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Cotton crop phenology in a new temperature regime

Qunying Luo[a,*], Michael Bange[b], Loretta Clancy[b]

[a] University of Technology, Sydney, PO Box 123, Broadway, NSW 2007, Australia
[b] CSIRO Division of Plant Industry, Locked Bag 59, Narrabri, NSW 2390, Australia

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ABSTRACT

The daily outputs of the CSIRO Conformal Cubic Atmospheric Model driven by four general circulation models (GCMs) were used by a stochastic weather generator, LARS-WG, to construct four local climate change scenarios (CCSs) at nine key cotton production areas in eastern Australia. These CCSs were then linked to daily temperature-driven models of cotton phenology to examine the magnitude of the effects of increased temperature on the initiation and duration of key crop phenophases and on the occurrence of heat stress and cold shocks during the growing season. The results show that when using 1st Oct. as sowing time (1) the timing of emergence, 1st square, 1st flower and 1st open boll advanced 1–9, 4–13, 5–14 and 8–16 days, respectively, for the period centred on 2030 compared to baseline; (2) when crops were planted 10 days earlier, the emergence stage occurred earlier in most of the locations while other phenological events changed slightly (~1 day) in comparison with 1st Oct. sowing; when crops were planted 10 days later, all these events were generally delayed (~1.5 days) in comparison with 1st Oct. sowing; (3) the timing of the last effective square, last effective flower and last harvestable boll were delayed 7–12, 6–9 and 3–9 days, respectively, across locations (except St George) and GCMs; (4) the fruit development period increased up to 2–3 weeks; (5) the number of hot days increased across all locations and growing season (GS) months except May with the warmer months (Dec., Jan. and Feb.) and locations increased more; and (6) the number of cold shocks decreased or remained the same across locations and GS months except Jan. and Feb. with cold months and places decreased more. The results show that there will be less impact of cold temperatures on earlier growth and potentially a longer growing season that can improve crop yield. However, there will be more incidences of hot days impacting growth, and more rapid crop development in late phenological stages (especially during boll filling) that may limit the opportunities associated with increases in growing season length without adjustments in management.

1. Introduction

Ambient temperature (*T*) is one of the major environment variables affecting the growth, development and yields of crops, especially the rate of development (Luo, 2011). Crops have basic requirements for *T* to complete a specific phenophase or the whole life cycle. On the other hand, extremely high and low temperatures (*T*s) can have detrimental effects on crop growth, development and yield, particularly at critical phenophases. While cotton is morphologically indeterminate, the rate of many phenological processes such as germination, floral initiation and development of fruiting bodies is controlled by *T* (Hearn and Constable, 1984). Average daily *T* also plays an important role in determining the earliest date of sowing, defining season length which can both influence yield potential and cotton fibre quality (Bange et al., 2008a; Bauer et al., 2000; Dong et al., 2006), and determining where cotton can be produced sustainably. Generally the longer the growing season (GS) the greater the potential for higher lint yields (Bange and Milroy, 2004a; Stiller et al., 2004). In Australian cotton production systems, *T* requirements for the development of cotton are described by the accumulation of degree days calibrated with a base *T* of 12 °C (Constable and Shaw, 1988). Other cotton systems elsewhere (i.e. America) have used a base *T* closer to 15 °C (Robertson et al., 2007).

Throughout most Australian production systems, minimum temperature (T_{min}) (≤11 °C) experienced early in the cotton season can cause delays in development, reduction in growth, and sometimes chilling injury (Constable et al., 1976; Bange and Milroy, 2004b). As the season progresses maximum *T*s (>35 °C, heat stress) are commonplace throughout cotton production regions and may adversely affect growth and development thus affecting water use, yield and fibre quality (Hodges et al., 1993). At the end of a cotton season cooler or cold *T* will influence the timing of crop maturity and impact on effectiveness of chemical harvest aids, both again directly affecting yield and quality. Cotton has an optimal thermal

* Corresponding author. Tel.: +61 0410 186 352; fax: +61 2 9514 4079.
E-mail address: luo.qunying122@gmail.com (Q. Luo).

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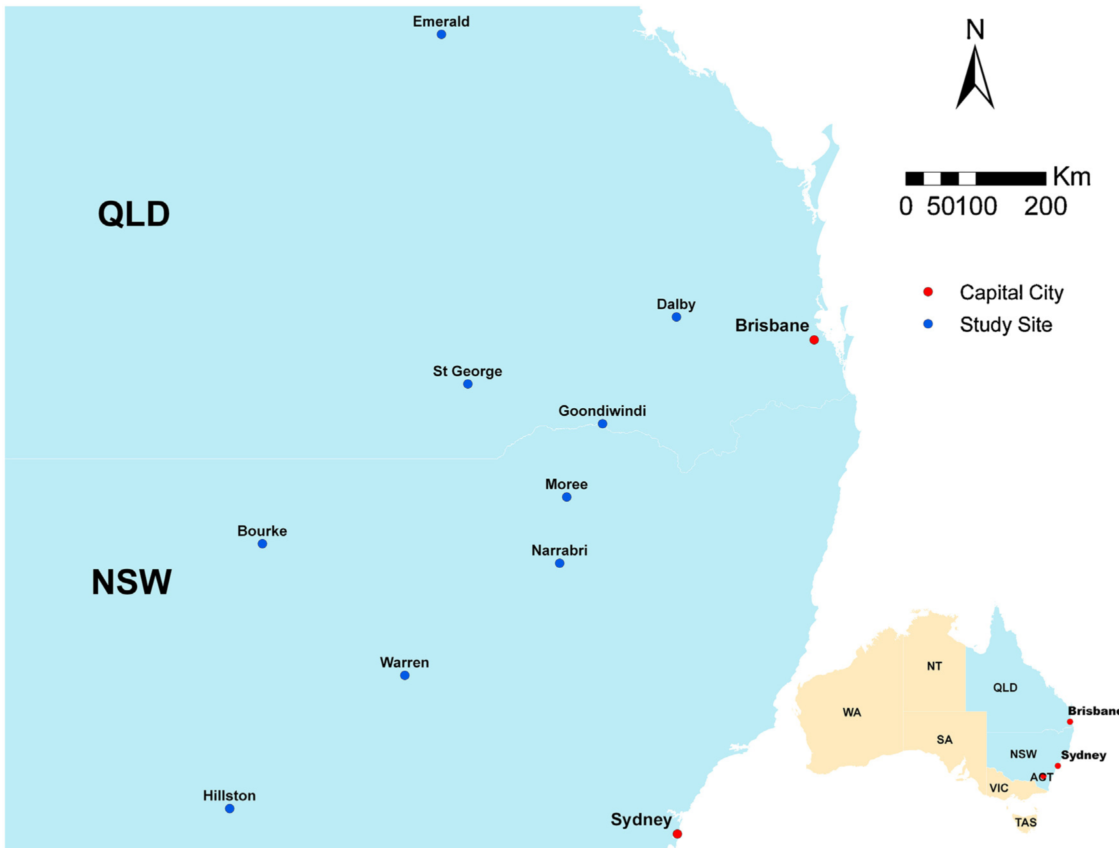

Fig. 1. Cotton production locations in Eastern Australia used in this study.

kinetic window of 23–32 °C in which metabolic activity is most efficient (Burke et al., 1988; Conaty et al., 2012).

High *T* affects reproductive processes of cotton thus affecting yield (Reddy et al., 2000, 2005). Effects may be attributed to impacts on pollen viability (Burke et al., 2004), fertilisation efficiency (Snider et al., 2009), boll size and seed number (Pettigrew, 2008), and fruit shedding (Hodges et al., 1993; Reddy et al., 1992b). Kakani et al. (2005) reported that instantaneous air *T* above 32 °C reduces cotton pollen viability, and *T* above 29 °C reduces pollen tube elongation. Reddy et al. (2005) demonstrated that the maximum growth rate per boll occurred at 25–26 °C and decreased at higher *T*s while boll harvest index was highest at 28 °C, declining thereafter and reaching zero boll harvest index at 33–34 °C. Boll size was largest when *T*s less than 20 °C. Percent boll set, boll number, boll filling period, rate of boll growth, boll size and yield all decreased when mean *T* reached 30 °C (Reddy et al., 2005). *T* of 40/32 °C led to zero boll yield (Reddy et al., 1992a,b). Heat stress can result in boll cavitation and reduces cotton lint yield (Bange et al., 2008b). From a fibre quality perspective sustained increases in *T* will reduce fibre length (Gipson and Joham, 1969) and increase micronaire (Gipson and Joham, 1968; Bange et al., 2010), and sometimes negatively impacting final fibre quality.

Cotton exposed to low *T*s takes longer to develop, and accumulates biomass at a slower rate (Gipson, 1974; Mauney, 1986). Cold *T* responses (below 10 °C) in early post-emergent seedlings can permanently arrest growth and development (Christiansen, 1967; Christiansen and Thomas, 1969). Bange and Milroy (2004b) also found that negative effects on development existed when plants were exposed to at least 10 nights at 10 °C, or for 5 nights at 5 °C on post-emergent cotton. In Australia, to account for early season effects of cold *T* on cotton development, a 'cold shock' effect is applied to degree days (DDs) accumulation. A 'cold shock' is defined as an event when the daily minimum *T* falls to 11 °C or less, which assumed to cause chilling injury and thus delays development.

Late in the season cold *T*s (≤2 °C) can signal the end of the GS. These low *T* may force bolls to open affecting lint fibre quality (colour and maturity), and will severely impede the efficacy of chemical harvest aids (optimal *T* ~18 °C) to remove leaf from the plant prior to harvest (Bange et al., 2009). The optimum sowing time aims to reduce the incidences of 'cold shocks', while in-season management aims to ensure that fruit has adequate time to mature and that harvest aids are applied prior to the onset of cold *T*.

Increase in *T* will change crop phenology, including the start and duration of phenophases and the probability and degree of extreme climate events such as heat stress and cold shocks. These changes may have significant implications for cotton lint yield and fibre quality. Hence this work aims to understand local climate change in Australian cotton production regions, quantify its impacts on cotton crop phenology and on the occurrence of heat stress and cold shocks in cotton GS. This work will support more complex studies and analyses into climate change on cotton production and assist in identifying effective adaptation options to deal with the risk and to take the advantage of climate change.

2. Materials and methods

2.1. Study locations

This study focused on nine major cotton production areas in Queensland (Emerald, Dalby, St George and Goondiwindi) and New South Wales (Moree, Bourke, Narrabri, Warren and Hillston) in Australia (Fig. 1). These cotton production areas also represent different growing environments: with Emerald, Bourke and St George being classified as being hot (annual mean *T*: 20.21–22.61 °C);