Postgraduate: Katie Broughton, University of Sydney : Improving prediction of cotton growth and production in a changing climate 2014

Abstract of Thesis

The integrated responses of Australian cotton varieties to warmer temperatures, elevated atmospheric [CO_2], and altered VPD were assessed in this thesis. Cotton responds strongly to changes in VPD, and hence the VPD environment should be characterised in future climate change studies. Elevated [CO_2] impacts cotton growth, physiology and water use, although the magnitude is largely dependent on air temperature and water availability. With elevated [CO_2], there are benefits of increased leaf and plant level WUE; however, glasshouse experiments indicate that warmer temperatures may negate the positive impact of increased WUEP with elevated [CO_2]. Glasshouse experiments indicate that warmer growing temperatures may increase plant water use and reduce tolerance of water deficits, potentially leading to increased demand for water in Australian cotton production systems; however, this is yet to be determined for plants grown in the field. Therefore, modern cultivars with smaller, more compact growth habits and higher photosynthetic capacity may have an advantage over older cultivars in terms of water use, but there is currently no evidence to suggest that older cultivars are more responsive to elevated [CO_2] and warmer temperatures than modern cultivars. These studies also have explored the utility of CETA chambers to assess the integrated effect of projected climate change for cotton grown in the field. Despite limitations of these chambers in terms of meaningful comparisons between chamber and non-chamber treatments, CETA chambers proved a successful method of elevating atmospheric [CO_2] and applying conditions of a projected climate to field-grown cotton.

Background

Changes in atmospheric [CO_2], temperature, precipitation and consequently atmospheric vapour pressure deficit (VPDa) under projected climate change scenarios present a challenge to crop production. This may have significant impacts on the physiology and yield of cotton and hence the profitability of the Australian cotton industry. Understanding the implications of integrated environmental impacts on cotton is critical for developing cotton systems that are resilient to stresses induced by climate change. Elevated [CO_2] generally increases photosynthesis, reduces transpiration and improves leaf- and plant- level water use efficiency (WUE) of well-watered C3 plants , but this effect may be altered by rising temperature and reduced water availability. Cotton responds to changes in vapour pressure deficit (VPD), yet there has been little research on the leaf-level physiological response to altered VPD in field-grown cotton. In addition, a number of studies have investigated the effect of elevated [CO_2] and temperature on physiology and growth of a range of cotton cultivars, yet there has not been a comparison between older and current varieties used in Australian production systems to identify if there has been inadvertent selection of beneficial traits for a changing climate. It is important to understand potential interactions as it is likely that multiple variables will be altered with future climatic changes.

This thesis investigated the integrated effects of projected climate change (warmer temperature, elevated [CO_2], altered VPD and water stress) on physiology, growth and water use of cotton in high-yielding and high-input modern cotton systems in Australia. This will facilitate development of crop management strategies and improve cotton yield and water use efficiencies.

ACHIEVEMENTS

Glasshouse experiments were conducted during 2010 and 2011 at the University of Western Sydney, Richmond, Australia. In these experiments, cotton was grown in sun-lit glasshouse bays in two [CO_2] (CA: 400 µL L-1 and CE: 640 µL L-1) and two temperature (TA: 28/17 °C day/night and TE: 32/21 °C day/night) treatments. Field experiments were conducted during the 2011/12 and 2012/13 cotton seasons at the Australian Cotton Research Institute, Narrabri, Australia.

The objective of glasshouse experiment I was to quantify the physiological and growth capacity of different cotton genotypes to current and future climate regimes. This experiment compared the early-season growth and physiology response of a past (DP 16) and a current (Sicot 71BRF) cotton cultivars grown in ambient and elevated atmospheric [CO_2] and two temperature treatments under well-watered conditions. This study demonstrated that elevated [CO2] increased biomass and photosynthetic rates compared with the ambient [CO2] treatment, and that warmer air temperatures (32/21 oC, day/night) also increased plant biomass. Although limited by the comparison of only one older and one modern cultivar, this study indicated that current cultivars may have an advantage over older varieties in future, warmer environments due to smaller, more compact morphology of the modern cultivar. However, no interaction between elevated temperature (TE) and elevated [CO2] (CE) indicated that substantial potential may exist to increase breeding selection of cotton varieties that are responsive to both TE and CE.

The aim of glasshouse experiment II was to assess the physiological and growth response of cotton to drought and drought-recovery phases of a production system in projected climates. This experiment investigated the interactive effects of elevated [CO2], warmer temperatures and soil water deficit on biomass production, leaf-level physiology and whole plant water use and efficiency of cotton. CE increased vegetative biomass, photosynthetic rates (A) and decreased stomatal conductance (gs-sat); however, warmer air temperatures (32/21 oC, day/night) negated the positive responses to CE. Cotton grown at TA were able to withstand soil water deficits for longer than plants grown at TE, due to reduced leaf biomass and lower evaporative demand compared with plants grown in a warmer environment. This indicates that cotton may be more susceptible to long dry periods in projected warmer environments. CE increased water use at TA, although plant WUE was improved, whereas increased water consumption at TE resulted in lower plant WUE regardless of atmospheric [CO2]. Therefore growth and water use benefits of CE may occur at TA with the cost of increased water requirements which may have implications on future cotton production in Australia, but CE will not mitigate the negative effects of rising temperature on cotton growth and physiology in future environments.

Field experiment I assessed the impact of altered VPD on leaf level physiology of field- grown cotton to improve current understanding of the plant x environment interaction, thereby contributing to validation and improvement of physiological and yield response models. Different VPD environments in the field were generated by planting cotton on three dates within the sowing window (early (S1) = 5th October 2011; mid (S2) = 9th November 2011; and late (S3) = 30th November 2011). Three irrigation treatments were (a) fully watered- "non-stressed" (NS); (b) limited water- "early stress" (ES); and (c) limited water- "late stress" (LS). VPD accounted for a proportion of the variation in both stomatal conductance and photosynthetic responses of cotton. Generally, smaller percentages of variation were also attributed to other factors such as the individual plant (Plant), leaf temperature- air differential (Tl-Ta), accumulated temperature stress hours (ASH) and leaf vapour pressure deficit (VPDL) x Tl-Ta, Plant x Tl-Ta and VPDL x ASH interactions; however, a proportion of variation was due to something that we did not or cannot measure. This study highlights the importance of accounting for VPD in climate change research, given that stomata are highly responsive to changes in VPD. In addition, the Asat/E (ITE) model developed using cotton grown in the glasshouse was tested to determine if the model and associated parameters applied to cotton grown in the field. Using parameters estimated from (a) field and (b) glasshouse data, modelled Asat/E and measured Asat/E were compared. This indicated that the Asat/E model developed using cotton grown in the glasshouse can also be used to estimate Asat/E of cotton grown in field conditions. This experiment provides a basis for physiology and production models, particularly in terms of cotton response to projected climatic environments.

The objective of field experiment II was to investigate the impacts of increased atmospheric [CO2] on whole canopy physiology of field-grown cotton in high-input/high-yielding production systems. Canopy EvapoTranpiration and Assimilation (CETA) chambers were used to elevate atmospheric [CO2] in the field. CETA chambers were a successful method of increasing atmospheric [CO2] of field-grown cotton, despite limitations with increased temperature and altered humidity and VPDa. CE increased early stage biomass by 67% of well-watered, field-grown cotton. Although there were increases in leaf-level photosynthesis (Asat), a reduction in stomatal conductance (gs-sat) and transpiration (E), and a corresponding increase in leaf-level photosynthetic efficiency (Asat/gs-sat), our data indicated there were no large changes in leaf-level biochemistry. In this study, we did not obtain a definitive answer to the integrated effects of CE on plant water use as there were no detectable differences in water use for early-stage cotton growth in the field, but CE increased plant water use in the glasshouse. Given the large increases in biomass with CE and the disparities between glasshouse and field studies, further studies should be conducted to explore the integrated environmental effects of climate change on field-grown cotton in Australian production systems.

This project highlights the implications for interactive effects of elevated atmospheric [CO2] and warmer temperatures on early-stage cotton growth and physiology in high-input/high-yielding systems. Overall, these studies have shown that projected climate change is likely to affect cotton physiology, growth and water use, but the magnitude will depend on the combination factors including temperature, [CO2], VPD, plant water availability and cultivar selection. The glasshouse experiments have shown that although plant water use efficiency may be improved with elevated atmospheric [CO2] at ambient temperatures, total water use is likely to increase. Although plant biomass is also increased with elevated [CO2] in field studies, differences in plant water use and efficiencies are yet to be confirmed. This will facilitate development of crop management strategies and could potentially lead to improvements in yield and water use efficiencies. Therefore, this data contributes to the understanding of how high-input/high-yielding cotton crops may respond to the integrated effects of projected climate change.