Recent research into the effects of climate change and extreme weather events on Australian cotton systems

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Abstract
Climate change may have significant impacts on the physiology and yield of cotton. Understanding the implications of integrated environmental impacts on Australian cotton systems is critical for developing management solutions resilient to stress induced by climate change. Uniquely, Australian cotton systems are characterised by high input/high yielding intensively managed systems which may lead to challenges not seen in other research on climate change in cotton. This study combined (1) an analysis of temperature trends throughout key Australian cotton regions, and (2) an investigation into the integrated effect of warmer temperature and elevated [CO_2] on physiology and growth of cotton grown in high-input field conditions. The research has demonstrated an increased accumulation of day degrees across a number of important cotton regions from 1957 to 2017, indicating season long temperature effects. This study found that although there was no difference in total biomass between the three treatments, cotton grown at warmer temperatures had greater vegetative biomass and less fruit biomass than the control. Thus, climate change will potentially cause significant rank growth, reducing yield and water use efficiency. Further research is currently investigating whether the recommendation for use of growth regulators to control excessive vegetative growth will need revision for future climates.

Key Words
Temperature, atmospheric CO_2 concentration, physiology, water use, agronomy, day degrees

Introduction

Climate change in Australian cotton regions

Current climate projections indicate that Australia can expect warmer temperatures and an increase in the frequency of heatwaves (air temperatures greater than 35^{o}C) (CSIRO and Bureau of Meteorology, 2018). It is also expected that there will be changes in rainfall distribution, including an increase in the intensity of drought and flooding. Drought conditions directly impact dryland crops during the season and reduce water availability for irrigated cotton systems. On the other hand, as much of the Australia's cotton is grown on Vertosols, crops can often experience yield losses due to waterlogging when heavy rainfall occurs. Agricultural production is highly sensitive to climatic variability and extreme weather events and projected changes in climatic factors may significantly impact plant growth and crop productivity. For instance, day degrees are an important measure of heat accumulation throughout the season, and is widely used to monitor the progress of a cotton crop and understand season-long climate impacts (Constable and Shaw, 1988). Day degrees for cotton is calculated: $day\ degrees = \frac{(Tmax-12)+(Tmin-12)}{2}$, where Tmax and Tmin are the maximum and minimum temperature (^{o}C) for each day. Understanding how the full growing season trend in day degrees has changed over time throughout key cotton production areas may assist understanding for the consequences of a climate change for Australian cotton regions. However, there has been little research specifically analysing the trends for how the accumulation of day degrees has changed over time throughout important Australian cotton regions.

Crop responses to climate change

There has been detailed research into the effects of climate change in the past utilising a range of approaches (e.g. Soil-Plant-Atmosphere-Research units (controlled environment glasshouses) in Mississippi, Free Air CO_2 Enrichment (field facilities in Arizona)) that has provided a foundation for understanding the impacts (Mauney et al., 1994; Reddy et al., 1999). However, there has previously been little specific research into climate change impacts for modern Australian cotton systems, and little research attempting to assess the combined interactive effects of climate change on cotton productivity; especially in the field. Australian cotton systems are vastly different high-input (> 200 kg N ha^{-1}) and high-yielding (> 1500 kg ha^{-1}) cotton production systems that may present unique challenges (Baird, 2016), compared with cotton systems in the USA where previous research was conducted (Arizona average yield was around 1200 kg lint ha^{-1} in 1991 with 130 kg N ha^{-1} applied (Mauney et al., 1994)). Therefore, it is important to gain an understanding of how integrated warmer temperatures and elevated [CO_2] affects seasonal growth of cotton grown in high-input

Australian systems. Over the past several years, a range of research initiatives have been conducted to better understand responses of the cotton system to this changing environment.
This study aims to (1) assess season-long temperature trends across Australian cotton regions throughout Queensland and New South Wales; and (2) investigate the effect of warmer temperature and elevated [CO_2] on physiology and growth of cotton grown in high-input field conditions.

Methods

Assessing the trends in climate across cotton regions

A study was conducted to assess trends in heat accumulation throughout the cotton growing season. This study focused on four representative locations spanning cotton production areas in Queensland (Emerald and Dalby) and New South Wales (Narrabri and Griffith). Day degree data from 1957 to 2017 at each location was retrieved from CottASSIST (https://www.cottassist.com.au/). Data for each cotton season was considered to be between 1st October and the 30th April. For each planting year, SigmaPlot (version 14.0) was used to fit regression lines for three time periods (a) 1957 to 2017; (b) 1957 to 1996; and (c) 1997 to 2017 to assess the trend in day degree accumulation for each time period. ANOVA was used to analyse the slope of the regression line fit, with a significance level of $P<0.05$.

Assessing the effects of warmer temperatures and elevated [CO_2] on cotton grown in the field

To investigate the impact of elevated [CO_2] and season-long warmer temperature on cotton growth and productivity, a field experiment was conducted at the Australian Cotton Research Institute at Narrabri, NSW during the 2015/16 cotton season. The experiment utilised purpose-built climate chambers, and consisted of a total of six plots: two ambient [CO_2] chambers (CA: 400 ppm), two elevated [CO_2] chambers (CE: 550 ppm) and two control plots without chambers (CC). All four chambers increased air temperature between 2-4^{o}C. Cotton (cv. Sicot 74 BRF) was planted 25th November 2015, and chambers were installed in the field 9th December 2015 (14 DAP). Injection of CO_2 commenced 14th December 2015 (19 DAP), and cotton was furrow irrigated throughout the season as required. Plant samples were harvested 18th April 2016 (145 DAP) to determine leaf area and biomass production. Data was analysed by REML using Genstat. Means of treatments were compared using least significant difference at a 5% level of probability.

Results and Discussion

Trends in accumulation of degree days across Australian cotton regions

There was an increase in the accumulation of the number of day degrees for the cotton season at each of the four locations assessed during the period 1957 to 2017 (Table 1, Figure 1). From 1957 to 1996, there was an increase in the number of day degrees only at Emerald, and similarly during the period 1997 to 2017 there was an increase in the number of day degrees only at Griffith (Table 1). Although the slopes of each regression line were positive (except Emerald from 1997 to 2017) suggesting a possible increasing trend in day degree accumulation, the variation in the number of day degrees between years was large over a relatively short timeframe. However, the significant increasing trend in the number of day degrees from 1957 to 2017 throughout all locations indicate that cotton has potentially already been bred and commercially grown throughout a period of significantly changing climate. Warmer temperatures combined with greater inputs (e.g. nitrogen and water) encourages excessive vegetative growth of cotton (Williams et al., 2018). Although it is not possible to tease apart the G x E x M effects, it is plausible that warmer seasonal temperatures have been a factor contributing to an increasing reliance on growth regulators such as mepiquat chloride (used to manage excessive vegetative growth through inhibiting Gibberellic acid production resulting in shortened internodes and reduced leaf area). Glasshouse studies investigating the physiological response of cotton to warmer temperatures and elevated [CO_2] of one older and newer cotton cultivar indicate that there has been no maladaptation in physiological responses to climate change for the modern cultivar (Broughton et al., 2017a). Therefore, it is important to gain an understanding around how warmer air temperatures (combined with other environmental conditions, such as elevated [CO_2]) are likely to affect the growth responses of Australian cotton varieties in a high-input, high-production agricultural system to better understand management implications and adaptation possibilities.

Table 1. Regression slopes for the accumulation of day degrees over three timescales for four representative Australian cotton production areas. Values in bold are significant at P<0.05.

Location	1957-2017	1957-1996	1997-2017
Emerald, QLD	**3.40 (P=0.0034)**	**7.14 (P=0.0001)**	-2.80 (P=0.7035)
Dalby, QLD	**2.96 (P=0.0030)**	1.42 (P=0.4133)	4.05 (P=0.5086)

Narrabri, NSW	**4.77 (P=0.0001)**	2.98 (P=0.1796)	5.42 (P=0.3858)
Griffith, NSW	**6.63 (P=0.0001)**	0.18 (P=0.9281)	**19.16 (P=0.0020)**

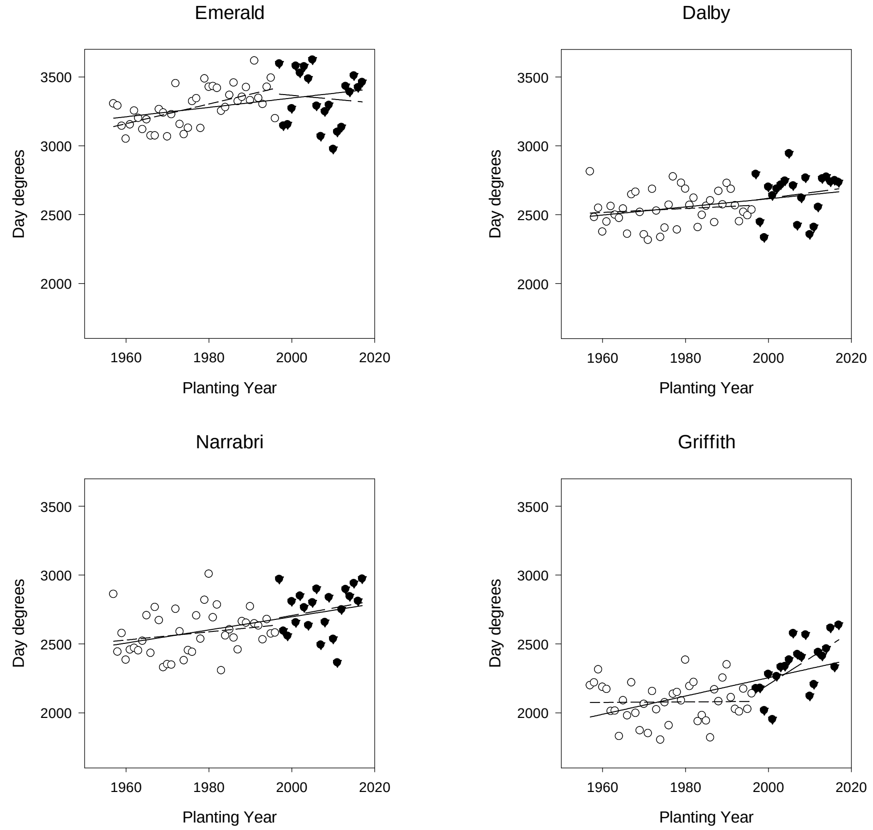

Figure 1. The number of day degrees for four cotton production locations in Australia for three periods (a) 1957 to 2017; (b) 1957 to 1996; and (c) 1997 to 2017. Regression lines have been fitted for each period; solid line represents 1957-2017, and dashed lines represent 1957-1996 and 1997-2017.

Understanding the effect of warmer temperatures and elevated CO_2 in the field

Cotton grown in the CA treatment was 42% taller than cotton grown in the CC treatment (Figure 2). Cotton grown in the CA treatment had a 53% greater vegetative biomass, and 75% less fruit biomass than cotton grown in the CC treatment; however, there was no significant difference in total (vegetative +fruit biomass) (P= 0.578). Warmer temperatures increased leaf area, with cotton grown in the CA treatment having 92% greater leaf area than cotton grown in the CC treatment. Consequently, taller plants with a greater proportion of vegetative biomass and leaf area, with no difference in water use (data not presented) results in large decreases in agronomic water use efficiency (yield/water use). Warmer temperatures have also been shown to decrease water use efficiency in glasshouse experiments (Broughton et al., 2017b), negating some of the benefits of elevated atmospheric [CO_2] reducing stomatal conductance and consequently improving leaf level water use efficiency. Therefore, strategies to manage crop growth may be necessary for cotton grown in warmer temperatures, particularly in relation to maintaining water use efficiency.

There was no significant effect of elevated [CO_2] on plant height, vegetative biomass, fruit biomass or total (vegetative + fruit) biomass of cotton at 145 DAP. Similarly, there was no difference in leaf area when comparing plants grown in the CA and CE treatments (Figure 2). Therefore, elevated [CO_2] does not appear to benefit cotton production with greater yield. Thus, our data suggest that warmer temperatures are the driving environmental factor for full-season growth of cotton, that may require further investigation into management strategies to reduce the proportion of leaf and vegetative growth.

Conclusion

This study assessed climatic trends across major Australian cotton regions. Trends in the accumulation of season-long day degrees across four locations spanning the Australian cotton region indicate that there are an increasing number of day degrees throughout the cotton season from 1957 to 2017. This may have implications for cotton production, as warmer temperatures may increase vegetative growth and could potentially lead to greater water requirements. Furthermore, it demonstrates that cotton breeding and production has already been taking place throughout a period of warmer seasons. Although it is hard to separate the different G x E x M factors, it is plausible that growers have already been contending with the effects of warmer temperatures contributing to greater vegetative growth rates and thus requiring increased application of growth regulators such as mepiquat chloride.

To understand the implications of these climatic effects, this study also investigated the effect of warmer temperature and elevated [CO_2] on physiology and growth of cotton grown in high-input field conditions. Full season field experiments showed that although there was no difference in total biomass, cotton grown at warmer temperatures had greater vegetative biomass, but large reductions in fruit biomass compared with the control. This resulted in large reductions in plant water use efficiency. Therefore, greater vegetative biomass does not necessarily equate to increases in yield. Our data also show that elevated [CO_2] does not negate the adverse effects of warmer temperatures on fruit retention. Management strategies, such as the use of plant growth regulators, may be required to control excessive vegetative growth into the future, and potentially may have already masked the effects of warmer temperatures throughout cotton regions in more recent years. These concepts require further research.

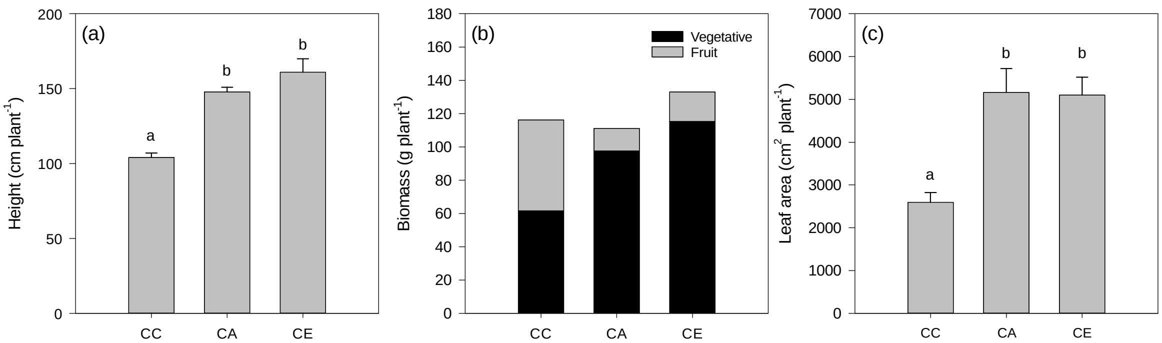

Figure 2. Height (a), vegetative and fruit biomass (b), and leaf area (c) for cotton grown at each CO_2 treatment. Values are means and where shown, error bars are SE of cotton sampled 145 DAP. Different letters represent a difference at P<0.05 level of significance.

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