The here and now of climate change: how climatic conditions in Australian cotton regions have changed

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Abstract

Much research has focused on assessing future climatic conditions on cotton production. However, understanding climatic changes that have already occurred throughout Australian cotton regions may provide insights on how existing and new regions are adapting to change. We utilised the CottASSIST decision support platform to undertake an analysis of regional climate using changes in: heat unit accumulation for seasonal assessment of temperature conditions; frequency of extreme weather conditions affecting cotton growth; seasonal evapotranspiration (ET_O); and the timing of key cotton developmental stages. Eight Australian cotton regions over three time periods from 1957 to 2018 were assessed. Our data shows some reductions in early season cold shocks (≤11 ºC min.), and increases in minimum temperature, seasonal heat accumulation, ET_o, and the frequency of extremely high temperatures (>40ºC). These climatic changes have resulted in an opportunity for longer reproductive periods and the potential for increased yields. It also appears that southern cotton growing regions now have climates like those in northern regions at the establishment of the modern Australian cotton industry (1970s). Recognising that regions have experienced specific changes may help to guide current and future agronomic practice in the different regions.

Keywords

Temperature, CottASSIST, phenology, reproductive phase, heatwave, day degrees

Introduction

Australia's climate has warmed on average 1.44ºC since 1910, leading to an increase in the frequency of extreme heat events (CSIRO and Bureau of Meteorology, 2020), and an increased severity of drought conditions during periods of below-average rainfall. Warmer temperatures are observed across Australia in all seasons with both day and night-time temperatures increasing, and with the shift to a warmer climate accompanied by more extreme daily heat events. However, there have been few studies specifically exploring how climate has changed across Australian cotton regions that relates to production practice. This may help to define the adaptation strategies and develop an agenda for producing Australian cotton in a changing climate. There also may be an opportunity to apply existing knowledge across regions that have experienced change throughout time to regions now experiencing similar changes.
Climate change will have both positive and negative effects on cotton production (Bange et al., 2016). Increased CO_2 may increase yield in well-watered crops and higher temperatures will extend the length of the growing season. However, warmer temperatures also accelerate the rate of crop development and could potentially shorten the time to maturity, which may then impact crop management decisions. Higher temperatures also have the potential to cause significant fruit loss, reduce water use efficiencies, lower yields, and alter fibre quality. This study aims to understand climatic changes that have occurred throughout Australian cotton regions and the implications of a changing climate on cotton development.

Methods

Assessing trends in climate change across cotton regions

Eight representative locations spanning cotton production areas in Queensland (Emerald, Dalby, and Goondiwindi) and New South Wales (Moree, Narrabri, Gunnedah, Narromine and Griffith) were assessed. Seasonal data from 1957 to 2018 at each location was retrieved from CottASSIST (https://www.cottassist.com.au/). Climate data for each cotton season was assessed between 1st September and the 30th April. For each planting year linear regression lines for three time periods (a) 1957 to 2018; (b) 1957 to 1996; and (c) 1997 to 2018 to assess the trend in DD accumulation for each period. Planting date was the 1st of October. ET_O (potential evapotranspiration (mm)) was assessed using primary pan data from 1970 onwards. An ANOVA was used to analyse for significance in the regression (at $P<0.05$).
Trends in heat accumulation (day degrees (DD)) (Bange et al., 2017) of rainfall (mm), minimum night-time temperatures, frequency of hot days (>40ºC) and cold shocks (≤11ºC), frequency of very hot days (>45ºC), time of first flower, and last effective flower (LEF) and last harvestable boll (LHB) throughout the cotton

growing season were assessed. Seasonal accumulation of DD reflects the length of the growing season, frequency of cold and heat events represents extreme effects on growing conditions. The time of first flower and LEF represents the length of the reproductive period; a longer phase usually equates to more yield. The timing of LHB affects the timing of harvest; a later date can mean that bolls have more time to fill and is related to the timing of LEF. ET_O throughout the cotton season reflects atmospheric evaporative demand, which influence crop water use. Minimum night temperatures affect the rate of crop respiration and can reduce yield.

Results and Discussion

There have been climatic changes across each of the eight regions throughout the three time periods assessed from 1957 to 2018 (Table 1). Overall, results show that there has been a decrease in the number of early season cold shocks, an increase in minimum night-time temperatures, an increase in the frequency of very high temperatures, and an increase in season long heat accumulation and ET_O.

Table 1: Environmental trends for eight key Australian cotton locations across three time periods. ↑ indicates a significant increase, ↓ indicates a significant decrease, and (-) indicates there has been no significant trend at $P<0.05$. * indicates where ET_o was assessed from 1970.

Time period & Location	Cold shocks (≤ 11°C)	Min (night) temp	Days > 40°C	Day degrees	ET_O	Rain (mm)	First Flower (DAS)	LEF (DOY)	Rep. Period	LHB (DOY)
1957*-2018										
Dalby	-	-	↑	↑	-	-	↓	-	-	-
Emerald	↓	↑	↑	↑	-	-	-	↑	↑	-
Goondiwindi	-	-	↑	↑	↑	-	↓	-	↑	-
Griffith	↓	↑	↑	↑	↑	-	↓	↑	↑	-
Gunnedah	-	-	↑	↑	-	-	↓	-	-	↓
Moree	↓	↑	↑	↑	↑	-	-	-	↑	-
Narrabri	↓	↑	↑	↑	-	-	↓	-	↑	-
Narromine	-	↑	↑	↑	-	-	↓	-	↑	-
1957*-1996										
Dalby	-	-	-	-	↑	-	-	↑	↑	↑
Emerald	↓	↑	-	↑	-	-	-	↑	-	-
Goondiwindi	-	-	-	-	↑	-	-	↑	-	↑
Griffith	-	-	-	-	-	-	-	-	-	-
Gunnedah	-	-	-	-	-	-	-	↑	-	↑
Moree	-	↑	-	-	-	-	-	-	-	↑
Narrabri	-	-	-	-	-	-	-	↑	↑	↑
Narromine	-	-	-	-	-	-	-	↑	-	↑
1997-2018										
Dalby	-	-	-	-	-	-	-	-	-	-
Emerald	-	-	-	-	-	-	-	-	-	-
Goondiwindi	-	-	↑	↑	-	-	-	-	-	-
Griffith	↓	↑	↑	↑	-	-	↓	↑	↑	-
Gunnedah	-	-	↑	↑	-	-	-	-	-	↓
Moree	-	↑	↑	↑	-	-	-	↑	↑	-
Narrabri	-	-	-	↑	-	-	-	-	-	-
Narromine	-	-	↑	↑	-	-	-	-	↑	-

Frequency of extreme temperatures and minimum temperature changes

There has been a decrease in the frequency of early season cold shocks at Emerald, Griffith, Moree and Narrabri from 1957-2018 (Table 1**Error! Reference source not found.**). This is combined with an increase in the seasonal minimum (night) temperatures across five locations assessed (Table 1). This suggests that some key cotton regions are experiencing warmer temperatures, or less risk of very cold days that may slow the growth and development at the beginning of the season, thereby enabling the opportunity to extend the cotton season by planting earlier. Rising night temperatures also may have implications for increased night respiration rates reducing growth (Reddy et al., 1991).

At all eight locations, there was an increase in the average number of hot days above 40ºC from 1957-2018 (Table 1). Five locations (Goondiwindi, Griffith, Gunnedah, Moree and Narromine) have had an increase in the number of days >40ºC from 1997-2018. There has also been a greater frequency of very hot days (>45ºC), especially in the more southern regions from 1997-2018 compared with the period from 1957-1996 (Table 2). Increased frequencies of very hot temperatures during the cotton season may result in fruit loss, and consequently reduced yield especially if water stress is encountered. High canopy temperatures (≥ 35ºC) will also have a negative effect on physiology, productivity and water use efficiency in cotton (Broughton et al., 2017; Reddy et al., 1992).

Table 2: The average number of hot days >45ºC from 1st September to 30th April across two time periods.

Location	1957-1996	1997-2018
Dalby	0	0
Emerald	2	0
Goondiwindi	0	2
Griffith	1	14
Gunnedah	0	2
Moree	0	2
Narrabri	0	2
Narromine	0	5

Seasonal trends in temperature, ET_O and crop development

From 1957 to 2018, there has been an increase in the number of DD across all locations (Table 1). The implications of warmer temperatures are also reflected by an increase in ET_O across locations and time periods (Table 1), highlighting the direct and indirect effects of warmer seasonal temperatures for both growth and development of the cotton and increased evaporation rates from the soil surface, potentially having led to a reduction in plant available soil water, despite no changes in seasonal rainfall.

Warmer seasonal temperatures have reduced the time to first flower across several locations from 1957-2018 as well as increasing the time to LEF, thereby lengthening the reproductive period of many cotton locations (Table 1). Warmer temperatures have not directly aligned with the trend for LHB to occur later in the season, due to increased variability during the period from 1997-2018 having resulted in no evident changes in LHB in more recent years. With warmer seasonal temperatures and the resulting effects on crop development, there has been an opportunity for increased yield across many Australian cotton regions whilst acknowledging that several studies have shown an in yield attributed to improvements in genetics and management over this period (Liu et al., 2013). However, it is also possible that greater heat accumulation throughout the season and increased frequencies of high temperatures (>35ºC) may have resulted in increased vegetative biomass and greater requirements for the application of growth regulators such as mepiquat chloride.

Our data shows not only an increase in the number of seasonal DD across many of Australia's key cotton regions, but also demonstrates how regions have shifted over time. As an example, the number of DD in Griffith prior to 2008 had been below 1400 DD, which had frequently occurred in Narrabri in the past (Figure 1). However, since 2008 there have been several years where the total number of DD in Griffith have exceeded 1400, with a significant trend suggesting further increases in the number of DD with projected climate change. In this example, the knowledge of cotton systems in Narrabri may be relevant to the future management strategies of cotton grown in Griffith.

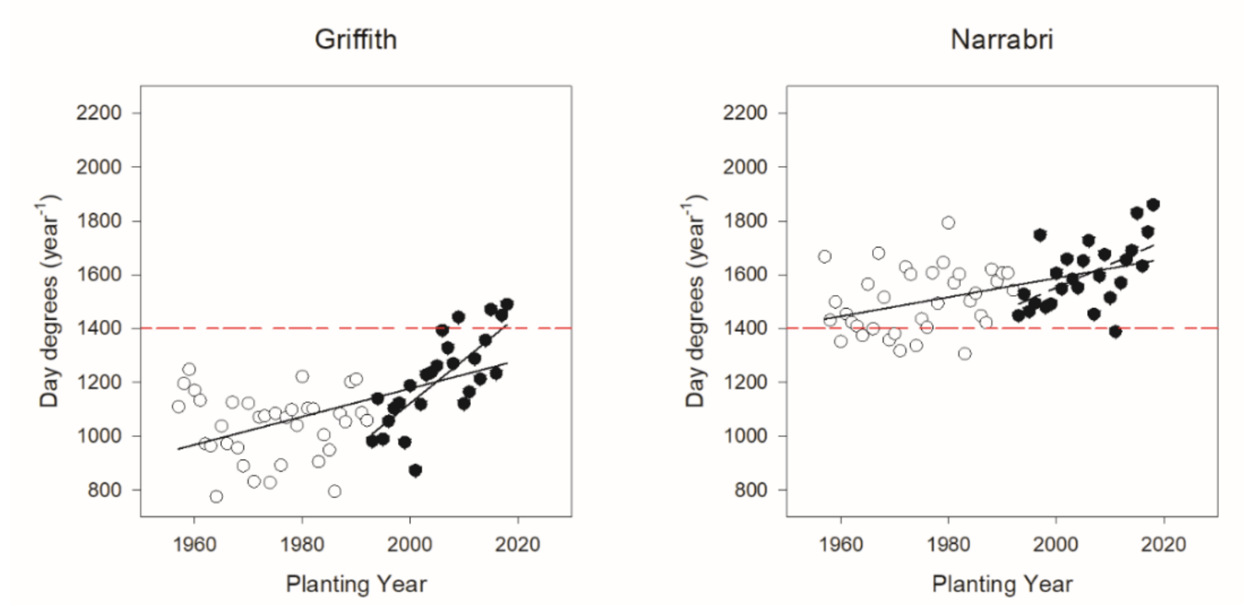

Figure 1: The number of day degrees per year (DD) in Griffith and Narrabri. The red dotted line at 1400 DD shows that the number of DD in more recent planting years are like the number of DD that Narrabri experienced in the past. Data is grouped by time periods (black circles= 1957-2018; white circles= 1957-1996; black triangles= 1997-2018). Regression lines are only shown where trends are significant.

Conclusion

Climatic changes including decreased frequency of early season cold shocks, increased minimum temperatures and frequency of high temperatures and evapotranspiration, and an increase in season long heat accumulation have occurred across Australian cotton regions from 1957 to 2018, affecting growth and development of cotton. Overall, warmer seasonal temperatures have reduced the time to first flower, increased the time to LEF, and resulted in some changes to LHB. Consequently, this has resulted in a longer reproductive period and thus potentially a greater opportunity for increased yield across Australian cotton regions. However, with these climatic advantages it is also important to acknowledge that there may have been concurrent disadvantages due to an increased frequency of extreme climatic conditions that may have resulted in fruit loss and increased $ET_{O.}$ Our results highlight that it is plausible that growers have already been contending with the effects of a changing climate and these adaptations and learnings are likely to be transferable across regions.

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