Cotton production in a changing climate

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Abstract
Daily outputs from the CSIRO Conformal Cubic Atmospheric Model driven by four general circulation models were used in a stochastic weather generator, LARS-WG, to construct local climate scenarios for key cotton production areas in eastern Australia. These scenarios along with elevated CO_2 concentration were then linked to a cotton model (OZCOT) to quantify their potential impacts on cotton lint yield, water use, and water use efficiency (WUE) under irrigated and rain-fed conditions in 2030. For irrigated cotton, we considered nine cotton production locations. For rain-fed cotton, we considered three planting configurations and four locations. Analysis of irrigated cotton (non-limiting water and nitrogen supply) in a changing climate showed that crop water-use would change from -3.4% to +2.7%; lint yield would change from -8.2% to +0.5%, and WUE would change from -11.0% to +2.1% across locations. For rain-fed cotton, future climate scenarios would increase cotton water-use by 3% to 6% at Emerald and Narrabri and decrease cotton water-use 5% to 9% at Dalby and Moree. The lint yield would increase 2% to 24% in 7 out of 12 cases (the combinations of three plant configurations and four locations) and WUE would increase by up to 15% except at Dalby in a double-skip configuration. Lint yield in rain-fed cotton responded the most (positively or negatively) at double-skip planting at Emerald, Dalby and Narrabri, while it decreased the most at single-skip planting at Moree.

Key words
Climate change, irrigated cotton, rain-fed cotton, water use efficiency, row configurations, modelling

Introduction

The impact of climate change including elevated CO_2 concentration (eCO_2) on cotton production has attracted attention since the 1990s. Both experimental and modelling studies have been conducted to address this important issue. Mauney et al. (1994) found that cotton water use efficiency (WUE) would increase under eCO_2 across irrigation levels and the increase in WUE was due to increased biomass production rather than a reduction of water use. Reddy et al. (2005) investigated the interactive effects of eCO_2 and temperature on cotton production and found that doubling of CO_2 concentration did not ameliorate the adverse effect of high temperature on reproductive growth (boll abscission or boll size). Reddy et al. (2002) quantified the effects of future climate change on cotton production in the Mississippi Delta by using the cotton simulation model GOSSYM with the effects of eCO_2 considered. A recent study by Luo et al. (2014) quantified the impact of increase in temperature on cotton crop phenology and the occurrence of cold shocks and heat stress for the period centred on 2030 in Australia. Changes in the probability of cold shocks and heat stress occurrence and in cotton phenology arising from future climate change will affect cotton growth. For example, an increase in temperature will increase water loss due to soil and plant evaporation, and increase the frequency of exceeding critical temperature thresholds for crop growth and development (Reddy et al., 2005), hence impact on cotton growth, boll production, fibre quality, and ultimately farm profitability. Even though eCO_2 may have some positive effects on cotton production, these effects may be constrained or impacted by high temperature, and access to soil water and soil nutrients (Reddy et al., 2005). For the Australian cotton industry to be sustainable, there is a strategic need to quantify the combined impacts of changes in temperature, rainfall, and eCO_2 on cotton production. This will help to identify and evaluate existing and potential adaptation options in the face of climate change. This research aims to quantify the potential impacts of future climate change on cotton production from the perspective of cotton lint yield, water use and WUE.

Methods

Study locations

For irrigated cotton, we considered nine major cotton production areas in Queensland (Emerald, Dalby, St George, and Goondiwindi) and New South Wales (Moree, Bourke, Narrabri, Warren and Hillston). The irrigated cotton production areas represent different growing environments, with Emerald, Bourke and St George being classified as hot; Dalby, Goondiwindi, Moree, Narrabri and Warren as mild; and Hillston as cool. These environments have resulted in varying crop management practices such as different sowing dates. For rain-fed cotton we focused on four rain-fed cotton production areas, namely Emerald, Dalby, Moree and Narrabri.

Local climate change & climate change scenarios (CCSs)

Dynamic downscaling is one of the major downscaling approaches for translating coarser spatial resolution climate change information to finer scales (Luo & Yu, 2012). In this study, the outputs of the CSIRO Conformal Cubic Atmospheric Model (CCAM), a dynamic downscaling approach, for baseline (1980-1999) and future period (2020-2039), were used by a stochastic weather generator, LARS-WG, to derive monthly local climate change information and to construct long time series (100 yrs) of climate scenarios. The CCAM model was driven by four general circulation models (GCMs), specifically, GFDL, CSIRO Mark 3.5, MPI, MIROC under the Special Report on Emission Scenarios (SRES) A2 greenhouse gas emission scenario (IPCC, 2000). Detailed procedures for constructing local CCSs and justifications for the downscaling approach, study periods, emission scenarios, and the number of climate models considered can be found in Luo et al. (2014, 2015).

The OZCOT model

CSIRO OZCOT model (Hearn, 1994) was used in this study to quantify the effects of future climate change on cotton lint yield, water use and WUE. The OZCOT model is a mechanistic model, which simulates the growth, development and lint yield on an area basis at a daily time step. This model was developed for Australian cotton production systems and has been validated for both irrigated and rain-fed cotton across a range of environments (Richards et al., 2008). This model has been modified to capture the physiological effects of eCO_2 on cotton production. Details can be found in Luo et al. (2015).

Simulation design

In this simulation analysis, cotton cultivar: S71BR was used. This cultivar is a high yielding modern cultivar with mid to late maturity, mimics high fruit retention associated with transgenic cultivars conferring high levels of insect pest protection. Table 1 shows the common sowing time for each cotton production area under current climate (Bange et al., 2010). Irrigated cotton was simulated on a 1 m row solid planting configuration as per industry standard practice. A water supply level of 8 ML/ha for each location was considered. Table 2 summarises the irrigation management rules used. Skip-row is commonly used to ensure viable cotton crop yield and fibre quality in rain-fed systems. A simulation analysis across three planting configurations (i.e. solid, single skip, and double skip) was carried out to assess climate change effects on cotton production across the four locations. The soil profile characteristics used by the OZCOT were selected as being representative of the major soil types for each location. Of particular importance in these simulations is the plant available water capacity of the soils, which is shown in Table 1. Nitrogen was assumed to be non-limiting to exclude its interaction with climate change and was set to an initial value of 200 kg/ha at sowing. An additional 50 kg/ha of fertiliser N was applied at approximately first flower for each location. The timing and amount of fertiliser N applied are in line with current cotton management practices. Atmospheric CO_2 concentration for baseline and future period were set to 400 ppm and 450 ppm respectively.

Table 1. Sowing time and plant available water capacity (PAWC in mm/mm) across locations

Locations	Sowing Time	PAWC
Emerald	25th Sep	220 mm
Dalby	15th Oct	250 mm
St George	1st Oct	170 mm
Goondiwindi	25th Sep	245 mm
Moree	25th Sep	180 mm
Bourke	1st Oct	110 mm
Narrabri	10th Oct	260 mm
Warren	1st Oct	210 mm
Hillston	25th Sep	140 mm

Table 2. Irrigation management information

Irrigation schedules	Value
Pre-irrigation time (days)	12 days before sowing
Deficit irrigation trigger (mm)	70 mm
Timing of 1st irrigation (days)	2 days after 1st square
Timing of last irrigation (%)	20% of open bolls

Results

Local climate change in 2030

Table 3 shows the multimodel ensemble mean changes between future period (2020-2039) and baseline period (1980-1999) in growing season (1st Oct – 31st May) mean rainfall, minimum and maximum temperature and the variability of mean temperature. From this table it can be seen that mean rainfall would increase by 2% to 16% across locations with southern areas increasing more. Minimum temperature would increase 1.1°C to 1.3°C and maximum temperature would increase 0.9°C to 1.1°C across locations. Mean temperature variability (defined as standard deviation) would increase by 5% to 9% across locations except for Emerald where a 2% decrease was found.

Table 3. Multi-model ensemble mean changes of climatic variables over cotton growing season for the period centred on 2030

Locations	GSR[1] (Ratio change)	Tmin[2] (°C)	Tmax[2] (°C)	Tvar[3] (Ratio change)
Emerald	1.02	1.23	1.07	0.98
Dalby	1.06	1.27	1.13	1.05
ST George	1.08	1.29	0.99	1.06
Goondiwindi	1.09	1.30	1.08	1.06
Moree	1.09	1.27	1.05	1.07
Bourke	1.11	1.21	1.05	1.09
Narrabri	1.10	1.26	1.04	1.07
Warren	1.14	1.22	0.96	1.07
Hillston	1.16	1.14	0.94	1.06

[1] growing season mean rainfall; [2] minimum/maximum temperature; [3] mean temperature variability

Simulated cotton lint yield, water use and WUE under irrigated condition

Table 4 shows the multi-model ensemble mean changes in cotton lint yield, water use, and WUE across the nine production areas under climate change conditions in 2030 with water supply level of 8ML/ha. It was found that cotton lint yield would change from -8.2% to +0.5% in 2030 across locations with Hillston decreasing the most. A change range of -3.0% to +2.7% would be expected for cotton water-use with seven out of nine locations showing a decrease. Cotton WUE would change from -11.0% to +2.1% with seven out of nine locations showing a decrease.

Table 4. Multi-model ensemble mean changes (%) in cotton lint yield, water use and WUE in 2030

Locations	Lint Yield	Water Use	WUE
Emerald	-1.68	-0.10	0.75
Dalby	0.53	1.91	-1.93
St George	-4.64	-1.84	-2.87
Goondwindi	-1.60	-3.35	2.07
Moree	-2.46	-2.70	-2.71
Bourke	-7.65	-2.94	-7.29
Narrabri	-1.82	-0.64	-1.70
Warren	-2.67	-2.82	-3.37
Hillston	-8.23	2.74	-11.03

Simulated cotton lint yield, water use and WUE under rain-fed condition

Figure 1 shows multi-model ensemble mean changes of cotton lint yield, water-use and WUE across planting configurations and study locations for the period centered on 2030. Cotton lint yield would increase 7% to 24% at Emerald and Narrabri across planting configurations and would decrease by 14% at Dalby and Moree (except for single skip at this location) under future climate scenarios (Figure 1a). Planting configurations: solid

and double-skip would result in greater increases in lint yield when compared to single-skip configuration at Emerald and Narrabri. However, single-skip performed the best at Dalby and Moree in a changing climate. From Figure 1b it can be seen that cotton water-use would increase 3% to 6% at Narrabri and Emerald except for solid configuration at this location, while it would decrease from 5% to 9% at Dalby and Moree across planting configurations in a changing climate. Future climate scenarios would have positive effects on cotton WUE by 15% across locations and planting configurations except at Dalby associated with double-skip (Figure 1c).

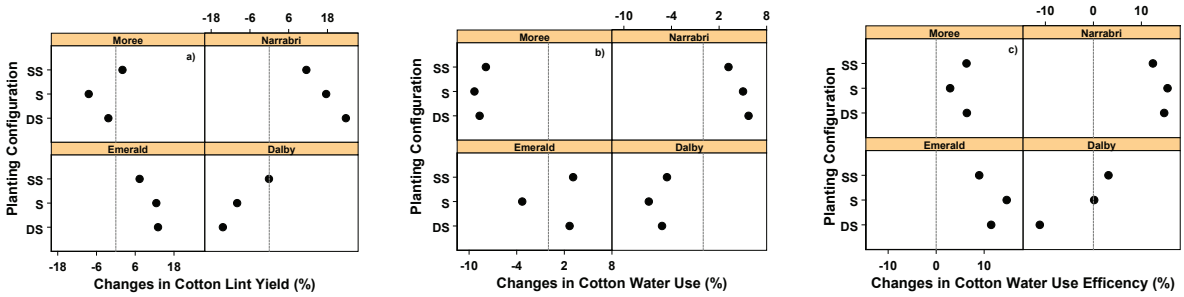

Figure 1. Multi-model ensemble mean changes (%) in cotton lint yield, water use and WUE in 2030 under rain-fed condition. SS: single skip, S: solid, DS: double skip. The dotted vertical lines represent no change.

Discussion and Conclusions

Cotton lint yield, water use and WUE would decrease at most of the locations considered under climate change and irrigated conditions (Table 4). Decrease in cotton lint yield may arise from exacerbated waterlogging problems under a high water supply level (8 ML/ha) and projected increase in cotton growing season rainfall (Table 3). The greatest decrease in cotton lint yield data at Hillston is probably due to the greatest increase in growing season rainfall (Table 3) under irrigated condition. The greatest decrease in cotton lint yield coupled with an increase in cotton water use (Table 4) led to the greatest decrease in WUE at this location. The physiological effects of eCO_2 may have offset the negative effects of future climate change thus led to small decline in cotton lint yield at other locations. On the other hand, increased season rainfall would benefit cotton lint yield under rain-fed condition. For rain-fed cotton, double skip planting would respond positively to future climate scenarios at Emerald and Narrabri while single skip planting would perform the best in terms of lint yield at Dalby and Moree. This indicates that adaptation options in dealing with climate change issues are site- and farming system-specific. These findings have practical value to the Australian cotton growers. The effectiveness of adaptation strategies such as changing planting time, irrigation schedule and rotation pattern on cotton lint yield has been evaluated in a couple of studies by Luo et al. (unpublished).

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