evaluate statistically significant relationships ($p \leq 0.05$, 0.01 and 0.001) at each site between simulated cotton yields and the climate variables.

Results

Variation in climate variables and cotton yield at the four study sites are summarised in Table 1. The greatest difference between the sites was the amount of cotton growing season (GS) rainfall accumulated from simulated sowing to harvest date, in-season rainfall (October-February) and summer rainfall (December-February). For instance, on an average, Biloela receives 36% more seasonal (Oct-Feb) rainfall than Moree. Site seasonal rainfall variability was high at all sites with coefficient of variation (CV) ranging from 33 – 51%. The number of extreme heat days also varied between sites and also exhibited high seasonal variability (CV >40%). Comparatively, site variability in maximum and minimum temperature was small (CV = 3 – 7%). Cotton yield showed high inter-annual variability across all the sites (CV = 33 – 49%). The magnitude of cotton yield also differed between the sites, likely reflecting differing combinations of climate, growing season length and PAWC. The likely influence of PAWC is shown by comparing average yield at Dalby (3.66 bales/ha) which had a PAWC of 285mm with average yield at Moree (3.11 bales/ha) which had a PAWC of 238mm.

Table 1. Mean rainfall (mm), temperature (ºC), extreme heat days (EH) and cotton yield (Bales/ha) with coefficient of variation in bracket (%) for the period of 1889-2016. GS is cotton growing season, OF denotes October through February months, DJF is December, January and February months. MaxT and MinT is mean maximum and minimum temperature.

Sites	GS Rain (mm)	OF Rain (mm)	DJF Rain (mm)	OF MaxT (ºC)	DJF MaxT (ºC)	OF MinT (ºC)	DJF MinT (ºC)	OF EH (days)	DJF EH (days)	Cotton Yield (Bales/ha)
Biloela (24°3789’ S, 150°5164’ E)	425 (38%)	440 (33%)	316 (40%)	31.9 (3%)	32.6 (4%)	17.3 (5%)	19.0 (5%)	27.8 (56%)	22.3 (60%)	3.20 (33%)
Emerald (23°5267’ S, 148°1617’ E)	392 (51%)	398 (42%)	298 (48%)	33.4 (4%)	33.9 (4%)	19.6 (5%)	20.9 (6%)	56.0 (40%)	39.9 (44%)	3.56 (37%)
Dalby (27°1839’ S, 151°2639’ E)	408 (39%)	408 (35%)	275 (40%)	30.5 (4%)	31.4 (4%)	16.3 (5%)	17.8 (5%)	21.8 (62%)	17.1 (64%)	3.66 (34%)
Moree (29°5000’ S, 149°9000’ E)	293 (51%)	323 (44%)	218 (48%)	31.9 (5%	33.4 (5%)	16.9 (7%)	18.7 (7%)	44.7 (47%)	36.6 (47%)	3.11 (49%)

To investigate the influence of climate variability on simulated dryland cotton yield, regression analysis was used (Table 2). For three sites (Emerald, Dalby and Moree), a linear relationship to rainfall was found to be statistically significant ($p < 0.01$), but the relationship was weak ($R^2 = 0.06 – 0.48$). Biloela was the only site to record a significant relationship between rainfall and yield when using a second order polynomial (Table 2 and Figure 1A). In general the regression coefficients were small (Table 2) and there was large variability in the dataset (e.g. Figure 1), reducing the confidence of this relationship. Such a weak relationship could be that the time-lag between rainfall amount and cotton critical physiological stages.

Table 2. The regression coefficients for the cotton yield and weather variables from Y= a + b X + c X^2 (rainfall, Biloela) and Y= a + b X (rainfall and extreme heat days). GS: Cotton growing season, OF: October through February and DJF: December, January and February.

	Biloela				Emerald			
Climate variables	**a**	**b**	**c**	r^2	**a**	**b**	**c**	r^2
GS rainfall (mm)	+1.670**	+0.006*	-0.000*	0.06	+2.750***	+0.002***	NA	0.10
OF rainfall (mm)	+1.470*	+0.007*	-0.000	0.05	+2.787***	+0.002**	NA	0.06
DJF rainfall (mm)	+1.580**	+0.010**	-0.000	0.07	+2.911***	+0.003**	NA	0.06
OF extreme heat (days)	+3.725***	-0.019**	NA	0.07	+4.575***	-0.018***	NA	0.09
DJF extreme heat (days)	+3.712***	-0.023**	NA	0.08	+4.689***	-0.028***	NA	0.14

	Dalby				Moree			
	a	**b**	**c**	r^2	**a**	**b**	**c**	r^2
GS rainfall (mm)	+1.726***	+0.005***	NA	0.36	+1.065***	+0.007***	NA	0.48
OF rainfall (mm)	+2.263***	+0.003***	NA	0.15	+1.268***	+0.006***	NA	0.28
DJF rainfall (mm)	+2.291***	+0.005***	NA	0.19	+1.303***	+0.008***	NA	0.33
OF extreme heat (days)	+3.944***	-0.013	NA	0.02	+4.634***	-0.034***	NA	0.23
DJF extreme heat (days)	+4.048***	-0.023*	NA	0.04	+4.765***	-0.045***	NA	0.26

*, ** and *** indicate the significant levels at p-value ≤ 0.05, p-value ≤ 0.01 and p-value ≤ 0.001, respectively

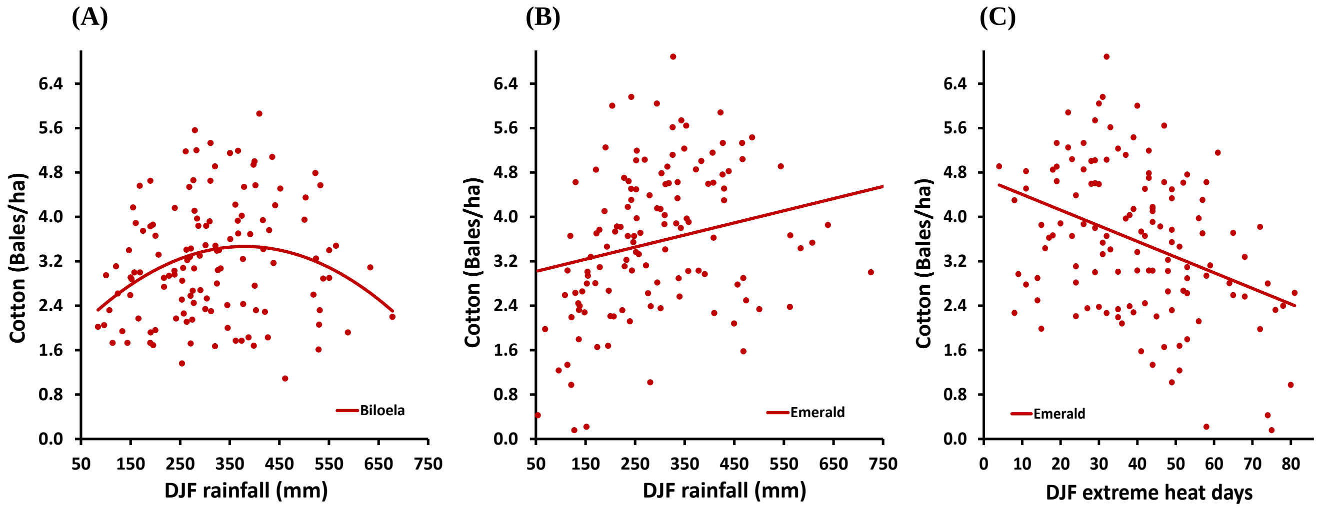

Figure 1. The response of dryland cotton yield at Biloela (A) and Emerald (B) to DJF rainfall (December, January and February) and (C) number of extreme heat days in DJF. The regression coefficients are given in Table 2.

Significant and negative relationships between yield and the total number of extreme heat days were found at all sites (Table 2 and Figure 1C). For all sites, larger regression coefficients were found for the total number of extreme days for the summer months (DJF), indicating extreme heat events over summer may have a greater impact on yield than total extreme heat days across the whole growing season. Using Biloela and Moree as an example, the reduction in yield for each one day increase in extreme heat events DJF was found to be 0.023 and 0.045 bales/ha, respectively. Using the average number of extreme heat days at these sites (Table 1) this average yield penalty equates to 0.5 and 1.6 bales/ha for Biloela and Moree, respectively. However, the variability around this linear relationship between number of extreme heat days and yield is high, as demonstrated at Emerald (Figure 1B). Hence, some years with average extreme heat days may not experience these yield penalties, most likely due to differences in the seasonal moisture balance, carbonbalance and interactions between specific growth stages and sequencing of weather events. For commercial production, management may further reduce the relationship between the number of summer extreme heat days and yield.

Conclusions

Across different dryland cotton regions in Queensland and NSW, inter-seasonal yield was found to be highly variable with coefficient of variation ranging from 33 – 49%. This variability emphasises the potential risks and rewards of growing dryland cotton. Dryland cotton grown in soils with higher PAWC (plant available soil water storage capacity) and in combination with higher growing season and summer rainfall resulted in higher yields (averaging about 3.66 bales/ha at Dalby). Extreme heat events across dryland cotton regions could reduce yield by about 0.51 bales/ha to 1.65 bales/ha, most likely due to negative effects of high temperatures which can increase cotton boll shedding, reduce the viability of the pollen at flowering and collectively reduce boll size and yield. Hence, the number of extreme heat days in summer should be taken into consideration when introducing dryland cotton into new areas. Although there was large variability in the relationship to yield for average growing season and summer rainfall, rainfall is still likely to be important in determining dryland cotton yields. Finer analysis of sequencing of rainfall events coinciding with key phenological stages (e.g. squaring, flowering and boll development) may show stronger relationships. This is important to understand when planning expansion of dryland cotton. Further, given the range of seasonal variability of climatic conditions in dryland cotton regions, particularly rainfall, application of higher accuracy of seasonal climate forecasts could additionally improve dryland cotton yield in light of probable weather trends.

References

Bange M (2007). Effects of climate change on cotton growth and development. The Australian Cottongrower 41-43. (http://www.greenmountpress.com.au/cottongrower/Back%20issues/283jjcot07/41_Effects.pdf).

Cotton Australia (2017). Cotton Australia is the key representative body for the Australian cotton growing industry. (http://cottonaustralia.com.au).

CSD (2015). Consideration For Dryland Cotton. 9th Oct 2015. Cotton Seed Distributors. (http://www.csd.net.au/system/fofs/attachments/000/000/307/original/FOF160923.pdf?1474589701).

Drylandcotton (2017). Welcome to Dryland Cotton; Resources. (http://drylandcotton.com.au/useful-tools/resources/).

Holzworth DP, et al. (2014). APSIM – Evolution towards a new generation of agricultural systems simulation. Environmental Modelling and Software 62, 327-350.

Roth G, Harris G, Gillies M, Montgomery J and Wigginton D (2013). Water-use efficiency and productivity trends in Australian irrigated cotton: a review. Crop and Pasture Science 64, 1033–1048.

Song G, Wang M, Zeng B, Zhang J, Jiang C, Hu Q, Geng G and Tang C (2015). Anther response to high-temperature stress during development and pollen thermotolerance heterosis as revealed by pollen tube growth and in vitro pollen vigor analysis in upland cotton. Planta 241, 1271-1285. (doi:10.1007/s00425-015-2259-7).

Williams A, White N, Mushtaq S, Cockfield G, Power B and Kouadio L (2015). Quantifying the response of cotton production in eastern Australia to climate change. Climatic Change 129,183–196.

Wrona AF, Oosterhuis D and McMichael B (1999). Getting to the root of your crop’s health. Cotton Physiology, National Cotton Council. (https://www.cotton.org/tech/physiology/cpt/plantphysiology/upload/CPT-v10No1-99-REPOP.pdf).

Yang Y, Yang Y, Han S, Macadam I and Liu DL (2014). Prediction of cotton yield and water demand under climate change and future adaptation measures. Agricultural Water Management 144, 42–53.