

Cotton farming systems for a changing climate

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Change has always been present, but the cotton industry like all Australian agriculture in general is facing change at an unprecedented rate and from different causes. In this article we consider changes that the cotton industry faces associated with: 'climate change' in the meteorological sense; regulatory issues relating to reductions in water availability and carbon emissions trading; rising costs of production; and competition from other commodities. For cotton 'climate change' per se will influence production directly through rising CO₂ levels, experiencing higher temperature more often, lower humidity and less water availability. To combat these changes as well as dealing with increasing costs caused by rises in energy, and future emissions trading will mean that sustainable cotton production will need to adopt practices in combination that will: increase and/or maintain high yield and quality; improve a range of production efficiencies (water, nitrogen, energy /bale etc.); seek to improve a better return for lint and seed; or consider other cropping options as alternatives. We present the impacts of these changes on cotton production systems and highlight some options. Management options include: high yielding/high quality stress tolerant varieties; optimising water use; manipulating maturity; varying planting time; optimising crop nutrition; and maintaining diligent monitoring practices for weeds, pests and diseases to enable flexible management.

A 'changing climate' and impacts on cotton production

Climate Change

While there is growing confidence in global scale observations and predictions of climate change it is still difficult to precisely determine how spatial variation in impacts of climate change will translate into impacts at regional scales. Nonetheless, there are some general principles about how climate change will affect cotton production McRae *et al.* (2007), they are from:

- *Increases in CO₂ (carbon dioxide) concentration.*

Three publications discuss the impact of CO₂ on cotton's growth and development. Studies were in controlled conditions in the USA (Pinter *et al.* 1994, Mauney *et al.* 1994, Reddy *et al.* 1996). This research suggest that doubling CO₂ concentrations increased photosynthesis by about 40% which led to increased growth and yield in well watered environments. This work also showed that increasing CO₂ increased water use and the efficiency of water use. They suggested that a rise in atmospheric CO₂ concentration may partially compensate for plant stress caused by water shortages. Other recent research into elevated CO₂ (doubling of current ambient) has also shown that it can affect leaf chemistry reducing concentrations of the Bt toxin expressed in transgenic cotton cultivars used to control *Helicoverpa* spp. by up to 3.1% (Wu *et al.* 2007) but this did not translate to changes in efficacy as other leaf chemicals were also affected reducing the overall health of *Helicoverpa* spp. (Chen *et al.* 2007; Wu *et al.* 2006).

- *Increases in daily temperature including marked increase in the frequency of hot days and warm nights, but a less-marked decrease in the frequency of frosts.*

Temperature has two main influences on cotton growth and development. Firstly it determines rates of morphological development and crop growth (eg. node development, rate of fruit

production, photosynthesis and respiration) (Hearn and Constable, 1984). Secondly, it also helps determine the start and end of a growing season (eg. timing of frosts). Consequently climate change may increase average daily temperatures resulting in longer and better cotton growth (a positive effect). As 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. Warmer temperatures in southern growing regions offers potential to increase average yields as season length may be increased. For every extra week that the growth period (time between sowing and maturity) can be extended through warmer temperatures there is the potential to increase lint yield by 68 to 136 kg ha⁻¹ (Bange and Milroy 2004).

In contrast, negative affects on cotton growth and development from climate change may result from increased number and severity of days with very high temperatures during the cotton season. These events will reduce yields by decreasing daily photosynthesis, and sometimes raising respiration at night, consuming stored assimilates which lead to increases in square and boll shedding and reducing seed numbers per boll. Increased incidences of heat stress can also directly damage cotton plant tissue causing parrot beaked bolls, boll freeze and cavitation also reducing yield. Hotter temperatures during boll filling also predispose crops to lower fibre lengths and higher micronaire values. The consequences of hot conditions for yield and quality are exaggerated if water stress also occurs during these periods. These issues will be important for all cotton producing regions.

- *Reduced water availability and increased atmospheric evaporative demand as a result of lower rainfall and relative humidity.*

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 (Hearn and Constable, 1984). Higher evaporative demand in well watered crops also has the potential to increase transpiration and soil evaporation lowering water use efficiency. Research is currently being undertaken for cotton to quantify the effects of evaporative demand on cotton growth on soils with different water holding capacities. There is some evidence that there is additional plant stress when growing on some soil types when higher evaporative demands are encountered (Nielsen 2006).

Overall the industry faces the dual challenge of coping with extreme climatic variation and shift to a drier climate as a result of predicted climate change.

Regulatory issues

Two regulatory issues that will impact on cotton production systems are changes in water policy and marketing which will limit water availability, and the impact of changing industrial operating climate resulting from implementation of a greenhouse emissions trading scheme. Undoubtedly in the face of decisions about water management involving balancing sets of economic, environmental and other interests (most with increased demands for water), will ultimately limit water available for irrigation purposes. Less water for irrigation will mean reduced cotton production unless improvements in farm and agronomic water use efficiencies are made. Research in Australia has shown that to optimise yield, cotton crops generally require on average enough water to allow 700 mm (7 ML/ha) of evapotranspiration (transpiration plus soil evaporation) (Tennakoon and Milroy 2003).

Agriculture is also a significant contributor (16% of total) of green house gas emissions (Keogh, 2008). In cropping systems the main source of emissions result from cultivation, volatilisation from nitrogen fertiliser, and burning of stubble. The Australian government is working to introduce an emissions trading scheme to help reduce 'carbon pollution' by 2010. Agriculture initially is not

included in the scheme but Keogh (2008) suggests the potential major impacts for agriculture when it is implemented include: limited opportunity for carbon offsets; increased fuel and energy costs; and reduce competitiveness with other overseas markets that have no carbon emissions trading schemes.

Rising commodity prices and costs of production

Reasons for rising commodity prices and costs are summarised by Wight and Laffan (2008). They outline that prices for most agricultural commodities (excluding cotton) rose sharply through 2007 and early 2008 and these increases have been driven by a combination of factors including: rising demand driven by economic prosperity in some developing countries; increased production of biofuels, reducing availability of food and feed; and a string of poor seasons of major agricultural suppliers affecting global supplies. Consequently international prices are expected to remain high at least for a few years while global stocks rebuild. Wight and Laffan (2008) also outline that Australian agriculture's ability to capitalise on these higher commodity prices has been limited by rising costs of production (fuel and fertilisers especially) and drought. These rising cost have been reflected in the cost of cotton production (Boyce, 2007). Fuel and fertiliser costs together have always been a significant direct overall cost to cotton production, together averaging 14% (from 1997 to 2006) but on an increasing trend, being 21% in 2006.

Utilising the number of bales/ha needed to cover total costs between 1997 and 2006 calculated by Boyce (2007) we were able plot and fit a response that showed that during this period the number of bales to meet costs was increasing at a rate of 0.2 bales/ha/yr (Figure 1). By utilising this estimate (which essentially signifies increase in costs per year) combined with current industry rate of yield increase (0.1 bales/ha/yr) we show that unless there were significant increases in the rate of yield increase, or reductions in the rate of increase of costs, the ability of cotton systems to make substantial returns will be limited not long after 2020 (Figure 1). The appeal to produce cotton would diminish considerably, especially if other commodity prices remain high.

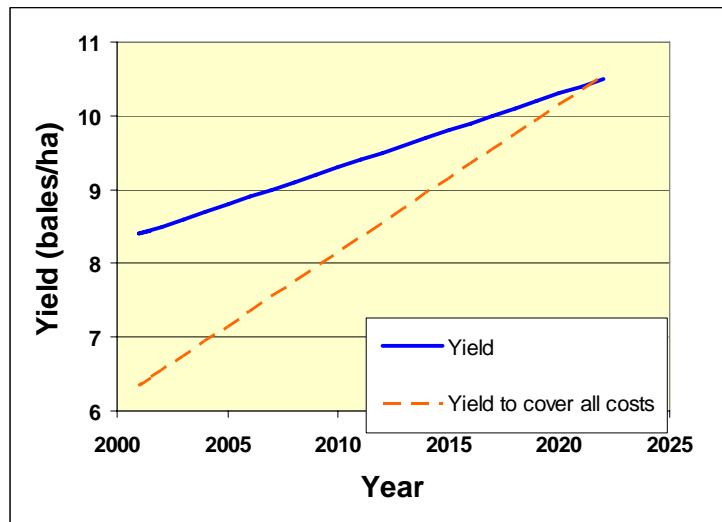


Figure 1: The rate of yield increase necessary to cover rising costs (from Boyce (2007)) compared with the industry rate of yield increase (from Constable et al (2001)) The intersection of lines is an estimate of when cotton production ceases to be profitable.

Cotton crop management options in a 'climate of change'

The management approaches we will discuss below are part of key broad strategies to respond to a climate of change, they encompass: means to improve cotton yields; lowering production costs and optimising efficiency of resource inputs; crop substitution; and improving the return for cotton

through better quality. There is no doubt there is a considerable role for research and extension, and many initiatives are already in place in helping the industry achieve these strategies. Some of these initiatives are presented in companion presentations given at this conference and will not be discussed in detail. Here we re-emphasise specific on-farm production strategies and practices that can be adopted to help build resilient cotton systems in a changing climate.

Although the rate of climate change is relatively slow, a small change in average temperature may have a relatively large impact. For example at 25/15°C (8 day degrees) it takes about 63 days from sowing to square; add 0.7 degrees to mean temperature and the days to square is five days quicker. Even so, the rate of climate change is still relatively small compared with the variability in our temperatures. For example we see that daily temperatures averaged for the month in cotton regions were up to 2 to 3°C higher than the average at times in the 2006/2007 season and were of similar magnitudes less in the 2007/2008 season (Figure 5). Therefore practices that are adopted on the farm to deal with climate variability and improve the sustainability offer opportunity to assist with climate change, a view supported by Howden *et al.* (2003). The wide geographic spread of the industry also means that management practices are different as growers have adapted their practices for various climates. This is also highlighted in Figure 2 where the average temperature between regions in the middle of summer (Jan) can be as different as much as 2°C (Hillston vs. Emerald).

Two key overall cropping strategies to consider employing to adapt to change include: firstly not rely on any one option (variety, frequent irrigation, sowing date strategies, etc). The best strategy will be to adopt a range of synergistic options that have an additive effect in reducing the impacts of climate change; secondly have options for flexibility to account for variability. It will not always be hot and dry and tactical crop management will need to take short term extremes into account (for example frequent irrigation to manage for hot dry conditions will cause waterlogging under mild and humid conditions). Specific cotton crop management tactics for dealing with issues relating to climate variability and change are summarised below:

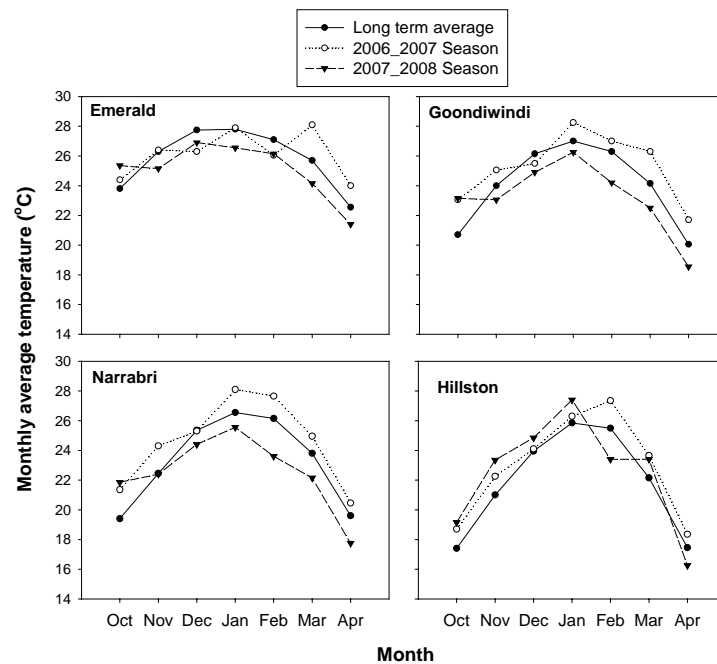


Figure 2: Daily temperatures averaged for the month in some cotton regions for the 2006/2007 and 2007/2008 cotton seasons compared with the long term average.

Tactic #1 - Variety choice

Variety choice is a strong component of realising both target yield and fibre quality levels on farm. A delicate balance needs to be resolved between yield, fibre quality, price and other important considerations such as disease resistance, and insect and herbicide resistance. To meet this need Australian cotton breeding programs are already aimed at developing cotton varieties well suited to the environmental and climatic conditions experienced throughout all the cotton production regions (hot and cool), and therefore give growers options for selecting varieties suitable to their conditions (Constable *et al.* 2001). In addition to these breeding efforts accounting for regional climatic diversity, there is also specific breeding programs in place for rain-fed cotton production. This means that there are already varieties that are better adapted to less than fully irrigated and stressed conditions.

There are also choices between varieties in terms of fibre quality. It may be that in future a smaller area of a higher value product would provide a greater return in situations of limited water. Choosing a variety with specific fibre properties can cover for some climate or management challenges. Examples include longer fibre cultivars reducing short fibre discounts in water stress environments, or low micronaire cultivars minimising high micronaire discounts as a result of hot environments during boll maturation.

As discussed previously, with continued research in the future we would see varieties that are better adapted to higher temperatures and water limited conditions. Breeding programs are already developing a portfolio of fibre quality varieties to provide a wider range of options for future market opportunities and environmental conditions.

Tactic #2 - Vary planting time

Changing planting time offers a 'systems solution' that can provide benefits both in terms of: maintaining yield; improving fibre quality; reducing the risk of adverse effects of high temperatures and low humidity (high evaporative demand); and reducing the incidence of seedling diseases early in the season.

Research by Bange *et al.* (2008) show that crops with higher fruit retention can maintain yield and improve fibre length and micronaire for delayed sowing dates in warmer seasons. In a changing climate with the introduction of new varieties there will need to be ongoing reassessment of planting time as a management option in the different cotton production regions.

We have initiated detailed studies of water use, growth, yield and water use efficiency by varying sowing date and cultivars with different growth habits with an aim to avoid periods of high temperatures and low humidity. This approach offers a potential management option in areas with longer growing seasons if the climate change scenario indicates less available water and lower humidity. A key to understanding how these interactions affect other efficiencies and factors means that they will need to be investigated carefully on cotton farms and these efforts will need to involve a range of research and extension specialists working with growers.

Overall higher temperatures may give more management options. Central regions need not be so much of a hurry to sow; shorter season regions can maybe sow earlier.

Tactic #3 – Optimise water use

Most cotton in Australia is fully or partially irrigated which serves to reduce climate variability associated with rainfall. However, recent drought conditions coupled with reductions in water allocation across all major cotton production regions has placed significant emphasis on managing water resources more efficiently which will assist in adaptation with climate change. Practices that cotton growers can adopt with an aim to improve the water use efficiency or utilise in water limited situations include:

- Implementation of systems that monitor and assess whole farm water use efficiency to identify parts of the system which are inefficient. Growers consistently adopt practices to improve water storages, and reduce transmission and application losses.
- Use of alternative irrigation systems such as lateral move or drip irrigation systems.
- Better schedule irrigations utilising technologies that monitor weather (automatic weather stations) and crop soil water use (capacitance probes, neutron moisture meters) allowing for differences in soil types, demands of the crop (crop stage), and climatic conditions (e.g. temperature and humidity).
- Improving soil management by adopting reduced tillage practices to minimise compaction which improves soil structure and increases the rooting zone.
- Adoption of management practices in limited water situations that:
 - Reduce the risk of crop failure by modifying the area of cotton grown to increase the MI/ha before the season begins. Determining the area to plant is a decision that has to consider the yield and thus the water needed (accounting for climatic risk and system irrigation efficiencies) to breakeven. Simulation technologies such as those in HydroLOGIC (which incorporates OZCOT (Hearn 1994)) that estimates yield with different water allocations and climatic impacts (including rainfall variability) can be used to assess cotton cropping areas. This concept is explained in more detail in an article by Hearn (1992).
 - Better utilise stored soil water collected from crop fallows and employ practices to capture and retain soil moisture. Strategies such as minimum tillage and stubble retention are becoming standard practice for moisture conservation. New technologies such as films (plastic, etc) deserve some research in how much soil moisture is saved and how much value is achieved. Use of rainfall to establish crops rather than pre-irrigation or watering-up are worth considering especially if Bollgard II offers some flexibility in sowing time.
 - Avoid excess nitrogen so that vegetative growth is discouraged. This also has the benefits of reducing nitrous oxide emissions (a greenhouse gas).
 - Sow as dryland cotton, utilising supplemental irrigation strategies or modified row configurations (eg. skip rows) to enhance crop access to soil moisture. These strategies are not necessarily the most water use efficient but offer significant risk mitigation in years where rainfall is very limited (Montgomery and O'Halloran 2008). Skip-row configurations can offer significant insurance against losses in both yield and quality in those regions and years where rainfall is highly variable and reduce input costs (e.g. Bollgard II licence fees) (Bange *et al.* 2005).
 - Consider dryland production in those years where prices for cotton are acceptable and there is a forecast for reasonable rainfall (Bange *et al.* 2005). If irrigation supplies are reduced, it stands to reason the irrigated crop area will reduce and dryland areas (cotton or other crops) will increase.
 - Avoid stress specifically during the flowering period.
 - Shorten the time to maturity (see manipulating crop maturity below).

Tactic #4 - Manipulate crop maturity

Crop maturity can be manipulated by choice of cultivar, insect management, nutrition, or late season irrigation management. Early crop maturity may avoid quality down grades and perhaps save on water or late season insect protection. However, this needs to be balanced against the fact that in the Australian environment reduces lint yield by 68 to 136 kg ha⁻¹ per week (Bange and Milroy 2004). Reducing the time to maturity and managing a crop to achieve targeted economic yield threshold is an option in those climates that have limited water availability. Roberts and Constable (2003) and Bange *et al.* (2006) have shown that after variety choice, the main factor driving differences in crop maturity is through fruit retention. Bollgard II with its ability to withstand early pest damage from *Helicoverpa* spp. maintaining higher fruit retention and avoiding

plant terminal damage (tipping out) can achieve similar yields to non-Bollgard II and use less water by maturing earlier (Richards *et al.* 2006).

Tactic #5 - Optimising crop nutrition

Monitoring soil fertility and crop nutrient uptake has become commonplace within the Australian cotton industry, as growers realise the importance of avoiding nutrient deficiency and the economics and environmental concerns of excess fertiliser use. Excess nitrogen fertiliser can also lower water use efficiency or yield by encouraging excessive vegetative growth and delaying maturity. The NutriLOGIC or NUTRIpak decision support systems provides information for determining the appropriate rates for N fertiliser use and the need other nutrients based on crop stage (utilising climate information) and performance.

While cotton yields have increased steadily over the past decade, so have N fertiliser application rates in most regions. Also, use of P and K fertilisers has increased. The cotton industry can develop best practices for use of fertilisers to minimise the risk of environmental damage from nutrient leaching and greenhouse gas emissions.

Crop nutrition research is reporting a wide range of nutrient use-efficiencies, indicating scope for improvement in some circumstances (Rochester *et al.* 2006). Legume rotation crops are grown so cotton growers can reduce N fertiliser use, improve P and K nutrition of following cotton, and improve overall soil quality (Rochester and Peoples 2005; Rochester 2004).

Nutrient removal escalates as yield increases. Hence, there is increased grower interest to maintain high soil fertility by applying equivalent amounts of macronutrients nitrogen (N), phosphorus (P) and potassium (K) to those removed in seed cotton (Rochester 2007). By applying these nutrients, growers can arrest soil fertility decline and delay or avoid the onset of nutrient deficiencies, even though there may be no lint yield response to P or K application. Growers are combining nutrient removal information with more traditional soil and tissue testing, so they can ensure soil fertility is maintained, crop nutrition improved and losses are minimised. Continued investigations into the timing of fertiliser applications to match crop needs as well as the varying the type of fertilisers applied to minimise losses will also be needed.

Tactic #6 – Employ responsive pest, weed and disease management

Seasonal climate variability (especially in relation to variations in temperature and rainfall) influences the distribution and abundance of insect pests. Temperature directly affects insect development, survival, number of generations, timing and the duration of diapause, while rainfall affects the growth of plant hosts leading to differences in distribution and abundance of insect pests. In the past the industry has experienced extremely wet and very dry years and the pest issues associated with these climates. Wet and warm years have seen abundant winter and summer weed hosts contributing to pest build ups. Hot dry years when irrigation water is available are favourable for cotton growth and most likely have less insect pest pressure - also contributing to improved yields.

One of the fundamental elements of an IPM approach adopted by the Australian industry is the regular and accurate monitoring of the numbers of pest and beneficial insects and the use of economic thresholds to guide decisions on pest management. In doing this growers are already responding accordingly and adapting to regional and seasonal variation.

Differences in weeds and diseases also occur across regions and seasons because of variation in rainfall and temperature. Most cotton growers use Roundup Ready® transgenic cotton that allows over the top application of glyphosate for weed control. With integrated weed management, this allows for rapid response to weed control. In the case of diseases, cold wet conditions are favour black root rot, fusarium wilt and verticillium wilt. When conditions are warm and moist, *Alternaria*

Leaf Spot can be an issue. The industry employs an integrated disease management approach, and breeding efforts are heavily focussed on developing germplasm with in-built disease resistance.

Opportunities and challenges

Overall in responding to some of the specific changes that may result from climate change affecting cotton, the industry is geographically dispersed which has meant that varieties and systems have already been developed for climatic effects such as increased periods of high temperatures and water stress. Bange *et al.* (2008) reviewed potential challenges that climate change presents to the viability of the cotton industry, many of these have already been discussed. Some key additional challenges include:

- A need to address the question of just how much climate change it would take to make it more appropriate to consider using land and water resources for purposes other than cotton or irrigated production.
- Regional specific impacts will need to be assessed thoroughly as the predominant cotton production regions span from southern NSW to north Queensland. This is necessary so that cotton growers can improve their capacity to assess likely impacts at their business level.
- Detailed integrative research that investigates a greater range of water stress and higher temperature scenarios (especially in Australian climatic conditions) to properly assess the impact that elevated CO₂ on cotton growth and insect pests, and the translation of these changes into yield and quality are needed.
- Investigate the likely impact of climate change on cotton production world wide.
- Distinguish between climate change and climate variability. Climate change is occurring against a background of naturally high climate variability in Australia and this variability is to increase with climate change. It is important to make the distinction between climate variability and climate change as there is the potential for maladaptation to occur if not identified.
- Introductions of transgenic technologies for pest management have no doubt delivered reduction in inputs and in future may offer opportunities to improve yields or help tolerate stress conditions. However, while these technologies continue to be costed on an equal footing to the costs that they help save or to the improvements they offer, there is little opportunity for raising crop profits overall. In addition while transgenic traits are being developed a key industry challenge will be to maintain research capability, particularly in crop physiology and agronomy, to ensure their benefits are realised in the field.
- The 'changing climate' is a multi-faceted and complex challenge to the cotton industry impacting the sustainability of farms, ecosystems and the wider community. To meet these challenges there will be a greater need to incorporate other efficiencies into the analysis of systems, for example diesel or energy/bale, carbon emissions/bale in addition to bale/ MI and N applied/bale. Importantly, an integrated systems-based approach to research and extension is needed to identify management for minimising economic, social and environmental harm, while maximising new opportunities.

Conclusion

We acknowledge up-front that most approaches we discuss here are decidedly production focussed, and therefore the list is by no means comprehensive. There are other significant efforts to combat 'a changing climate' from other perspectives and scales - policy and catchment scale efforts are examples. Ultimately it is a multi-faceted approach that combines all elements that provides the best insurance and options that best allow the industry to adapt.

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