Using field-based Canopy EvapoTranspiration and Assimilation (CETA) chambers to assess the impact of climate change on early cotton growth

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Abstract
Changes in temperature, CO_2, and precipitation under the scenarios of climate change present a challenge to crop production, and may have significant impacts on the yield of cotton (*Gossypium hirsutum* L.). Understanding the implications of varied environmental conditions for agricultural crops is critical for developing cropping systems resilient to stresses induced by climate change. The aim of this study was to investigate the impacts of increased atmospheric [CO_2] on the growth of field-grown cotton in high-input/high-yielding Australian production systems. Canopy EvapoTranspiration and Assimilation (CETA) chambers were used to elevate atmospheric [CO_2] in the field. Cotton plants were grown under CETA chambers at higher temperatures (on average 4^{o}C warmer) either at ambient [CO_2] (C_A: 400 ppm) or elevated [CO_2] (C_E: 650 ppm) from 44 days after planting (DAP) until 72 DAP (28 days total). The CETA chambers were a successful method of increasing atmospheric [CO_2] of field-grown cotton. Elevated [CO_2] increased early stage biomass by 67% of well-watered, field-grown cotton. Data from this study contributes information on the possible impact of climate change on crop production and thus may shape management decisions for crop production in future environments by providing information for crop simulation models.

Key words
Elevated [CO_2], temperature, *Gossypium hirsutum*, greenhouse gas

Introduction
Current projections for climate change indicate that Australia can expect more heatwaves, changes in rainfall distribution, an increase in the intensity of droughts, and small decreases in relative humidity (Whetton and Power, 2007). Changes in temperature, CO_2 and precipitation under the scenarios of climate change present a challenge to crop production, and may have significant impacts on the growth of cotton (*Gossypium hirsutum* L.). Understanding the implications of varied environmental conditions for agricultural crops is critical for developing cropping systems resilient to stresses induced by climate change. The global atmospheric [CO_2] has increased from pre-industrial value of about 280 ppm to 400 ppm in 2013 (CSIRO and Bureau of Meteorology, 2012, IPCC, 2013), and will continue to rise in the future, affecting plant physiology and growth. Elevated atmospheric [CO_2] generally stimulates photosynthesis, leading to increased crop growth and yield, especially in C_3 species.

A range of experimental systems, including environmental chambers, glasshouses, Soil-Plant-Atmosphere Research (SPAR) units, open-top chambers (OTC) and Free Air CO_2 Enrichment (FACE) facilities, have been developed to expose plants to elevated atmospheric [CO_2]. In controlled environmental chambers and glasshouses, individual plants are typically grown in pots, and light, water, humidity and nutrients are controlled. Therefore, there are often higher levels of environmental control than in field conditions, but such facilities may restrict root growth, which can negatively influence photosynthetic capacity, shoot growth and harvestable yield potential, and thus reduce the response to CO_2 stimulation (Ainsworth and McGrath, 2010, Arp, 1991). FACE experiments allow the exposure of plants to elevated [CO_2] under natural and fully open-air conditions. However, limitations of FACE systems include difficulty in controlling air temperature, water inputs, as well as cost (Kimball et al., 1997).

Canopy EvapoTranspiration and Assimilation (CETA) chambers are relatively portable, open systems that have been used to measure canopy gas exchange of pot-grown and field-grown cotton plants in the U.S. (Baker *et al*., 2014, Baker *et al*., 2009). This research investigates the use of CETA chambers as a method of imposing CO_2 treatments in field-based studies, and explores the effect of CO_2 enrichment on growth

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characteristics of field-grown cotton. This paper presents research that aims to provide additional knowledge on the degree of climate change impacts on field-grown cotton in high input/high yielding Australian cotton systems.

Methods

A field experiment was conducted at Narrabri, NSW Australia during the 2012-2013 cotton growing season. The transgenic cotton variety Sicot 71 BRF [Bollgard II® Roundup Ready Flex®] (Stiller, 2008) was planted on 19th February 2013. The plots were prepared according to current production methods and plants were well-fertilised; however, sowing time of cotton was late in the season to avoid extremely high temperatures inside the chambers and to better simulate early season growing conditions.

Canopy EvapoTranspiration and Assimilation (CETA) chambers used were similar to the chambers described by Baker et al. (2009), and modified to allow for greater control of [CO_2] inside the chamber according to Baker et al. (2014). The chambers were 0.75 m x 1 m and 1 m in height. Transparent lexan (GE, Polymershapes, Coppell, TX) was used for the chamber walls, which reduced photosynthetically active radiation (PAR) by approximately 13% (Baker et al., 2014). Six aluminium bases were inserted approximately 5 cm into the ground. CETA chambers were set on top of four of the six bases and the remaining two were reference plots without either chambers or elevated [CO_2] (C_c treatment). Two chambers were ambient atmospheric [CO_2] (C_A treatment) and CO_2 gas was injected into the remaining two chambers and maintained at 650 ppm (C_E treatment). [CO_2] inside each of the chambers was recorded using a datalogger CR-3000 (Campbell Scientific Inc, Logan, UT). Temperature and relative humidity were not controlled, but were measured using a Tiny Tag Ultra (Gemini Data Loggers, West Sussex, UK) sensor. Plants were grown inside the CETA chambers for 28 days. Chambers were set up over the plants on 3rd April 2013 (43 DAP). CO_2 was injected into chambers from 4th April 2013 (44 DAP) until the 1st May 2013 (71 DAP).

Plants from each of the three treatments were harvested on 2nd May 2013 (72 DAP) and processed for biomass. Each plant was processed individually for height, nodes, total biomass, and leaf area. Samples were oven-dried at 80°C for 7 days and weighed. These data were analysed by residual maximum likelihood (REML) using Genstat version 16. Data were assessed at a P=0.1 level of significance.

Results

Chamber environment

The environment inside the chambers (C_A and C_E) varied with external field conditions. Daily air temperature was on average 4°C warmer inside the chamber than outside and at times was higher in C_E than C_A (Figure 1a). Mean daily relative humidity was on average 7.5 ± 0.77 % drier inside the chambers than outside (Figure 1b). Mean daily [CO_2] inside the C_A chambers was consistent over the experimental period, averaging 387 ± 0.8 ppm [CO_2] (Figure 1c). Mean daily [CO_2] inside the C_E chambers was more variable averaging 626 ± 6.8 ppm [CO_2], but consistently at least 200 ppm higher than C_A chambers.

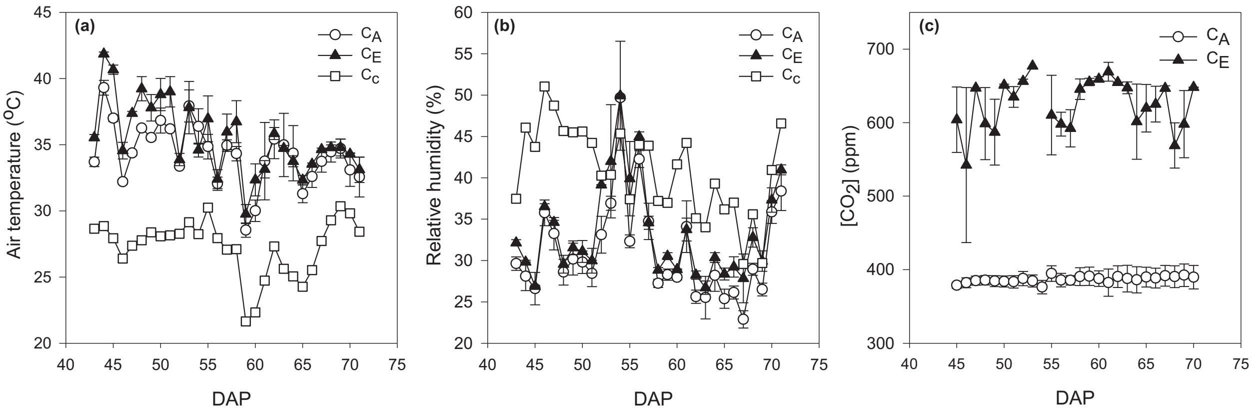

Figure 1: Average daily (a) air temperature, (b) relative humidity and (c) [CO2] from 8 am – 6 pm for ambient CO2 (CA, circle), elevated CO2 (CE, triangle) and control (Cc, square) for 43 – 71 DAP. Values represent mean ± SE of two chambers (sample size of one in the control treatment). Target [CO2] was 650 ppm, data range between 300 – 800 ppm with a gap in data at 54 DAP due to malfunction of data-loggers (panel c).

Plant growth and biomass

C_E increased vegetative biomass of cotton by 67% compared with the C_A treatment; however C_E did not increase fruit biomass compared with C_A (Table 1). Cotton grown at C_E had 51% greater leaf area and was 17% taller than plants grown at C_A, but there was no significant difference in the number of nodes (Table 1). Despite warmer air temperatures inside the chambers (Figure 1), there was no significant difference in biomass, leaf area or the number of nodes between the C_c and C_A treatments; however, C_A increased height by 30% compared with C_c (Table 1).

Table 1: Treatment means, standard errors (SE) and F-values for vegetative biomass, fruit biomass, leaf area, height and nodes for plants grown with no chamber (C_c), ambient chamber (C_A) or elevated chamber (C_E). † represents significance at P<0.1, * represents significance at P<0.05, ** represents significance at P<0.01 and * represents significance at P<0.001. Values in bold represent significant difference at P<0.1.**

Variable	C_C		C_A		C_E		F-value	
	Mean	SE	Mean	SE	Mean	SE	C_C compared with C_A	C_A compared with C_E
Vegetative biomass ($g\ plant^{-1}$)	6.6	0.44	7.0	0.42	11.8	0.95	0.556	0.039*
Fruit biomass ($g\ plant^{-1}$)	0.2	0.03	0.4	0.06	0.6	0.09	0.296	0.251
Leaf area ($cm^2\ plant^{-1}$)	388.0	22.64	445.6	25.05	673.5	47.10	0.220	0.040*
Height ($cm\ plant^{-1}$)	34.2	0.89	44.4	1.44	51.9	1.44	0.001***	0.061†
Nodes ($plant^{-1}$)	10.8	0.25	11.2	0.29	12.1	0.09	0.296	0.251

Discussion

CETA chambers were successfully used to elevate atmospheric [CO_2] of field grown cotton. Advantages of these systems are that they are portable and do not require as much infrastructure and CO_2 as larger-scale free air carbon dioxide enrichment (FACE) experiments. In addition, plants were grown in the field, thereby better capturing crop and canopy effects, and eliminating pot effects (Thomas and Strain, 1991). However, some of the limitations of these chambers include warmer air temperatures and substantially lower relative humidity, and thus higher atmospheric vapour pressure deficit (VPD_a) which affects gas exchange in cotton (Conaty et al., 2014, Duursma et al., 2013). Therefore, CETA chambers allow for the study of interactive effects of projected climate change, although it is not possible to differentiate temperature and VPD_a effects. For these reasons, comparisons for the effects of elevated atmospheric [CO_2] on cotton can only be made between C_A and C_E chamber treatments.

Our data showed that C_E increased vegetative biomass by 67%, whereas the increase in biomass due to elevated [CO_2] was 37% in FACE experiments (Mauney et al., 1994). However, the FACE experiment was conducted over a longer period of time (C_E for 144 days compared with 28 days), thus early growth benefits may be reduced with an extended period of time. In addition, differences in temperature, light and VPD may have also had an effect. Our data also showed large increases in leaf area with C_E, which increases area for leaf photosynthesis and transpiration, and thus may contribute to greater plant-level water use. Despite large increases in vegetative biomass, our data indicated that fruit biomass may not be significantly increased by C_E. Reddy et al. (1995) also found that floral initiation of cotton grown over a similar timeframe to this study, was not influenced by elevated [CO_2] (700 ppm compared with 350 ppm [CO_2]). However, studies of later stage growth, development and fibre quality are necessary before these conclusions can be drawn.

Conclusions

This study has highlighted that CETA chambers are a successful method of increasing atmospheric [CO_2] of field-grown cotton, however limitations of warmer temperatures, and altered humidity and VPD_a limit the comparison and interpretation of some of the data. This study also showed that early season biomass and leaf area of field-grown cotton were greatly increased with C_E which could potentially increase plant-level water use. However, this study did not indicate that increases in vegetative biomass with elevated [CO_2] were reflected in fruit biomass and consequently yield. Further research is needed to assess the impact of C_E over the full length of a season, to quantify plant water use of cotton grown in projected future environments and to provide information for crop simulation models.

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