Cotton is a perennial with an indeterminate growth habit. Wild ancestors of cotton are found in arid regions often with high temperatures and are naturally adapted to surviving long periods of dry weather.

Modern cultivars have inherited these attributes, making the cotton crop well adapted to intermittent water supply that occurs with rain-fed and irrigated production. Compared with other field crops however, its growth and development is complex. Vegetative and reproductive growth occur simultaneously making interpretation of the crop’s response to climate and management sometimes difficult.

Climate change impacts on cotton growth and development that influence yield and fibre quality will most likely be a result of the net effects of:
- Increases in CO$_2$ concentration;
- Reduced water availability and increased atmospheric evaporative demand as a result of lower rainfall and relative humidity; and,
- Increases in temperature.

These effects are discussed in more detail below.

**Effects of climate change on cotton growth and development**

By Michael Bange, CSIRO Plant Industry, Cotton Catchment Communities CRC

Climate change may impact on cotton growth and development through increases in atmospheric carbon dioxide (CO$_2$) concentration, reduced water availability, increased atmospheric evaporative demand (lower humidity), and increases in temperature.

- Increased CO$_2$ levels may increase photosynthesis and water use efficiency leading to higher yields in the absence of water stress.
- Increases in atmospheric evaporative demand may increase water use in well watered crops and increase the impact of stress when water is limited.
- Temperature increases at the start and end of seasons may have a positive effect on yield by extending time for cotton growth.
- An increase in the frequency of days with very high temperatures will negatively impact on both growth and development.
- Climate change will impact on many facets of cotton physiology. An integrative research process will be needed to assess the exact effect of climate change will have on cotton production.
INCREASE IN CO₂

Through the process of photosynthesis, plants synthesise organic compounds used for growth using water and CO₂ using energy absorbed by chlorophyll from sunlight. Two sources of research are currently available that discuss the impact of CO₂ on cotton’s growth and development.

The first block of research summarised by Reddy et al. (1996) discusses impacts of CO₂ increase on cotton in growth chambers. This work showed that doubling CO₂ concentrations in the atmosphere increased photosynthesis by about 40 per cent which led to increased growth and yield in well watered environments (see Figure 1).

This work also showed that increasing CO₂ increased water use — but the efficiency of water use was improved. From their studies they postulated that increased growth and yield would occur with higher CO₂ concentrations even in dry or nutrient deficient situations. Using this work we could assume that with an increases in CO₂ to levels predicted for 2020 (406 to 415 ppm) and 2050 (473 to 555 ppm), photosynthesis would increase by approximately 23 and 29 per cent respectively.

In other work by Pinter et al. (1994) on field grown cotton, they explored increases in CO₂ using free air CO₂ enrichment (FACE) facilities. They found that radiation use efficiency (dry matter per unit of intercepted radiation) was improved on average from 1.56 to 1.97 g MJ⁻¹ resulting in increased biomass when CO₂ was increased to 550 ppm. They also investigated the impact of CO₂ elevation with different irrigation regimes. They found that regardless of irrigation treatment (wet or dry), radiation use efficiency was increased in CO₂ elevated treatments. This suggested that a rise in atmospheric CO₂ concentrations may partially compensate for plant stress caused by water shortages. As a consequence, lint yield on average was increased by 43 per cent — due to increased early leaf area and a longer flowering period.

REDUCED WATER AVAILABILITY AND HIGHER EVAPORATIVE DEMAND

Less water for irrigation will mean lower cotton yields unless farm and agronomic water use efficiencies can improve. Water stress in cotton restricts both vegetative and fruit growth. Cotton’s response to stress varies on the stage of growth, the degree of stress, and the length of time imposed.

Research in Australia has shown that to prevent yield reductions, cotton crops generally require enough water to allow 700 mm of evapotranspiration (transpiration plus soil evaporation — see Figure 2).

Lower relative humidity caused by climate change will increase evaporative demand by the atmosphere surrounding crops. Changes in evaporative demand will influence the amount of evapotranspiration — affecting both transpiration and soil evaporation.

Transpiration is used by crops to regulate temperature of their...
canopies. Higher evaporative demand in well watered crops has the potential to increase transpiration and soil evaporation — lowering water use efficiency. In situations where water is limited and there is high evaporative demand, crops will struggle to transpire enough to keep the canopies cool. Leaf temperatures are then increased to a point where photosynthesis and growth are impaired.

Recent research in cotton has shown that regardless of the water availability in the soil there is an increase in plant stress associated with higher evaporative demands. Research is continuing to quantify the effects of relative humidity on cotton growth on soils with different water holding capacities.

**INCREASE IN TEMPERATURE**

Temperature has two main influences on cotton growth and development. Firstly it determines the rates of morphological development and crop growth (eg. node development, rate of fruit production, photosynthesis and respiration). Secondly, it also helps determine the start and end of a growing season.

Climate change raising temperatures may:
- Increase average daily temperatures warming both the start and end of cotton seasons allowing for longer and better cotton growth (a positive effect);
- Increase average temperatures during boll filling predisposing crops to high micronaire issues (a negative effect); and,
- Increase the number and severity of days with very high temperatures during the cotton season (negative effect).

The effects are discussed below.

**Increase in frequency of very hot days**

Many areas in which cotton is grown in Australia already experience extremely high temperatures during the growing season, particularly during flowering and boll development. Climate change may increase the frequency of these high temperatures. Cotton plants maintain optimum growing temperatures by opening stomates in the leaves, allowing water to pass out and evaporate, thus cooling leaves (transpiration).

Excessively high temperatures (greater than 35°C) during the growing season will lead to high micronaire issues, decreased boll weights and yields, and soil water consumption.

**FIGURE 4: Fewer bolls per metre trends towards higher micronaire**

Data from Cotton Seed Distributors segmented picking projects in 2004-05 and 2005-06 which involved sampling commercial crops across many growing areas (Kelly et al. 2006).

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day can reduce photosynthesis (Figure 3) while warm nights (above 25°C) mean that leaf temperature remains high, and respiration remains high, consuming stored assimilates. Maintenance respiration approximately doubles for every 10°C rise in temperature.

Both situations reduce the amount of assimilates available for growth, and in turn reduce yield by:
- Causing increases in square and boll shedding; and,
- Reducing seed number per boll.

Loss of fruit may cause the crop to grow excessively vegetative (rank) following the period of heat stress.

In addition to reductions in assimilates available for growth, heat stress can also directly damage cotton plant tissue. At night the plant loses the ability to cool evaporatively (no transpiration), so tissue temperatures approach air temperature. During the day very high relative humidity (which restricts evaporative cooling) in combination with clear skies can also increase tissue temperature to approach or exceed air temperature.

Two known consequences of direct tissue damage from severe heat stress are:
- Parrot beaked bolls. High temperatures reduce the viability of the pollen at flowering. This reduces boll size and can reduce yield. The result is small bolls with uneven seed numbers between the locks caused by poor pollination/seed set particularly in one lock. There are no known studies to show if the plant compensates for parrot beaked bolls by having other normal bolls grow bigger.
- Boll freeze or cavitation or boll dangle. This occurs when young bolls die before the abscission layer forms. Again this loss of fruit may cause the crop to grow excessively vegetative (rank) following these symptoms.

Large increases in temperature also reduce the interval between flowering and boll opening, shortening the time to maturity and reducing yield. This may increase final micronaire by limiting the number of late set bolls that can have lower micronaire (Figure 4).

Fibre length can also be affected by sustained periods of high temperatures as the time required for fibre elongation is reduced, not allowing for the genetic potential of fibre length to be reached. Fibre length is reduced as boll temperatures increase above 32°C.

The consequences of hot conditions for yield and quality are exaggerated if water stress also occurs during these periods.
Warming the start and end of cotton seasons

Increased average temperatures especially at the start and end of the cotton season can have positive effects on growth, development and ultimately yield.

Low temperatures after sowing increase the time to emergence and reduce cotton seedling vigour — often leading to poor establishment, poor early growth and increased risk of seedling diseases. A key indicator used in the Australian cotton industry of the degree of very cold temperatures that contribute to the conditions mentioned above is the ‘cold shock’ concept.

A cold shock is defined as when minimum daily temperatures are below 11°C and each event extends the duration to flowering by 5.2 day degrees. In some cotton producing regions in Australia early in cotton growth the number of cold shocks can be on average as frequent as 40 (from 15 September to 30 November).

In an analysis prepared for the Australian Cotton Conference (2006) by Chris Mitchell, CSIRO, he showed that climate change had the potential to raise minimum temperatures and significantly reduce the number of cold shocks. (See Figure 5)

Cotton is a perennial crop. Warmer temperatures at the start and the end of cotton seasons will increase the length of time cotton has to grow and produce yield, provided adequate water and crop nutrition are available. For every extra week that the growth period (time between sowing and maturity) may be allowed to be extended through warmer temperatures it has the potential to increase lint yield by 68 and 136 kg per hectare (Figure 6).

Warmer temperatures during boll filling

A key factor effecting micronaire (s the temperature during boll filling. Micronaire is a measure of fibre fineness and maturity. Finer fibres means that there are more fibres in the cross section of a yarn when it is spun and the yarn is stronger. The degree of fibre maturity impacts dye absorbency and retention.

Fibre fineness is determined primarily at fibre initiation on a seed.

Fibre maturity is the proportion of fibre cross section occupied by cellulose and is influenced by impacts on photosynthesis and demand for resources by the developing bolls. As photosynthesis increases with temperature in the absence of water stress, more resources are available to mature the fibres thus increasing micronaire (Figure 7). Situations where seasons are warmer more often during boll filling predispose crops to situations where high micronaire will be more likely to occur.

SUMMARY

As there are many facets of cotton physiology potentially impacted by climate change, assessing the overall impact will be complex. There will be a need to investigate the impacts of changes in rainfall, rises in temperature, increases in CO₂, and evaporative demand together to establish if climate change will substantially impact cotton growth, development, and yield in a positive or negative way. There will also be a need to identify the degree to which these impacts may occur with growing cotton in different regions.

Some further studies of cotton physiology in Australian conditions with climate change scenarios will be needed — especially the relative impact of lower water availability, high-temperature, increased evaporative demand, and higher CO₂ together. But the Ozcot cotton crop simulation model will be a powerful tool coupled together with predictions of climate change to investigate management practices that may be adapted to offset impacts of climate change. Research is progressing to update to assess these impacts in an integrated way.