

# COTTON AND CLIMATE CHANGE

## IMPACTS AND OPTIONS TO MITIGATE AND ADAPT



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Report focusing on the interface between cotton, climate change and trade – examines the impact of cotton production and consumption on climate change and the options and incentives for reducing emissions; also discusses the impact of climate change on cotton production and the options for adaptation; includes bibliography (pp. 29–32).

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## Acronyms

CH <sub>4</sub>	methane
CO <sub>2</sub>	carbon dioxide
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (A French research centre working with developing countries to tackle international agricultural and development issues)
GHG	greenhouse gas
GM	genetically modified
ICAC	International Cotton Advisory Committee
ICCCA	Impacts of Climate Change on Chinese Agriculture
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
ITC	International Trade Centre
N <sub>2</sub> O	nitrous oxide
NCAR	National Center for Atmospheric Research
PCF	product carbon footprint
PSAP	Private Sector Advisory Panel
SEEP	Social, Environmental and Economic Performance (ICAC panel)
UNFCCC	United Nations Framework Convention on Climate Change





## Executive summary

One of the great development challenges is to guarantee food security for the world's poor while also ensuring greater sustainability of food production and consumption. Cotton is an important crop for the world's poor. Exports of the crop from developing countries reached US\$ 2.8 billion in 2009–2010, providing incomes to millions of farmers. The cotton value chain both contributes to climate change and is at risk from its impacts. This paper examines the threats to cotton production posed by climate change and the options for mitigation and adaptation.

### Impact of cotton production on climate change

Cotton production is both a contributor to and a 'victim' of climate change. Agricultural production, processing, trade and consumption contribute up to 30% of the world's emissions when forest clearance is included in the calculation. Cotton production contributes to between 0.3% and 1% of total global GHG emissions.

Production, particularly in the tropical regions of the world, looks set to suffer under predicted rising temperatures, decreased soil moisture and more extreme weather events and flooding.

This report summarizes the impact of cotton production and consumption on climate change and the options and incentives for reducing emissions. It also examines the impact of climate change on cotton production and the options for adaptation.

The report is not a formal scientific review of these impacts but is rather intended to highlight the main issues and to stimulate discussion on the interface between cotton, climate change and trade.

### Mitigation of cotton value-chain emissions

Greenhouse gas emissions in the cotton value chain are derived mainly from the consumer use phase (30%–60%), and manufacture (20%–30%) Emissions from cotton production amount to only 5%–10% of the total emissions.

Energy efficiency measures, consumer education, technological innovation and carbon pricing are therefore the main tools to reduce emissions in the supply chain. Nevertheless, the agricultural sector is focusing on ways to reduce its emissions.

Approximately 90% of the technical potential to reduce emissions from agricultural production lies in carbon sequestration in the soil. Seventy percent of this potential lies in developing countries. Improved carbon sequestration is mainly achieved through changes to good agricultural practice. Further reductions in emissions can be achieved through increasing efficiency in the use inputs (water, fuels and agrochemicals).

Within the supply chain itself, retailers are increasingly requiring exporters to report on product carbon footprints (PCFs) providing information on their efforts to reduce carbon emissions. Opportunities for farmers in voluntary carbon markets, whereby markets pay for environmental services like carbon sequestration, are currently very limited. Demand for organic cotton is partly driven by its lower carbon footprint than cotton produced with agrochemicals.

### Impact of climate change on cotton production

Agriculture is extremely vulnerable to climate change. Higher temperatures will eventually reduce yields and increase the prevalence of pests and diseases. Changes in precipitation are likely to lead to crop failures and production declines. While there will be some gains depending on crops grown and regions, the overall impacts on agriculture are expected to be negative, thus threatening global food security. This assessment applies largely to the regional impacts of cotton production.

### Impacts of climate change on cotton production by country

Cotton is grown commercially in more than 70 different countries, mostly in the longitudinal band between 37°N and 32°S. Cotton is especially adapted to semi-arid and arid environments, where it is either grown rain-fed or through irrigation. About 53% of the world's cotton growth areas and 73% of all fibre growth areas benefit from full or supplementary irrigation.

Cotton has a certain resilience to high temperatures and drought due to its vertical tap root. The crop is, however, sensitive to water availability, particularly at the height of flowering and boll formation. Rising temperatures favour cotton plant development, unless day temperatures exceed 32° C. Limited increases in atmospheric CO<sub>2</sub> also favour the cotton plant's development.

Insects are expected to adapt to climate change through their capacity to adapt their body temperature to the temperature of the environment. The insects currently plaguing cotton are expected to continue to be live and possibly thrive in new environmental conditions.

Cotton supplies may benefit from higher temperatures as new production areas are established where cotton was not grown before. Yet, the overall impacts of climate change on cotton production and trade are very hard to predict, although certain observations can be made:

- *China* is by far the largest cotton producer and consumer. Production in the western Xinjiang region depends almost entirely on irrigation. Water availability is expected to decrease and pressure on water use to rise. Production along the Yangtze River will likely decrease following relatively low yields and competition from food crops. Production along the Yellow River is very important and may come to benefit from a longer growing season as temperatures rise. Rainfall in China is expected to increase, which is favourable for production, particularly in combination with limited rises in temperature and atmospheric CO<sub>2</sub>.
- *India* is the second largest producer of cotton worldwide. Production is spread out over multiple regions and agro-ecological zones. Temperatures are expected to increase all over India. Rainfall intensity during monsoons may become an increasing problem. Higher temperatures in already hot areas may hinder cotton development and fruit formation. Rain-fed cotton production may suffer from higher climate variability leading to periods of drought or flooding. Irrigated cotton, particularly in northern India, may suffer from lower water availability due to the upstream reduction of snow and ice from Himalayan and Tibetan Plateau glaciers and snowfields.
- *The United States of America* is the third largest producer country and the largest cotton exporter in the world. Cotton yields are expected to increase with limited increases in temperature and atmospheric CO<sub>2</sub>. However, the number of very hot days is expected to increase. Climate change impacts on rainfall are regionally diverse. The mostly rain-fed cotton areas in the south-east and mid-south may see an increase in rainfall, but also an increase in extreme weather events. Production in the south-west and the west relies mostly on irrigation. Here, water availability is likely to become an ever bigger problem due to aggravating groundwater depletion and to reduced and more irregular meltwater in summer from the Rocky Mountains.
- *Pakistan* is likely to be the country that will suffer most from climate change as far as agriculture and cotton production are concerned. In the country, agriculture is mostly dependent on irrigation with water from the Indus River, which will carry less water as the Himalayan and Tibetan glaciers and snowfields diminish in size. The Indus River is very important to agriculture in Pakistan. Here, cotton production already takes place in sub-optimal conditions with respect to high temperatures. Further increases in temperature during the growing season will depress yield.
- *Uzbekistan* may benefit from limited temperature rises, provided soil salinization can be prevented. Higher soil temperatures following climate change may favour production through an earlier start and a later ending of the cotton growing season. Water availability is a crucial constraint as all Uzbek cotton is irrigated. Cross-boundary water distribution is the issue of concern. Finally, large-scale monocropping of irrigated cotton has led to severe soil exhaustion and salinization. Climate change might intensify the salinization process with crop yield reduction as a result.

- *Brazil's* cotton sector has grown rapidly over the last decade following the cultivation of new lands in the *cerrado*, a vast tropical savannah particularly in Mato Grosso. Projections are that temperatures will rise with climate change. The impacts on rainfall are unclear, however, because climate models are not yet sufficiently sophisticated to paint a clear picture. Predictions for Central and tropical South America range from a reduction of 20% to 40% to an increase of 5% to 10% for 2080. Future development of cotton in Brazil will generally depend in particular on the rate of deforestation in the '*cerrado*', the future of competing soy production, and the long-term soil fertility of newly cultivated lands.
- Cotton is the economic driver of the rural economies in many French-speaking countries in *West and Central Africa*. Unfavourable exchange rates policies currently discourage exports, and problems in sector organization and restructuring hamper cotton production growth. Temperatures are expected to rise due to climate change. The impact on rainfall patterns, however, is unclear for this part of Africa.
- Cotton production in *Turkey* is on the decline due to relatively high costs. Cotton consumption relies heavily on imports from the United States. All cotton in Turkey is irrigated. Half of the cotton is grown close to the Mediterranean, in the Aegean region and around Antalya. Temperature rises in Turkey will be more severe in the Aegean region. Precipitation will decrease along the Aegean and Mediterranean coasts. However, most cotton is now grown in south-eastern Anatolia, where water availability for irrigation is expanding due to the construction of new dams. Here, temperatures and precipitation are expected to increase, yet meltwater from snow and ice will decline.
- *Australia* cotton production is in the hands of a relatively small number of farmers (about 1,200). Production is large-scale and capital-intensive. Eighty percent of production is irrigated. Water availability is a serious problem in New South Wales and Queensland. River systems are currently over-exploited. Drought in recent years has further aggravated the water problem and severely limited production. Climate change is expected to increase temperatures such that the growing season may start earlier and end later, while the number of 'cold shock' events will decline, and new production areas may be developed in the North, provided water is available. Heat stress, however, is also likely to increase and may depress cotton development and fruit formation.

Overall, the negative impacts of climate change on cotton production relate to the reduced availability of water for irrigation, in particular in Xinjiang (China), Pakistan, Australia and the western United States. Heat stress risks creating depressed yields in Pakistan in particular, while in other countries limited increases in temperatures could favour cotton plant growth and lengthen the cotton growing season. Limited increases in atmospheric CO<sub>2</sub> could also favour cotton yields. The impacts of climate change on rainfall will likely be positive in the Yellow River area (China), in India, the south-eastern United States and south-eastern Anatolia (Turkey). Impacts on rainfall in Brazil and West and Central Africa are unclear.

### **Options to adapt to climate change**

Climate change is changing the economics of production, forcing rural cotton farming communities to consider multiple livelihood strategies including planting different crops and seeking alternative non-farm income streams. This entails complex and resource intensive responses from government and international aid flows.

With respect to the production level, cotton has limited capacity to respond to heat stress, through 'compensatory growth'. Its vertical tap root also provides resilience against spells of drought, but also makes it vulnerable to water-logging. Cotton relies heavily on irrigation and thus groundwater or freshwater availability.

A number of adaptation strategies include:

- Maximizing plant diversity;
- Flexibility of sowing dates;
- Maintaining soil cover;
- Minimizing soil tillage;
- Breeding more resistant cotton varieties.

## Introduction

Agriculture is both a contributor to and a “victim” of climate change.

Up to 40% of global greenhouse gas emissions are attributed to agriculture when land clearance is included in the calculation.

The Intergovernmental Panel on Climate Change (IPCC) predicts that climate change will result in a substantial loss in agricultural productivity in developing countries. Climate change influences agricultural production through increased temperatures, altered precipitation, changes in atmospheric CO<sub>2</sub>, extreme events, and sea level rises. The World Bank and other expert groups predict that this impact on agriculture will result in greater poverty in rural areas particularly in Africa and South Asia.

Cotton is an important crop for the world’s rural poor. Exports of the crop from developing countries reached US\$ 2.8 billion in 2009–2010, providing incomes to millions of farmers. It is therefore important to understand the scope for cotton farmers to adapt to the changing climate and how cotton production can have a reduced emissions profile. This report outlines the main impacts that climate change will have on cotton production and summarizes the scope for both mitigation and adaptation.

The report is not a formal scientific review, but is intended to highlight the main issues and to stimulate discussion on the interface between cotton, climate change and trade.

## 1. The impact of cotton production on climate change

### 1.1. Agriculture value chain as a source of greenhouse gas emissions

Agriculture accounts for about 14% of total greenhouse gas (GHG) emissions, contributing to 52% of the world's methane (CH<sub>4</sub>) emissions and 84% of the world's nitrous oxide (N<sub>2</sub>O) emissions.

These are the most relevant GHGs in the context of agriculture: N<sub>2</sub>O traps 310 times more heat than CO<sub>2</sub> (carbon dioxide), and CH<sub>4</sub> traps 21 times more heat than CO<sub>2</sub>. Nitrous oxide is emitted mainly from fertilizer and manure applications to soil, while methane is emitted mainly in livestock production (fermentation in digestion), rice production and manure handling.

This overall figure rises to 30%–40% if deforestation through land clearance for agriculture and trade in agricultural products are included (IPCC, 2007). Agricultural emissions grew by 17% during the period 1990–2005. According to Smith *et al.* (2007), absolute emissions were between 5.1 and 6.1 gigatons (Gt) of CO<sub>2</sub> equivalents (CO<sub>2</sub>e) per year in 2005.

Agricultural emissions are predicted to rise by almost 40% by 2030 (Smith *et al.*, 2007), due to increased demand for food from a growing population and to changing diets favouring meat (i.e. beef, veal and lamb).

In principle, land (and water) may act as a 'sink' by absorbing CO<sub>2</sub> from the atmosphere. There is a small net flux of CO<sub>2</sub> between agricultural land and the atmosphere, released from microbial decay and burning of plant litter and organic matter in the soil.

The emissions from fuel and electricity used in agriculture are accounted for in other sectors, including transport and building (Smith *et al.*, 2007). Agricultural emissions would rise further if deforestation in developing countries were added. Agriculture is a leading cause of deforestation, but the Intergovernmental Panel on Climate Change (IPCC) does not attribute related emissions to the agricultural sector.

The agricultural sector also has the potential to mitigate climate change mainly by increasing the carbon sequestration rate (i.e. the rate at which carbon is stored in the soil), and to a lesser degree through the reduction of some GHG emissions, principally N<sub>2</sub>O and CH<sub>4</sub> (Smith *et al.*, 2007). Savings can be made along the supply chain through various means, such as reducing energy in irrigation, storing and cooling, low-energy transport, more energy-efficient packaging, reduction of losses in the supply chain and improved agricultural management.

### 1.2. The cotton value chain as a source of GHG emissions

The cotton sector value chain beyond the cultivation of cotton includes all associated activities such as the transport of seeds, inputs and crop, ginning of the seed cotton, baling of cotton fibre and cottonseed, pressing of the cottonseed for oil, and transport of cotton fibre, cottonseed oil and cottonseed cake to the buyer.

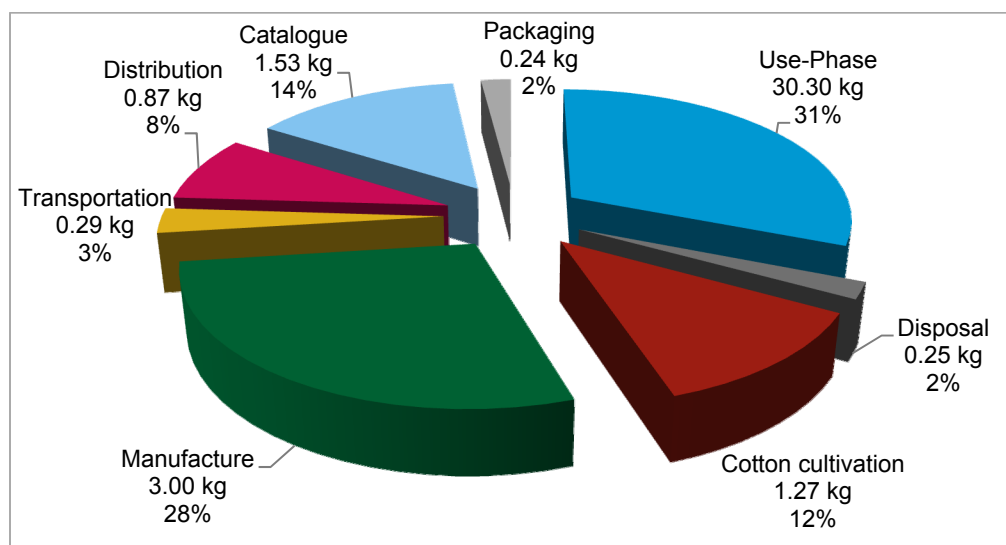
International fuel-based transport is important because at least one-third of global cotton fibre is exported from its country of origin.

GHG emissions from cotton production vary greatly across countries.

Countries with high incomes and high yields tend to rely upon intensive production systems that depend heavily on carbon-based fuels - for irrigation, field operations, fertilizers and pesticides. In low-income countries, in turn, labour and cattle are generally used for field operations instead of carbon-based fuel-driven equipment, fertilizers and pesticides, thus limiting GHG emissions per hectare and per product.

The carbon footprint of a cotton apparel product may be established through life-cycle analysis (LCA). Three recent studies have been carried out that review GHG emissions in the cotton value chain.

As shown in figure 1, the manufacture and consumer use phase each account for almost one third of total emissions of a t-shirt.

**Figure 1. CO<sub>2</sub>e emissions of a long-shirt, white, 100% cotton, size 40-42**

**Source:** Sustain (2010), *A step in the right direction*, EcoTextilesNews, October 2009

The transport of the cotton to US production fields to Bangladesh and finally to consumer markets in Germany, accounted for only 290 grams of CO<sub>2</sub>e (3% of total emissions). This figure rose to 4 kg CO<sub>2</sub>e if the t-shirt was air freighted to Germany, for example in the case of re-orders. The study found that the distribution of the garment within Germany results in more emissions than the inbound logistic chain from around the globe. A total of 870 grams of CO<sub>2</sub>e are linked to domestic transport, delivery, warehousing and returns.

Production of the garment accounted for 3 kg CO<sub>2</sub>e. Most of these emissions came from natural gas based generators at the production units in Bangladesh. Emissions are split between four processes, spinning, knitting, dyeing and ready garment (RMG). The dyeing process is sensitive to the fuel type used – there is a trend to switch from natural gas to coal which is cheaper but more carbon intensive.

However, according to Sustain (2010), utilization of capacity has an even bigger effect on carbon footprint. At months of low textile production and thus utilization, the product-related CO<sub>2</sub>e emissions double, because emissions from fixed energy consumers such as light, office, or preheating of the boiler, which both are independent from fluctuation of production, are allocated to less output. The use phase, assuming the t-shirt is washed 55 times, accounts for 31% of emissions. The study finds that if a household dries each laundry automatically and irons the shirt each time, the carbon footprint at the use phase would triple from 3.3 kg CO<sub>2</sub>e to 10.7 kg CO<sub>2</sub> kg. The carbon footprint of the shirt is also affected by the following:

- The washing temperature;
- The load level of the washing machine and the dryer;
- The efficiency level of the devices;
- A washing machine with an energy efficiency level of a++ reduces the carbon emissions by one third compared to a standard washing machine. A washing temperature of 40° C instead of 60° C reduces the carbon footprint by 45%. Filling the machine and dryer completely instead of half load helps decrease the carbon footprint too.

A study by Levi Strauss and Co. (2008) attributes a higher proportion of GHG emissions (for a pair of Levi's 501 jeans) to the consumer use phase (58%). The rest of the emissions is due to the following:

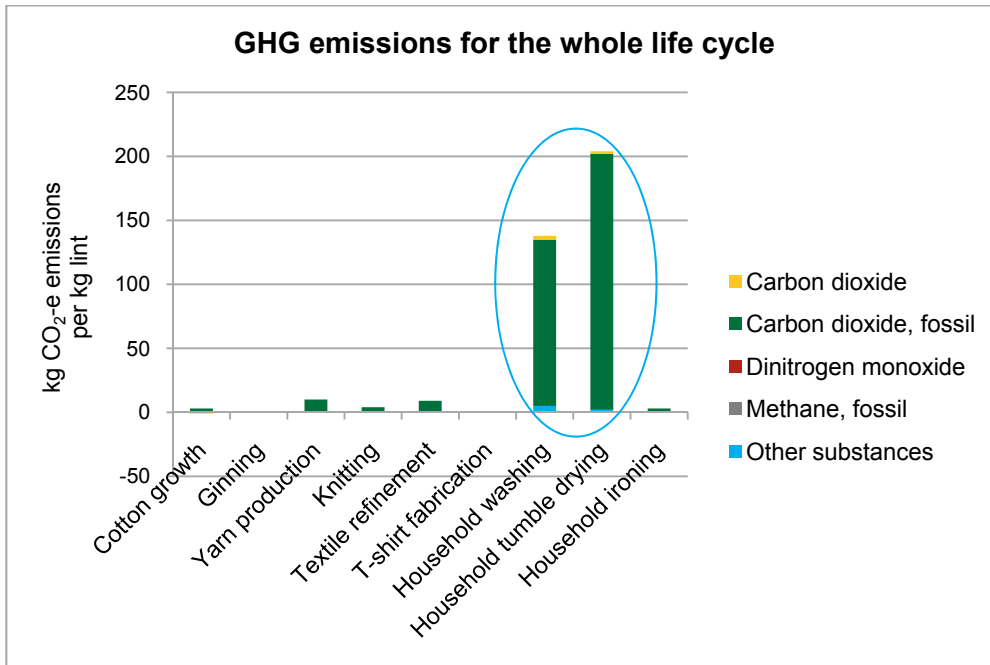
- 21% due to fabric production;
- 9% due to garment manufacturing (cut/sew/finish);
- 6% due to logistics/retail; and
- 1% due to end of life.



The share of cotton production was only 5% (Levi Strauss & Co., 2008).

A study, carried out by Grace (2009) attributes a much higher figure to the consumer use phase, with 98% of emissions resulting from washing, drying and ironing (see figure 2).

**Figure 2. Greenhouse gas emissions for the life cycle of a t-shirt**



**Source:** Grace (2009). *The impacts of carbon trading on the cotton industry.*

Therefore, support and advice to processing companies in order to rationalize and reduce their energy and input use will be more relevant to mitigating climate change than adjustments in cotton growth.

The carbon footprint of cotton growth as such is not easy to establish because growing conditions, cultivation practices and production efficiency differ widely per country or region. Methodologies for measurement and attribution of CO<sub>2</sub> equivalent emissions also differ and further complicate the generation and the interpretation of carbon footprint data.<sup>1</sup>

The International Cotton Advisory Committee (ICAC) Panel on Social, Environmental and Economic Performance (SEEP, 2009) estimates GHG emissions in cotton production to range from 0.15 to 4 tons CO<sub>2</sub>e per hectare. Table 1 shows the emissions for cotton produce with low inputs and high inputs respectively.

<sup>1</sup> In the t-shirt example (figure 1), cotton fibre production contributed 6 kg of CO<sub>2</sub>e emissions. The Levi's LCA, however, only relates 1.7 kg CO<sub>2</sub> eq. emissions to cotton production for a much heavier pair 501 jeans.

**Table 1. Individual factors in cotton production that contribute to GHG emissions**

Operation of factory	Low input		Comment for low input production	High input		Comment for high input production
	Kg CO <sub>2</sub> e/ha	%		Kg CO <sub>2</sub> e/ha	%	
Fertilizer and pesticide production	0	0%	If organic or unfertilized	1,263	31%	Based on application rates from ICAC (2008)
Tillage and planting (fuel for machines)	0	0%	Animal traction, unequipped production	119	3%	Few data sources; examples from the United States
Applications (fertilizers, pesticides)	0	0%	Organic production or unequipped	103	3%	Few data sources; examples from the United States
Irrigation pumps	0	0%	Rain-fed	642	16%	Few data sources; examples from the United States
Harvest (without ginning and transport)	0	0%	Hand-picked	89	2%	Few data sources; examples from the United States
Nitrous oxide emissions	150	0%	Rain-fed; low N rate	1,800	45%	Calculated from ICAC (2008_ and Scheer <i>et al.</i>
Total emissions	150	100%		4,016	100%	

Source: SEEP (2009).

N<sub>2</sub>O emissions contribute the most to cotton's GHG emissions, followed by fertilizer and pesticide production, and energy for irrigation. Irrigated conditions produce more greenhouse gas emissions than dryland farming - particularly N<sub>2</sub>O emissions. This figure is similar to findings by Systain (2010) who *Systain point out that during cotton cultivation, half of the GHG emissions are associated with nitrous oxide emitted when using mineral fertilizer; the other half results from energy consumption, in particular for soil cultivation and ginning.*

Table 1 clearly indicates that GHG emissions in cotton production, as in agriculture in general, are highly dependent upon human choices as to farm, field and crop management, in this case 'organic' versus 'conventional'.

According to Cotton Incorporated (2009), however, cotton production could even be considered a 'carbon sink' (see figure 3). The amount of carbon stored in the fibre and soil<sup>2</sup> exceeds the total GHG emissions that occur while growing and ginning the crop.<sup>3</sup>

In the cotton production process, more CO<sub>2</sub>e is sequestered in the fibre and soil than CO<sub>2</sub>e GHG's emitted into the atmosphere.

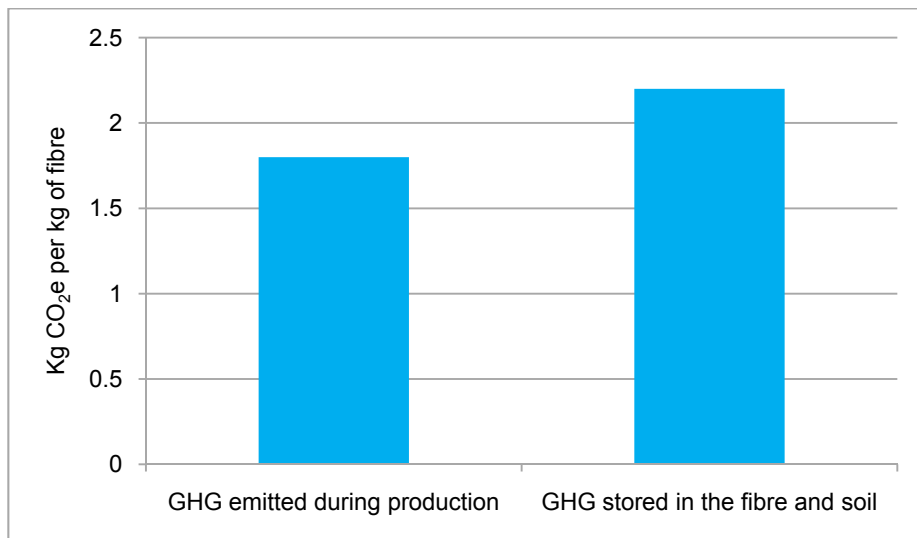
It is clear from these tentative data that the establishment of the carbon footprint of cotton fibre from a certain country, region or production system is difficult to do in terms of definition, measurement and attribution.

Further research is required to generate reliable, coherent and comprehensive data that allow a global comparative approach.

<sup>2</sup> For example, the 42% carbon content of the cotton fibre plus the carbon stored in the soil (Cotton Incorporated, 2009).

<sup>3</sup> If credit were given for the amount of biodiesel that could be produced from the cottonseed oil and if the carbon emissions from petroleum diesel were replaced with biodiesel (~0.6 kg CO<sub>2</sub>e per kg of fibre), then cotton production from the field to the bale would have higher stored GHGs than portrayed (Cotton Incorporated, 2009).

**Figure 3. Greenhouse gas emissions from United States cotton production, and GHG reductions due to carbon stored in the fibre and soil**



**Source:** Cotton Incorporated (2009), Summary of life-cycle inventory data for cotton.

## 2. Mitigation of cotton value chain emissions

Technical options to reduce processing and consumer emissions

The life cycle and carbon footprint analyses discussed in Section 1.2 have highlighted the hotspots of GHG emissions in the cotton value chain. By increasing the transparency of the value chain with respect to emissions, it is possible to identify actions to reduce emissions. Key actions in this respect include the following:

- For governments to introduce carbon pricing policies to make the cost of energy fully incorporate the environmental damage of its use and stimulate the development and adoption of energy efficient and renewable energy technologies.
- To educate the consumer on the climate and financial benefits of reducing washing temperature, using full load, using a washing line to dry clothes and moving to a more energy efficient washer and dryer.
- Support and advice to processing companies on adoption of more energy efficient technologies.
- Support and advice to farmer on more efficient use of nitrogen fertilizer and/or the adoption of low input/organic farming practices.
- Given the high share of emissions from consumer use and manufacturing phase, actions in these areas of the supply chain should be given priority.

### 2.1. Technical options to reduce production emissions

According to the Food and Agriculture Organization of the United Nations (FAO), there is considerable technical potential for reduction of emissions from agriculture. Eighty-nine percent of the potential lies in soil carbon sequestration. This can be achieved through changes to good agricultural practice.

Mitigation refers to options for limiting climate change by, for example, reducing greenhouse gas (GHG) emissions such as carbon dioxide, methane and nitrous oxide, or removing some of the heat-trapping

gases from the atmosphere. Lower emissions will lessen the magnitude of climate change, its impacts and the rate at which they appear.<sup>4</sup> (Karl *et al.*, 2009).

At the farm level, there are three main ways to reduce the GHG emissions from agriculture:

- Improve cropping and grazing land management to increase carbon storage;
- Improve rice cultivation techniques and livestock to reduce methane emissions;
- Improve nitrogen fertilizer application techniques to reduce nitrous oxide emissions (IPCC). Agricultural intensification may contribute to reducing the speed of conversion of natural forests into grazing and farmland.

Cotton covers about 2.5% of the world's arable lands (Cotton Incorporated, 2009), and would thus be related to a rough estimate of 0.1% to 0.3% of global GHG emissions. It is therefore not a principal source of GHG emissions. Yet cotton can contribute to mitigating climate change, in particular *by increasing efficiency and reducing emissions from the more efficient use of carbon-based fuels and inputs made therewith (irrigation water, fertilizers, pesticides, etc and adoption of low input and organic practices.*

On a field level, the following mitigation measures can be identified in order to increase cotton crop efficiency in terms of yield per unit of GHG emitted:

- Minimize soil tillage on cotton cropland in order to prevent soil to air emissions;
- Minimize carbon-based fuel mechanization and transport;
- Minimize the use of synthetic fertilizers in general and nitrogen fertilizers in particular, because these are an important source of N<sub>2</sub>O emissions;
- Minimize the use of irrigation water, because of its carbon-based fuel footprint, and reduce competition for freshwater for man and nature;
- Minimize the use of industrial preparations such as pesticides, herbicides and defoliant because of their carbon fuel footprint;
- Minimize the burning of cotton crop residues where still applied, and recycle these for soil fertility management when not used as a fuel for cooking and heating;
- Adopt where feasible organic farming practices.

## **2.2. Market incentives to reduce cotton value chain emissions**

Raising the cost of energy through carbon pricing policies will reduce emissions from the cotton value chain and provide incentives for consumers and processors to be more efficient in their use of energy and thus lower the carbon footprint of the cotton item over its lifecycle. As highlighted above, the majority of emissions derive from energy use by consumers, transport and processing.

On the production level, there are several incentives for cotton producers and processors to reduce emissions. These include requirements by retailers to meet product carbon footprint standards and the voluntary carbon markets.

### **2.2.1. Product carbon footprint standards**

In response to concerns over climate change, retailers and manufacturers are increasingly requesting that suppliers provide them with information on GHG emissions in the supply chain, i.e. in the production, processing, transport, sale and use of the product. The result of these calculations is referred to as the product's product carbon footprint (PCF).

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<sup>4</sup> However, some amount of climate change and resulting impacts will continue due to the effects of gases that have already been released. Firstly, some gases are very long-lived and the levels of atmospheric heat-trapping gases will remain elevated for hundreds of years or more. Secondly, the Earth's oceans have absorbed much of the heat added to the system and will retain it for many decades (Karl *et al.*, 2009).

This information is used internally to help companies identify carbon 'hot spots' in the supply chain and to communicate the carbon footprint of products to consumers.

PCFs are distinct from GHG assessments performed at the level of projects, corporations, supply chains, municipalities, nations or individuals. Product carbon footprinting is currently dominated by private standards and by certification schemes operated by small for-profit and not-for-profit consultancy companies, and in a few cases by large retailers and manufacturers. They display large differences in scale and product coverage, type of claim made and (where applicable) certification offered, GHG assessment methods, communication approaches, and levels and means of verification and transparency (Bolwig and Gibbon 2009).

Consumers show some interest in PCF information and seem to indicate that they would probably prefer carbon-labelled products and firms, all other things being equal. It is also likely that a minority would be willing to pay a price premium for products with significantly lower footprints. However, consumers are also sceptical about the credibility of climate-friendly claims made by retailers and manufacturers and show a preference for products with third-party verification (Bolwig and Gibbon 2009).

### **2.2.2. Carbon market opportunities for cotton**

Farmers require strong economic incentives to move to more climate-friendly farming practices. However, these incentives for emissions reductions in agriculture are weak or missing. One of the main reasons for this has been the lack of a strong framework for monitoring, reporting and verification (MRV) of emissions reductions (Kasterine and Vanzetti, 2010). Without MRV, it is difficult for regulators to set up a credible carbon market for agriculture.

In the European Union, a mandatory carbon market called the European Union Emissions Trading Scheme (EU-ETS) is in place for large industrial energy users. However, agriculture is not currently eligible under this scheme.

The Clean Development Mechanism (CDM) allows developed countries the option of buying carbon 'credits' (certified emission reductions) from developing countries instead of making their own emissions reductions. This system does include agriculture, but projects are limited thus far and oriented towards the capture of methane.

It is unlikely, though, that agriculture will soon be included into mandatory carbon trading mechanisms. Voluntary market-based mechanisms may emerge that take agriculture, certain production systems and/or crops into account. In the United States of America, the cotton sector is looking at how the development of GHG mitigation projects, such as no till and cover cropping, could generate offset credits with the potential to create a net gain for cotton farmers (Agricultural Working Group, 2010).

'Bottom up' initiatives are being used to find ways to reward farmers who reduce their carbon footprint:

- 40% of Chicago Climate Exchange projects fund farming schemes (methane and soil carbon offsets), particularly in grass tillage and no till agriculture.
- Genetically modified (GM) soy producers claim recognition of the carbon they sequester through conservation agriculture; which in their case consists of no tillage following weed control with herbicides and herbicide-tolerant GM varieties.
- The organic agriculture movement aims for recognition of carbon sequestration through low external input agriculture; i.e. without the use of any synthetic fertilizers, herbicides or pesticides that use carbon-based fuels.<sup>5</sup> The organic sector can boast an elaborate certification system that might facilitate inclusion in carbon trading.

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<sup>5</sup> Soth (2009), for example, calculated that West African organic cotton farmers would reduce their cotton carbon footprint with 1 to 3.2 tons CO<sub>2</sub>e per hectare. If no transaction and certification costs are considered, this would translate at current carbon market price (15 euros/ton) into an extra income per hectare of 4% to 14%.

### 3. Impact of climate change on cotton production

Agriculture is extremely vulnerable to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. Changes in precipitation patterns increase the likelihood of short-run crop failures and long-run production declines. Although there will be gains in some crops in some regions of the world, the overall impacts of climate change on agriculture are expected to be negative, threatening global food security (IFPRI, 2009).

Climate change will affect cotton production as a result of higher concentrations of CO<sub>2</sub> and increases in temperature. Both these changes will set off a series of other actions that will have direct and indirect impacts on cotton production, for example through water availability and the incidence of cotton pests and diseases. Following is an inventory of how serious these actions and impacts may be for cotton as a crop.

#### 3.1. The agronomy of cotton

Cotton is a perennial plant by nature, but has long been grown as an annual crop. Varieties grown commercially today belong to four species of *Gossypium*. *Gossypium hirsutum*, or Upland cotton, produces the bulk of cotton worldwide. *G. barbadense* comes in second. It is associated with high staple length. Cotton is grown mainly in the longitudinal band between 37°N and 32°S; yet cultivation has been extended to 45°N in China (Chaudhry & Guitchounts, 2003).

Cotton needs favourable growing conditions with respect to temperature, sunshine and soil moisture. A marked dry season is also essential for the bolls to open properly and for harvesting.

The cotton plant, once established, rapidly develops a vertical tap root that provides resilience against drought during the growing season. The vertical tap root gives the plant access to lower soil layers and nutrients than cereal crops such as maize, sorghum or millet can access. This makes cotton a particularly useful plant in crop rotations. However, the vertical tap root makes cotton sensitive to stress from water-logging after floods or heavy rains.

Cotton requires a total of 105 to 125 days of sufficient soil moisture to grow. In tropical regions, 2 to 4 mm of water are needed daily at the beginning and the end of the growing period, while at the height of flowering 5 to 7 mm are required daily according to climatic zone. Thus 500 to 700 mm of water are sufficient for the crop to develop fully. Rain-fed cotton, however, can in practice only be grown in regions where average annual rainfall is 700 mm or more, since inter-annual and intra-annual rainfall variability, and the amount of resulting run-off, have to be taken into account (Sément, 1988).

Cotton is resilient to sub-optimal growing conditions. Cotton responds to loss of vegetation or fruiting parts (buds, flowers, bolls) through so-called 'compensatory growth'. If a flower bud, flower or boll is shed, the cotton plant quickly tries to compensate that loss through the production of more flower buds or even retaining buds that would otherwise have been shed (Chaudhry & Guitchounts, 2003).

#### 3.2. Impact of specific climatic changes

Cotton plants respond to changing environments. The response depends on the stage of development the plant is in. Key stages in cotton plant development are: a) conditions at the time of planting; b) plant development in early season; c) flowering, d) boll formation and e) conditions towards the end of the season.<sup>6</sup>

##### 3.2.1. Temperature

Climate change is leading to a rise in average temperatures, changes in the water cycle and precipitation patterns, and to an increase of some extreme weather events.

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<sup>6</sup> This paragraph is largely based on ICAC (2007), Global warming and cotton production – Part 1.

Depending on the region, higher temperatures may for example lead to a longer growing season and more rainfall or to lower rainfall and a shorter growing season. Extreme weather events may affect the plants any time of the season, and are by definition hard to predict.

Higher temperatures could affect different regions in different ways. Low soil temperatures at planting time hamper timely planting of cotton in many countries. Rising temperatures will benefit those countries and regions as they will be able to plant cotton much earlier than they do now.

Conversely, higher temperatures in cotton producing areas and regions already suffering from high temperatures could have a negative impact as a result of increased shedding of flower buds. The rise in temperature could have a positive effect on yields, though, in those areas and regions where the effective fruiting period is squeezed between two phases of lower temperatures: one early in the season to start effective flowering and boll formation, and one at maturity that results in termination of fruit formation.

Boll retention is more sensitive to high temperatures than any other condition, except for nutrient deficiency, which is relatively easy to correct. While it is not possible to avoid the effects of high temperatures, this condition can produce bud shedding, which is the most common reason for loss of fruit forms (Reddy *et al.*, 1999). Reddy *et al.* (1999) also observed that temperature regimes alter boll development: boll size and the maturation period both decreased as the temperature increased.

**Table 2. Monthly average maximum temperature (in ° C) for a six-month cotton season**

Country	Months						Mean
	1	2	3	4	5	6	
Turkey (South-East Anatolia)	20	27	33	38	38	33	31.5
China (Henan)	21	28	32	31	30	27	28.2
United States of America	24	28	32	34	33	30	30.2
Australia	27	30	33	34	33	31	31.3
Argentina (Chaco and Formosa)	30	33	34	34	32	32	32.5
India (North)	36	41	40	36	36	36	37.5
Pakistan (Punjab)	40	40	37	36	35	33	36.8
Sudan (Gezira)	41	42	42	42	42		41.8

Source: ICAC (2009), Global warming and cotton production – Part 2.

Reddy *et al.* (2000; cited in ICAC, 2007) determined that boll growth decreases significantly and fruit is shed 3–5 days after blossom in temperatures over 32° C. Thus, the upper limit of cotton for blossom and fruit period is 32° C. However, referring to the monthly average maximum temperature, ICAC (2009) stresses that cotton production is currently viable also in hotter environments (see figure 10).

Table 2 shows that cotton is successfully grown at 28.2° C in China and 37.6° C in India, 36.8° C in Pakistan and 41.8° C in Sudan. It has not been established that 41.8° C is the upper limit, but experience in many countries, particularly in India, Pakistan and the Syrian Arab Republic, has shown that heat stress is a big constraint to increasing yields. These countries successfully developed heat tolerant varieties during the 1970s and 1980s.

The countries listed in table 2 cover almost three-quarters of the world cotton area, and many of them will be able to produce cotton at slightly higher temperatures than current averages. If global warming continues, the first five countries could experience a positive impact on yields as a result of a rise in temperatures of only a few degrees Celsius. Conversely, regions that are already producing cotton at close to 40° C would seem to be at a disadvantage. They already have longer growing seasons and any rise in temperature could induce sterility and inhibit boll formation. Breeding in these countries will have to focus on heat tolerance (ICAC, 2009).

Rising temperatures will not only have a complex effect on plant growth and yield, depending on the site, but also on fibre characteristics. Literature reveals that increased temperatures could result in higher micronaire values (the size of an individual cotton fibre taken in cross-section), stronger fibre and more

mature fibres. While higher micronaire values are not a desirable characteristic when they are already close to the upper limit, they could have a desirable effect in areas characterized by low-micronaire and low-maturity cotton (ICAC, 2007).

### 3.2.2. CO<sub>2</sub> level

Higher CO<sub>2</sub> levels in the immediate surroundings of the cotton plant will increase photosynthetic activity. Cotton will grow more vigorously as the amount of CO<sub>2</sub> in the air increases.<sup>7</sup> Leaves will likely be larger, thereby giving plants a greater photosynthetic surface area, which subsequently facilitates growth.

With more atmospheric CO<sub>2</sub>, greater numbers of branches and fruiting sites will likely develop, and this, in turn, should ultimately provide for higher lint yields (ICAC, 2007). However, increased photosynthesis will first foster vegetative growth. Vegetative growth may translate into an increase in fibre yield but reproductive growth is not automatic. Also, the impact of atmospheric CO<sub>2</sub> on growth is conditioned by temperature. According to Reddy *et al.* (1998), at temperatures greater than 30° C most of the fruit was aborted regardless of CO<sub>2</sub> concentration (ICAC, 2007).

Higher levels of photosynthesis expressed in the form of greater growth may lead to an increased demand for inputs, including water and soil nutrients, particularly if the balance is inclined towards vegetative growth. Especially in marginal production areas where water is not available in sufficient quantities, the result could then be quite negative (ICAC, 2007).

Another impact of higher atmospheric CO<sub>2</sub> is that weeds will be growing more vigorously as well. When cotton is in the seedling stage, competition with weeds is critical. In spite of the fact that cotton planting and development will start earlier as temperatures rise, the same development will be observed in weeds. The critical period in the development of cotton and weeds will coincide. Unlike cotton, which is a C3 plant (a classification describing how it fixes carbon; in the right conditions, these plants let in more carbon dioxide, but carbon losses through photorespiration are high), most weeds are C4 plants and will show less reaction to CO<sub>2</sub> (C4 plants let in even more carbon dioxide than C3 plants, and this reduces, and sometimes eliminates, carbon losses by photorespiration. That is why cotton can compete with weeds more effectively under conditions where there is enough water and nutrition (Kaynak, 2007).

Yet, climate change will affect the entire cotton-weed relationship. Climatic change will likely be more beneficial to weeds due to the fact that genetic variations and selective ecological adaptations are more developed in weeds than in cultural plants (Grenz and Uludag, 2006). Some weed species may already exist in cotton areas but not yet be considered important species. Weed species carrying tropical characteristics can benefit from increasing temperatures and may turn into dangerous species (Kaynak, 2007). Weed control will then become more critical to achieving optimal cotton plant development and yield.

Furthermore, increases in atmospheric CO<sub>2</sub> will decrease the nutritional value of leaves for pests due to an increasing ratio of carbon to nitrogen in plant tissues. That is why increasing CO<sub>2</sub> levels and temperature fluctuations were assumed to affect pest population (Conroy, 1992). Global warming will have some inevitable effects on pests because of the fact that pests can better adapt their body temperatures to their environment. Several studies have exhibited that global warming will influence the pest's metabolism and increase their population rate, spreading to the cooler terrains in the North and South, and resulting in the existence of different plant variations and novel species. An increase in pest pressure is expected (Karl *et al.*, 2009).

Pest control would therefore become more critical in achieving optimal growth and yield. Furthermore, atmospheric CO<sub>2</sub> levels and higher temperatures may also have an impact on the effectiveness of certain pest management tools currently in use, such as certain seed varieties or insecticides. Wu *et al.* (2007) report that genetically modified *Bacillus thuringiensis* (Bt) cotton shows less Bt toxin after exposure to elevated CO<sub>2</sub>, which might affect plant-bollworm interactions. Karl *et al.* (2009) state that higher temperatures reduce the effectiveness of certain classes of pesticides (pyrethroids and spinosad).

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<sup>7</sup> Schlenker & Roberts (2006), however, stress that the magnitude of CO<sub>2</sub> fertilization is still debated. 'At present, possible CO<sub>2</sub> effects associated with climate change are not sufficiently understood. (...) existing laboratory studies as well as field experiments might overestimate this effect.'



### 3.2.3. Water availability

Plants need adequate water to grow and to maintain their temperature within an optimal range. Without water for cooling, plants may suffer heat stress. In many regions, irrigation water is used to maintain adequate growing and temperature conditions for cotton. The amount and timing of water availability during the growing season, through precipitation or irrigation, are critical for cotton. If water supply variability increases, it will affect plant growth and cause reduced yields (Karl *et al.*, 2009).

Irrigation is of vital importance to current cotton production. Cotton surface that is dedicated to irrigation is already high; about 53% of the total area (Soth *et al.*, 1999; cited in Chapagain *et al.*, 2005). However, yields for irrigated cotton are much higher (3,000–4,000 kg of seed cotton/ha) than in rain-fed cotton (1,000–2,000 kg of seed cotton/ha). Therefore, no less than 73% of all cotton fibre worldwide has actually been grown under some conditions of irrigation (full or supplementary irrigation).

Irrigation is particularly important in China's Xinjiang province and along the Yellow River (Henan, Hebei, Shandong), the south-western part of the United States, Pakistan's Indus Valley, the Indian state of Gujarat, Uzbekistan, Eastern Turkey, Egypt, Israel, Peru and Australia. Rain-fed cotton is prevalent along China's Yangtze River (Hubei, Jiangsu), on the Texan plains and in the south-eastern United States, in most states of India, in Western Turkey, in Brazil, in Argentina and in western and southern African cotton producing states.

With increasing demand and competition for freshwater supplies, water availability may in many countries become an important factor limiting cotton production. Globally, agriculture is by far the heaviest user of freshwater, primarily for irrigation, with about 70% of the total. The sheer size of agricultural water use for irrigation implies that any pressure on freshwater resources from other sectors of society will translate immediately into pressure on agriculture to cut down its current water footprint.

Cotton's share of the global agricultural water footprint<sup>8</sup> is estimated at 3% (Hoekstra and Chapagain, 2007). This is proportionate to cotton's global land use footprint of 2.5% (Cotton Incorporated, 2009) but will of course be very pronounced in large irrigated production areas. Cotton affects freshwater both quantitatively and qualitatively, through fertilizers and pesticides in effluents, and it also plays a significant role in soil degradation through a rising water table and salt build up in surface soils (WWF, 2005).

Where demographic pressure is high and land resources are limited, such as in China and in many parts of India, competition from food crops for land and water will further impact on the scale and the regional distribution of cotton production.

### 3.2.4. Pests and diseases

Insects are a recognized threat to cotton production throughout the world. Most insects can adapt their body temperature to the temperature of the environment. The effect of global warming on living organisms is slow enough for cotton insects to adjust to rising temperatures and other changes accruing from global warming. Thus, the insects currently plaguing cotton are expected to continue to be live and possibly thrive in new environmental conditions (ICAC, 2007).

Many fear that global warming will affect insects' metabolism, allowing them to increase their multiplication rate. Rising temperatures will open new areas for colonization by insects and more of them will spread to newer areas. Increases in the populations of currently important insects, such as bollworms, may also take place as a result of higher multiplication rates, along with the elimination of the need to go into diapause during winter to avoid colder temperatures. The effects could be further amplified under conditions where alternate host plants are already available for wintering (ICAC, 2007).

Global warming could also impact disease control in three ways: through its effect on pathogens; by creating disease-propitiating environments; and by affecting host tissues. It is feared that a rise in temperature will affect some disease control methods as a result of changes in the pathogen emergence time. Chemical control methods may also become less effective due to the possibility of faster

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<sup>8</sup> The water footprint of a nation is defined as the total volume of freshwater that is used to produce the goods and services consumed by the inhabitants of that nation. It shows water use related to consumption (Chapagain *et al.*, 2005).

decomposition of chemicals under higher temperatures. According to Chakraborty *et al.* (2002), higher CO<sub>2</sub> levels will increase the severity of diseases, induce fungal growth and spore formation, and will destroy more plant tissue. In general, the disease problem will become more important (ICAC, 2007).

## 4. Impacts of climate change on cotton production by country

Climate change is most likely to impact cotton yields through weather condition variations that lead to increased atmospheric CO<sub>2</sub>, changes in temperature, rainfall, soil moisture, and evapo-transpiration rates, and the levels of pests and diseases. The impacts will differ by country. This chapter analyses what climatic and other factors characterize cotton production for each of the main cotton production countries or regions in the world, and what national or regional climate change impacts may be expected on the basis of current projections.

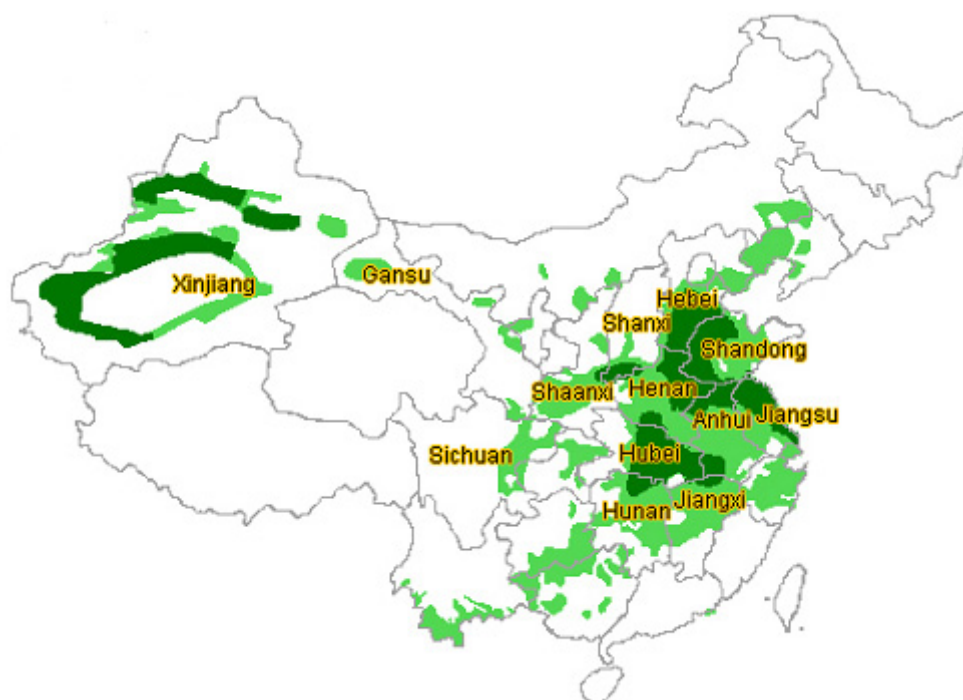
### 4.1. China<sup>9</sup>

#### 4.1.1. Production

Cotton production in China is concentrated in three regions (see figure 4): the Yellow River valley (42% of total), the Yangtze River valley (26%), and the northwest region (32%). There are huge differences in climate, soil quality, ecological conditions and the incidence of diseases and pests.

The *Yellow River region* includes the Northern provinces of Shandong, Hebei, Henan, Shanxi and Shaanxi. The weather is often dry in spring and irrigation is needed for cotton production. Because of its northern location, this region has to adopt early-maturing cotton varieties, which are usually double-cropped with winter wheat. In the Yellow River region, corn is the chief crop competing for cotton acreage.

**Figure 4. Major cotton producing regions in China**



**Source:** China National Cotton Information Centre.

The *Yangtze (Changjiang) River* includes Jiangsu, Anhui, Hubei, Hunan and Jiangxi provinces. In contrast with the Yellow River and Xinjiang regions, rainfall is relatively abundant, at more than 1,000 millimetres.

<sup>9</sup> This section is largely based on Hsu & Gale (2001). *Regional shifts in China's cotton production and use.*

Excessive rainfall in late summer and early fall often hurts cotton quality by fostering the development of cotton pests and diseases. With a long growing season, cotton is usually double-cropped with a winter crop (wheat or rapeseed). Transplanting of seedlings is a common practice, saving about two weeks of seed germination and growing time.

In the Yangtze River and Yellow River watersheds, the cotton fields are small and dispersed, with relatively low yields and high production costs. Both regions are China's main grain-producing areas. Therefore, there is intense competition for land for food crops, and cotton areas fluctuate considerably (Zhao and Tisdell, 2009).

The northwest region includes the Xinjiang Uyghur autonomous region and Gansu province. Xinjiang covers one-sixth of China, and has long been a major cotton producer. Since 1995, production has doubled, making Xinjiang the largest cotton producing province in China. The northwest climate is arid, with annual rainfall below 200 mm and wide daily swings in temperature, but dryness keeps pest and disease problems to a minimum. Xinjiang cotton is entirely irrigated and appreciated for high quality, colour and fibre length. It also grows long-staple cotton. Plantations are large and highly mechanised (Hsu & Gale, 2001).

Cotton production in China has almost doubled over the last 20 years, from around 4.5 million tons in 1990 to more than 8 million tons in 2008. Most of this increase can be attributed to an increase in yields, from an average 850 kg of lint/ha to over 1,300 kg/ha in 2008. Yields are highest in the northwest region; in 2006 it was 50% higher than those in the Yangtze River region and 62% higher than in the Yellow River region (Zhao & Tisdell, 2009). In fact, a large part of the national average yield increase is attributable to increased irrigation, following important production shifts since 1995 from the largely rain-fed Yangtze River area (-33%) and the supplementary irrigated Yellow River area (-12%) towards the entirely irrigated cotton area in Xinjiang province (+114%) (Bremen Cotton Conference, 2010).

#### **4.1.2. Impact of climate change**

According to a 2008 report by the United Nations Framework Convention on Climate Change (UNFCCC), climate change will lead to warming above the global mean in central Asia, the Tibetan Plateau and in northern and eastern Asia. There will be an increase in precipitation in most of Asia, except for a decrease in central Asia during summer. The frequency of intense precipitation will increase in eastern Asia. However, the amount of snow and ice in Himalayan and Tibetan Plateau glaciers will decline. Therefore, water stress will increase for many millions of people due to a decrease in freshwater availability in central and East Asia, particularly in large river basins. On the contrary, thanks to warming, agriculture may expand in the more northern areas (UNFCCC, 2008).

Climate change will impact the Himalayan glaciers, their related watersheds and five major rivers. The Yellow and Yangtze Rivers, for example, are not as reliant on meltwater as are other rivers, such as the Indus and the Brahmaputra. The important agricultural areas along the Yellow River in China would actually become more humid due to increased precipitation in winter (Van Raaij, 2010).

The British-Chinese research project 'Impacts of Climate Change on Chinese Agriculture' (ICCCA) found that climate in all parts of China will continue to warm (see figure 5), possibly by as much as 4.5° C by the 2080s (relative to the mean annual temperature for 1961–1990): 'There will be a consistent and progressive shift to wetter conditions, although some seasons and regions will have moderately drier conditions in the 2020s. (...) Heat waves, temperature extremes and precipitation intensities will tend to increase.' (ICCCA, 2009).

The direct impact of temperature rises on production is expected to be quite positive. Each 1° C increase of annual average air temperature would result in an increase of 10 days frost-free conditions. The cotton growing season would thus be extended for about 10 days, and the peak growing period ( $\geq 20^{\circ}$  C) would continue for an additional 7–10 days. The proportion of opening bolls before frost would likely increase by 5%–10%, and the strength and maturity of cotton fibre would be somewhat improved (China, 2004).

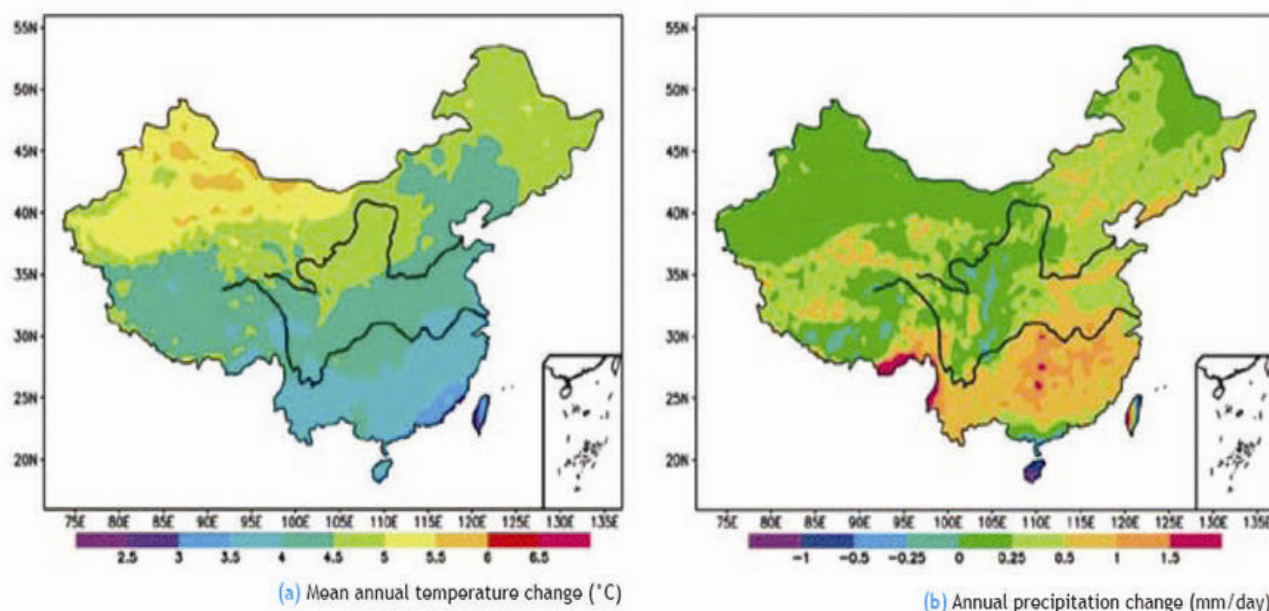
Along with climate change, the occurrence of unusual disasters such as drought, flood, high temperatures and freezing events might increase. Under the assumption of no changes to the present planting system, planting varieties and production levels, total cereal production might drop by about 10% due to climate

change and extreme climate events in the period 2030–2050. The production of three major crops – wheat, rice and maize – might all decrease. ‘Though climate change would not shake China’s capacity of self-supply in grains, it would put a high demand on management techniques of agricultural production and extra input into agriculture’ (China, 2004).

ICCCA (2009) found mixed simulation results regarding the climate change impacts on rice, maize and wheat yield patterns across China. Irrigated rice and rain-fed maize tended to show reductions in yield while yields of rain-fed wheat tended to increase when averaged across China. All crop yields decreased though without the effects of CO<sub>2</sub> fertilization.

Water availability is crucial for cotton production in Xinjiang. Due to irrigation works and the use of both surface and groundwater, the irrigated area of Xinjiang expanded from 1.5 million ha in the early 1950s to over 4 million ha in 2007. In 2007, the cotton area in Xinjiang was 1.8 million ha, or close to half of the total area (Zhao & Tisdell, 2009). Water availability for irrigation will likely be a major limiting factor for cotton in the future due to higher crop water requirements and increasing demand for water for non-agricultural use. Rising competition from cereal production will further limit land and water available for cotton fibre production.

**Figure 5. Changes over China for the 2080s relative to the baseline period (1961–1990) under the IPCC scenario (medium-high emissions)**



Source: ICCCA (2009). *Impacts of Climate Change on Chinese Agriculture*.

## 4.2. India<sup>10</sup>

### 4.2.1. Production

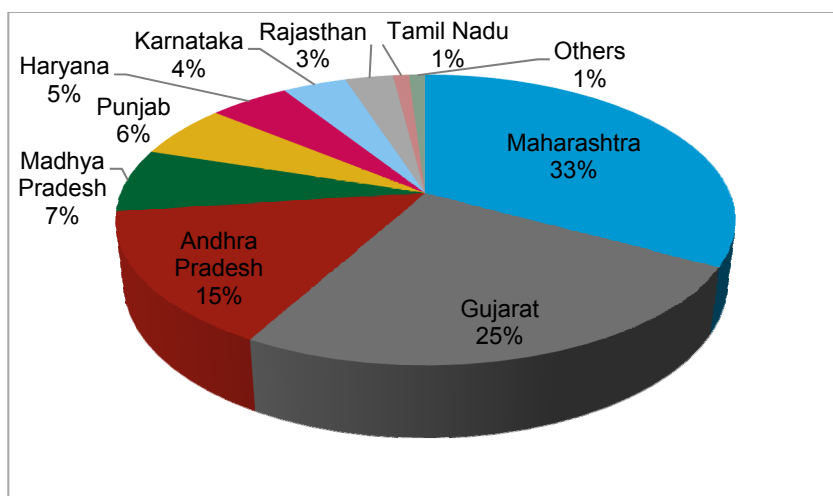
India is the second largest cotton producing and consuming country in the world following China. Climates vary from humid in the northeast (about 180 days of rain per year) to arid in Rajasthan (20 days). A semi-arid belt extends between the humid West coast and the central and eastern parts of the country. The most important feature of India’s climate is the monsoon; i.e. the season of concentrated rain from May–September (India, 2004).

Cotton is grown in India in three distinct zones: central zone (65% of total area; Gujarat, Madhya Pradesh, Maharashtra), the South (20%; Karnataka, Andra Pradesh and Tamil Nadu) and the North (14%; Punjab,

<sup>10</sup> This section is largely based on Venugopal et al. (1999). Crop production practices for maximising yield of cotton in India.

Haryana and Rajasthan). Maharashtra has the highest area under cotton cultivation, followed by Gujarat and Andhra Pradesh (see figure 6).

**Figure 6. State-wise cotton acreage in India, 2008–2009**



**Source:** Ministry of Textiles (2010), Cotton fibre policy. Draft version.

The central zone has a hot semi-arid climate, and comprises more dry-land cotton (93% of total in Maharashtra, 66% in Gujarat and about 60% in Madhya Pradesh). Yields are of course much lower (800–1,500 kg of seed cotton/ha) than in irrigated cotton (2,500–4,000 kg/ha, in western Maharashtra, parts of Madhya Pradesh and Gujarat). Monsoon rains are scant and ill-distributed in parts of Maharashtra and Madhya Pradesh, and the shallow black soils (*murrums*) of poor fertility and moisture retaining capacity. Here, even hardy crops like sorghum and millet cannot compete with cotton despite low yields (500–600 kg/ha).

In the southern zone, both rain-fed and irrigated cotton are grown, including high-quality long and extra-long staple cotton. The agro-climate is more suitable for cotton, with bimodal rainfall in parts of Karnataka, southern Andhra Pradesh and Tamil Nadu. Yield in irrigated cotton is about 2,500–3,000 kg/ha, and 1,000–1,500 kg/ha in dry-land cotton.

All cotton in the northern zone is irrigated. The climate is adverse at sowing season, with high temperatures, and the growing period is limited to six months. Double cropping 'cotton-wheat' is common with little time for tillage between the two crops. Cotton yield potential is 1,500–2,000 kg of seed cotton/ha due to adverse climate and pest damage (Venugopal *et al.*, 1999). Water availability for irrigation is a big issue in the northern zone. Soils have become saline and crust prone, and germination is hampered by high soil temperatures (CICR, 2009).

Cotton cultivation in India, especially rain-fed cotton, is a combination of mixed cropping and intercropping; while in irrigated areas and in high rainfall zones, cotton is grown in sequential cropping or through intensive relay cropping. This results in a mosaic of varied cotton-based cropping systems (Venugopal *et al.*, 1999).<sup>11</sup>

#### 4.2.2. Impact of climate change

The UNFCCC (2008) expects that climate change in Southern Asia will lead to warming above the global mean. Precipitation will increase, and the frequency of intense precipitation will increase in parts of Southern Asia. The reduction of snow and ice in Himalayan and Tibetan Plateau glaciers will decrease freshwater availability for irrigation, particularly in the large river basins in northern India (UNFCCC, 2008).

<sup>11</sup> The recent introduction of Bt cotton, however, has led to an increased prevalence of monocropping (Kranthi, personal communication, 25-3-2010).

The annual global average surface air temperature has increased significantly in the past one hundred years (0.4° C). The annual India-wide average monsoon rainfall has been without any trend in the same period; however increases in monsoon seasonal rainfall have been recorded along the West coast, in North Andhra Pradesh and northwest India (10%–12% higher than normal over 100 years) and decreasing trends in East Madhya Pradesh and adjoining areas, in northeast India and in parts of Gujarat and Kerala (6%–8% lower than normal over 100 years).

A marked increase in seasonal surface air temperature is projected in the future, becoming conspicuous after the 2040s. Projections indicate increases in both maximum and minimum temperatures in the region south of 25°N. Maximum temperatures are projected to increase by 2° C–4° C by the 2050s. In the northern region the increase in maximum temperatures may exceed 4° C. Minimum temperatures would increase by 4° C all over the country.

Little change in monsoon rainfall is projected India-wide up to the 2050s. However, the number of rainfall days will decrease over a major part of the country. This decrease is greater in the western and central parts (>15 days) while near the Himalayan foothills (Uttaranchal) and in northeast India the number of rainfall days may increase by 5–10 days. Rainfall intensity will increase throughout India by 1–4 mm per day, except for small areas in northwest India where rainfall intensity may decrease by 1 mm per day.

Climate change will likely significantly change the hydrological cycle. The severity of droughts and the intensity of floods are likely to increase, and the quantity of available runoff to decrease. The Sabarmati and Luni river basins, which cover about a quarter of Gujarat and 60% of Rajasthan, are likely to experience acute water-scarce conditions, and the Mahi, Pennar, Sabarmati and Tapi river basins constant water scarcity. The Cauvery, Ganga, Narmada and Krishna river basins are likely to experience seasonal or regular water-stressed conditions. The Godavari, Brahmani and Mahanadi river basins are projected to experience water shortages only in a few locations (India, 2004).

Simulations show a decrease in crop yields as temperatures increase. Decreases are generally offset by increases in CO<sub>2</sub>, yet the magnitude of this response varies with crop and region. Irrigated rice yields may slightly improve throughout India, whereas wheat yields in central India may drop 2% or increase 6%, depending on scenario. Sorghum, a C4 plant, does not show any significant response to CO<sub>2</sub> increases. If temperatures increase further, western India may experience lower productivity due to a reduced crop duration (India, 2004).

The Central Institute for Cotton Research (CICR) found that selected conventional cotton varieties/hybrids are well adapted to elevated CO<sub>2</sub> levels alone – due to better morpho-physiological and biochemical attributes. The productivity of cotton in terms of total number of bolls and weight increased significantly (73%). Fibre quality also improved significantly. Elevated CO<sub>2</sub> levels in the atmosphere of up to 650 ppm and temperature of 40° C was found to be optimum for cotton plant growth. It thus appears that cotton will benefit from the changed atmospheric scenario during the later part of the 21st century, yet studies indicate that the pest problem will be aggravated. By and large, though, research in India indicates that the impact of climate change on cotton production and productivity will be favourable (Kranthi, 2009).

### **4.3. The United States of America**

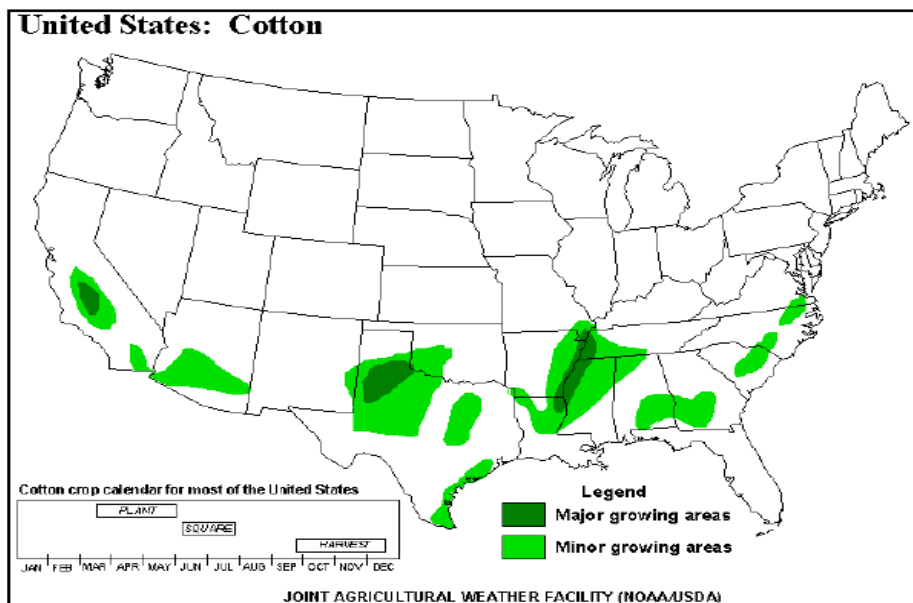
#### **4.3.1. Production**

Upland cotton is grown in the United States in four major geographic areas: the southeast, mid-South, southwest and the West, together called the Cotton Belt (see figure 7). Most production, about 70% of the total, is in the southwest and the mid-South.

The southwest (35% of total) comprises Texas, Kansas and Oklahoma. Planting in South Texas begins in late February, and harvesting runs from late July until mid-September. In the rest of the region, planting begins in mid-April and harvest lasts from mid-October through December. The mid-South (34% of total) is comprised of Arkansas, Louisiana, Mississippi, Missouri and Tennessee. Planting begins in mid-April and continues through early June. Harvest runs from early September to early December. The southeast (22% of total) has a similar crop cycle. Finally, the states of Arizona, California and New Mexico form the western region (9% of total). Here, the warm and dry climate is ideal for high-yield, irrigated cotton production.

Planting is from early April until early June, and harvest runs from late September until early December (Cotton Council International, 2009).

**Figure 7. Cotton producing regions in the United States**



Source: Womach (2004), Cotton production and support in the United States.

In 2009, genetically modified (GM) varieties with resistance to bollworms and herbicides made up about 95% of total cotton planted (Cotton Council International, 2010). In 2007, some 1.4 million hectares, or 36% of total acreage, were irrigated, at an estimated average rate of 4,270 m<sup>3</sup> of water per hectare (Cotton Incorporated, 2009).

Cotton production in the United States is highly mechanized and fuel-dependent. High-tech and capital-intensive precision agriculture, in which crop management is carried out in accordance with the in-field variability of, for example, soil fertility and crop growth, has made great strides.

#### 4.3.2. Impact of climate change

Climate-related changes have already been observed globally and in the United States. These include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea levels, and reduced snow cover, glaciers, permafrost, and sea ice. A longer ice-free period on lakes and rivers, lengthening of the growing season, and increased water vapour in the atmosphere have also been observed. Over the past 30 years, temperatures have risen faster in winter than in any other season, with average winter temperatures in the midwest and Northern Great Plains increasing almost 4° C.

These climate-related changes are expected to continue while new ones develop. Likely future changes for the United States and surrounding coastal waters include more intense hurricanes with related increases in wind, rain, and storm surges (but not necessarily an increase in the number of these storms that make landfall), as well as drier conditions in the southwest and Caribbean. These changes will affect human health, water supplies, agriculture, coastal areas, and many other aspects of society and the natural environment (Karl *et al.*, 2009).

Cotton yields are likely to increase if CO<sub>2</sub> levels continue to rise as projected this century, and if farmers can adapt their agricultural practices to the resulting climate change. Atmospheric CO<sub>2</sub> enhances plant growth by stimulating photosynthesis (National Center for Atmospheric Research, NCAR, 2001). A crop model for the south-eastern United States (see figure 8) shows the results of two climate scenarios using



two different management cases.<sup>12</sup> The fine-scale model predicts a cotton yield increase of 5% over the region, while the large-scale model shows a 15% increase. The second case includes elevated CO<sub>2</sub> levels and farming adaptations like planting crops earlier to take advantage of a longer growing season. Here, the fine-scale model predicts a 26% increase, and the large-scale model a 36% increase in cotton yields for the region (NCAR, 2001).

However, NCAR later found that the impacts of a doubled level of atmospheric CO<sub>2</sub> may vary greatly by region. The Great Plains and the Mississippi Delta, for example, would see increased yields, whereas the Midwest Corn Belt would suffer. The southeast would lose at least 20% of its agricultural economic base, yet cotton production would soar (NCAR, 2004).

Through climate change, the number of days in which the temperature exceeds 37.8°C is projected to increase strongly across the United States (see figure 9). For example, under a higher emissions scenario, parts of Texas that recently experienced 10 to 20 days per year over 37.8°C are expected to experience more than 100 days per year in which the temperature exceeds 37.8°C by the end of the century (Karl *et al.*, 2009).

Water is the most important factor affecting activities on the Great Plains. Current water use is unsustainable because it surpasses recharge. Most of the water used for irrigation comes from the High Plains aquifer, which stretches from South Dakota to Texas. The aquifer holds both current recharge waters from precipitation, and so-called 'ancient' water, trapped by silt and soil washed down from the Rocky Mountains. As population increases and irrigation spreads, annual water withdrawal has begun to outpace natural recharge. In heavily irrigated parts of Texas, Oklahoma, and Kansas, groundwater levels have fallen from 30 metres to over 75 metres. Increasing temperatures, faster evaporation and more sustained droughts due to climate change will only add more stress to overtaxed water sources (Karl *et al.*, 2009).

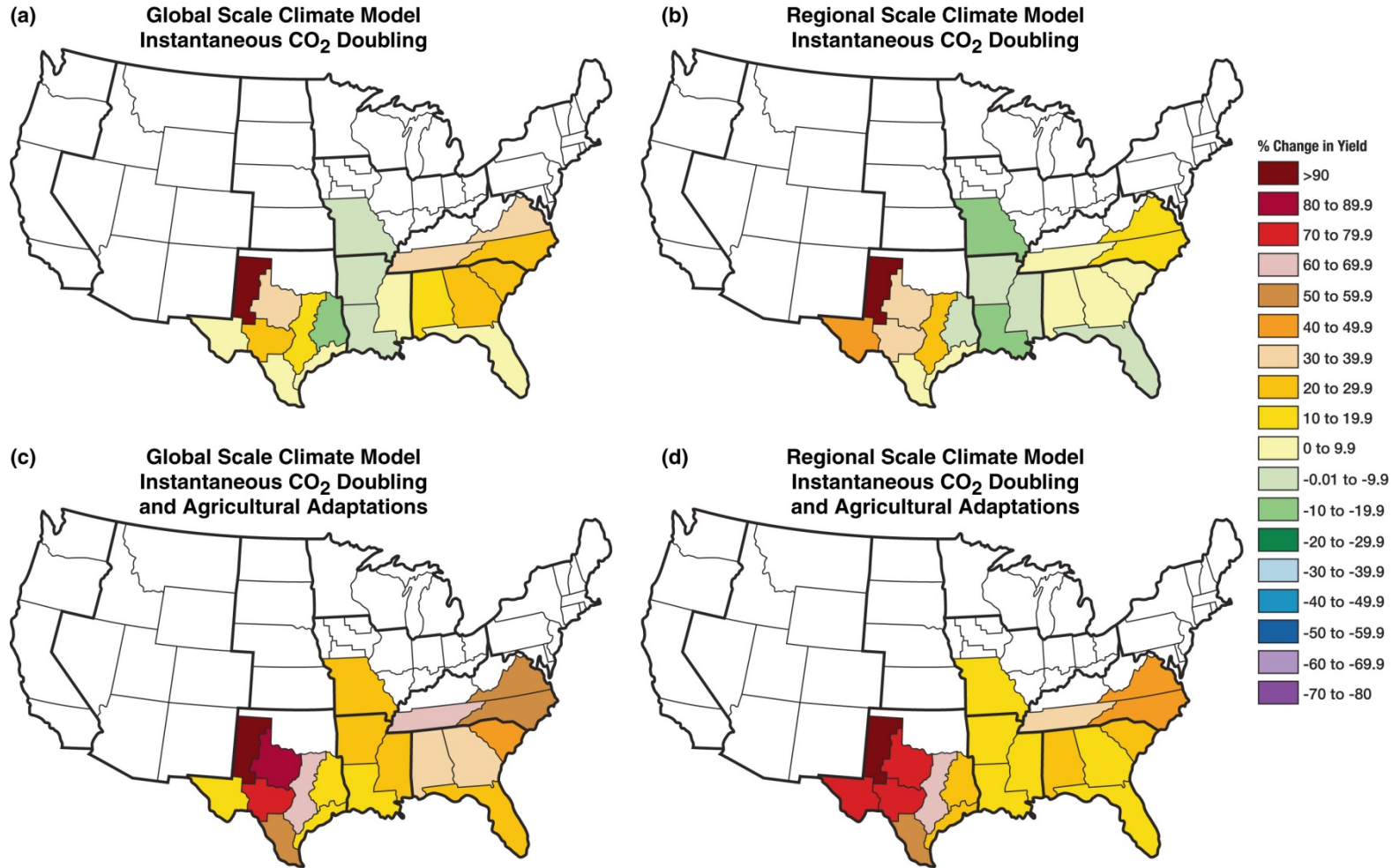
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<sup>12</sup> The cotton models and the climate scenarios were rather simplistic according to NCAR. The climate models projected climate change based on an instantaneous rather than a gradual doubling of CO<sub>2</sub>.



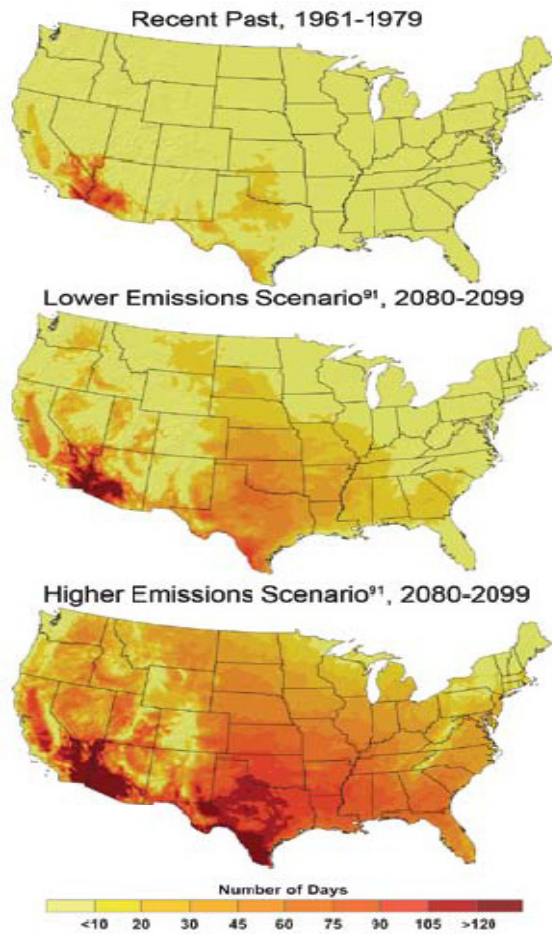
Figure 8. Possible future cotton yields in the south-eastern United States

POSSIBLE FUTURE COTTON YIELDS IN SOUTHEASTERN U.S.



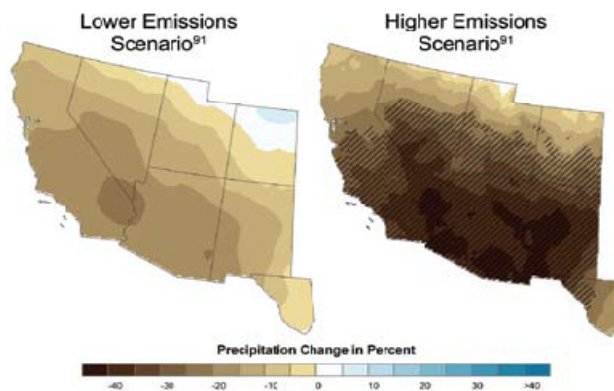
Source: NCAR (2001). *The Effect of the Spatial Resolution of Climate Scenarios on Cotton Production in the Southeastern United States.*

**Figure 9. Number of days over 37.8° C**



Source: Karl *et al.* (2009). *Global Climate Change Impacts in the United States*.

**Figure 10. Projected change in spring precipitation (2080–2099) for the western United States**



Source: Karl *et al.* (2009). *Global Climate Change Impacts in the United States*.

In the Western region, from the southern Rocky Mountains to the Pacific Coast, the largest use of water is associated with agriculture, including some of the nation's most important crop producing areas in California. Water supplies are already becoming limited in some areas, and future water shortages are likely. Pumping is lowering groundwater tables, while rising temperatures reduce river flows in vital rivers including the Colorado River. Water supplies will be tightened by substantial reductions in rain and snowfall in spring, when precipitation is most needed to fill reservoirs to meet summer demand (see figure 10). Climate change in the West is likely to bring more droughts as well as an increased risk of flooding (Karl *et al.*, 2009).

Finally, in the southeast, the climate is uniquely warm and wet, with mild winters and high humidity, compared with the rest of the continental United States. Climate models project continued warming in all seasons across the southeast. The number of very hot days is projected to rise at a greater rate than average temperatures. Average temperatures are projected to rise by about 2.5° C to 5° C by the 2080s (Karl *et al.*, 2009).

## 4.4. Pakistan

### 4.4.1. Production

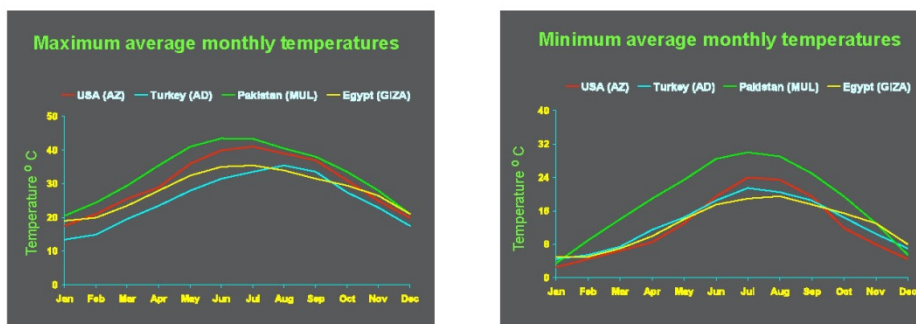
Pakistan ranked fourth in world cotton production and third in world cotton consumption in 2009–2010 with a 10% share of each. Punjab and Sindh are the main cotton producing provinces, with 79% and 20% of total respectively in 2008–2009. The cotton belt extends over about 1,200 km along the Indus River and its tributaries, between latitudes 23°N and 33°N, at altitudes from 153 metres in the North to 27 metres in the South. Soils vary from sandy loam to clay loam with clay dominant towards the South (Gillham *et al.*, 1995).

Temperatures in May and June are as high as 40° C to 45° C, often reaching 50° C on individual days. Winter temperatures often fall below freezing in the Punjab and upper Sindh but the lower Sindh is frost free. There are two distinct cropping seasons for summer (*Kharif*) crops, from April to October, and winter (*Rabi*) crops, from October to April/May. Some short-season crops are sandwiched between these main cropping seasons. The main crops are wheat, cotton, rice and sugarcane (Gillham *et al.*, 1995).

Due to very limited rainfall (150–750 mm according to zone), agriculture in the Indus Valley depends entirely on irrigation. Cotton takes the third biggest share of freshwater in Pakistan (WWF, 2005). Water is supplied on a weekly basis. Supply is regulated through a series of dams that store water until it is needed during relatively dry periods. Supply cannot be varied according to crop water requirements (Gillham *et al.*, 1995).

The average cotton fibre yield per hectare is higher in the Southern Sindh province (850 kg/ha) than in Punjab (692 kg/ha); however, both are low for irrigated cotton in general. Raza (2009) suggests that this is due to the very high average maximum and minimum temperatures in Pakistan as compared to other countries growing cotton in a hot climate (see figure 11). Boll weight in Pakistan (2–3 grams per boll) is less than half that in the United States, Egypt and Australia (each 5–6 grams per boll), and half that in Turkey (4–5 grams per boll).

**Figure 11. Average maximum and minimum temperatures for four countries and locations growing cotton in a hot climate**



Source: Raza (2009). Cotton production in Pakistan: A grower's view.

#### 4.4.2. Impact of climate change

The impacts of climate change on the Himalayan glaciers will be of particular importance to the Indus River basin. The Indus River depends heavily on meltwater because there is hardly any rainfall downstream (Van Raaij, 2010). If net irrigation water availability in the Indus valley decreases, farmers are likely to switch to crops that demand less water than cotton, such as coarse grains, fruits and vegetables (Pakistan, 2003).<sup>13</sup>

Maximum temperatures in summer exceed 40° C in the central and southern parts of Pakistan. A future increase in temperature coupled with a decrease in rainfall would have a negative impact on the production of major crops. Irrigation water requirements for crops vary by climatic zone. The increase in temperature coupled with changes in rainfall will increase net irrigation water requirements, particularly in the three main production systems: rice-wheat, maize-wheat and cotton-wheat. Furthermore, the increased use of poor quality groundwater would induce secondary salinization (Pakistan, 2003).

A study of the potential vulnerability of crops to heat stress under a climate change scenario of a rise in temperature of 0.3° C per decade shows that all crops suffer heat stress, but crops like wheat, cotton, mango and sugarcane are more severely affected, while the prevailing maximum temperature is more than 10° C higher than the optimal range. Any fractional rise in temperature would therefore have serious adverse effects on growth, maturity and productivity. Irrigation water requirements would increase to compensate heat stress, with the cooling of crops becoming an essential element of the crop production system.

### 4.5. Uzbekistan

#### 4.5.1. Production

Central Asia is the fifth largest producer of cotton worldwide (6% of world total) and the second cotton exporter after the United States (17% of world total). Most Central Asian cotton originates from Uzbekistan. Of Uzbekistan's 45 million ha, about 60% is used for agricultural purposes, and of that 4.3 million ha, or 12%, is irrigated. Although the irrigated area is a small part of overall land use, irrigation accounts for almost 80% of all water use in the country. Irrigation accounts for the vast majority of all cotton, as well as wheat, production.

Water for irrigation largely emanates from the prime tributaries to the Aral Sea, the Amu Darya and Syr Darya rivers. Water is first stored and then released at suitable times in the cropping season, particularly in summer (Abdullaev *et al.*, 2007). Uzbek cotton has a poor environmental record as it has been associated with the dramatic decline of the Aral Sea observed over the last few decades, following agricultural expansion and poor soil and water management.

#### 4.5.2. Impact of climate change

A 2008 United Nations Framework Convention on Climate Change (UNFCCC) report argues that climate change will lead to warming above the global mean in Central Asia. Precipitation is expected to increase all over Asia; however, Central Asia will experience a decrease in precipitation during summer. Crop yields are predicted to fall by up to 30%, creating a very high risk of food insecurity.

Retreating Himalayan and Tibetan Plateau glaciers will decrease freshwater availability for irrigation (UNFCCC, 2008). However, in itself there is enough water in the Aral Sea's tributaries to keep the current irrigation systems functioning indefinitely. Lack of water has at times been an issue for production in the past, but this was principally due to the upstream creation of artificial lakes, not to an overall lack of water availability. Water availability in Uzbekistan is dependent on upstream water management in neighbouring countries (Abdullaev *et al.*, 2007).

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<sup>13</sup> Pakistan has experienced a *rise* in the water table in the cotton growing areas over the last 30 years. Since 1975, cropping area of high water demand crops, like rice, cotton and sugarcane increased, whereas areas for low water demand crops decreased (Pakistan, 2003).

The large-scale production of irrigated cotton has led to severe exhaustion and salinization of soils. Land with low natural fertility has been exhausted by monocropping. In 2005, 51% of total irrigated land area was saline,<sup>14</sup> of which 4% strongly saline, 17% moderately saline and 30% slightly saline. Land area with moderate and strong salinization increased by 14% between 1995 and 2005. Climate change will enhance the process of salinization through an increased use of groundwater in the upper soil layers, resulting in secondary salinization and crop yield reduction. Research indicates that cotton yields decline by 20%–30% even in slightly saline conditions, maize by 40%–50%, and wheat by 50%–60% (Uzbekistan, 2008).

Climate change is not expected to significantly impact agricultural productivity in Uzbekistan in the next two decades. Changes in temperature and moisture supply will, however, become major productivity factors by 2050–2080. Impact assessment indicates a loss in cotton crops of 4% by 2030 and 10% by 2050. The main future crop losses will be determined by water security for irrigated farming. By 2050, cotton crop losses could achieve 11%–13% in the Syr Darya river basin and 13%–23% in the Amu Darya river basin due to increased evaporation and reduced flow (Uzbekistan, 2008).

In turn, higher soil temperatures may favour production through an earlier start and a later ending of the cotton growing season. Soil temperatures in Central Asia are currently too low to plant cotton early, and winter comes too soon to complete the number of heat units required for an optimum harvest (ICAC, 2009). However, cotton is most vulnerable to a lack of water during fruit formation and accumulation (June–August). The increase of the number of days with extremely high air temperatures (over 39° C) due to climate change will cause a decrease in yield in some provinces. In low moisture conditions, yield losses due to extremely high temperatures could average an estimated 9%–15% (Uzbekistan, 2008).

## 4.6. Brazil

### 4.6.1. Production

Brazil grows 6% and uses 4% of global cotton fibre. Cotton is primarily grown in the Centre-West region, mainly in the states of Mato Grosso, Mato Grosso do Sul and Goias. The soil in the *cerrado*<sup>15</sup> regions of the centre-West is very poor, but with the help of corrective fertilizer and the excellent weather for cotton, the crop has grown substantially over the last 15 years, converting Brazil from being a net cotton importer into a net cotton exporter. Since moving to the centre-West, cotton production in Brazil has become far more efficient and farmers are now amongst the most technically advanced in the world (Graham, 2009).

### 4.6.2. Impact of climate change

Latin America will be particularly affected by climate change as the Andean glaciers are expected to disappear before the end of the 21<sup>st</sup> century. The cotton production areas in central and West Brazil, however, rely on rainfall not Andean discharge. Virtually all cotton is rain-fed. There are uncertainties over the effects of climate change on rainfall in Latin America. However, it is predicted that arid and semi-arid areas will receive even less rain due to climate change, leading to degradation of agricultural land and impacting food security. Yields are expected to decrease throughout Latin America by the end of the 21<sup>st</sup> century, except for mid-latitude areas, where CO<sub>2</sub> fertilization effects may balance out the negative effects of climate change (UNFCCC, 2008).

For 2020, temperature increases will range from 0.4° C to 1.8° C, and for 2080, from 1.0° C to 7.5° C. The highest increases are projected in tropical South America. For precipitation, the global climate models used to project changes in hydrological cycle at regional scales have a high degree of uncertainty. For Central and tropical South America, projections range from a reduction of precipitation of 20%–40%, to an increase of 5%–10% in 2080 (Magrin *et al.*, 2007).

<sup>14</sup> Soil is considered saline if it contains in its mass more than 0.10% of salts that are toxic for plants or more than 0.25% salts of dissolved solids (for non-gypseous soils) (Uzbekistan, 2008).

<sup>15</sup> The *cerrado* is characterized by low and twisted trees, isolated or grouped over a continuous grassy surface. Because of intense human activity, much of its native vegetation has been replaced by agriculture, pasture and reforestation (UNFCCC, 2008).

## 4.7. West and Central Africa

### 4.7.1. Production

Cotton production in West and Central Africa is rain-fed and concentrated in the Soudano-Sahelian belt. Burkina Faso is the main producing country, followed by Benin, Mali, Côte d'Ivoire and Cameroon. Virtually all cotton is exported. Average annual rainfall is about 700–1,200 mm. Production in the more humid agro-ecological zones to the South is possible, but yields are lower due to less sunshine and a higher incidence of pests.

West and Central Africa have marked dry seasons, which is favourable to cotton quality. Yield is highly dependent on sowing date, as the rainy season only lasts 4–5 months (May/June–September/October). Drought spells as well as water-logging during the rainy season may impact yields significantly. Pest incidence tends to increase with plant stress following drought or water-logging. All cotton crop operations are done manually or with oxen. Tractors are very few and only used for ploughing.

Regional differences in cotton production within West and Central African countries can generally be explained by factors, like agro-ecological conditions, population density, access to markets for food crops, degree of agricultural intensification, political instability, etc. There is no evidence that any major regional shifts have occurred within countries - for example due to desertification. Indeed, new regions have joined in cotton growing over the years, but this growth could not be related to any production decrease in the traditional 'cotton basins' (Ton, 2004).

### 4.7.2. Impact of climate change

Climate significantly controls Africa's day-to-day economic development, particularly in the agriculture and water sectors. Africa's climate is influenced by complex maritime and terrestrial interactions that produce a variety of climates across a range of regions, for example from the humid tropics to the hyper-arid Sahara (Boko *et al.*, 2007). Climate change may alter climatological and hydrological conditions, bringing about substantial changes in temperature, rainfall and evapo-transpiration. The productivity of dry-lands is mainly determined by temperature and precipitation during the vegetation period. Dry-lands are therefore particularly vulnerable to climate change (Kapur *et al.*, 2008).

Observed temperatures have indicated a warming trend since the 1960s. Between 1961 and 2000, the number of warm spells over southern and western Africa increased, and the number of extremely cold days decreased (Boko *et al.*, 2007). Projections up to the end of this century indicate an average temperature increase of 3.3° C in West Africa (Toulmin, 2009). For precipitation, the situation is more complicated. Rainfall exhibits notable spatial and temporal variability. Inter-annual rainfall variability is large over most of Africa and, for some regions, multi-decadal variability is also substantial. Rainfall trends in the West African Sahel, the Guinea Coast and the Southern Sahara are not certain, with some models predicting an increase and others a decrease (Toulmin, 2009).

Climate change may have many impacts on cotton production in West and Central Africa. Production in current areas could decrease following reduced rainfall, and could possibly move southwards to more humid areas. Water availability will be the critical factor for cotton production in West and Central Africa, as is the length and predictability of the beginning and the end of the rainy season. An increase in the frequency and intensity of extreme events, such as droughts and floods, will also have its bearing on crop production.

## 4.8. Turkey

### 4.8.1. Production

Turkey is responsible for 2% of production and 5% of cotton fibre consumption in the world. All cotton produced benefits from full or supplementary irrigation. About 50% of Turkish cotton comes from south-eastern Anatolia, where the climate is semi-arid. Summers are very hot and mean temperatures higher than 30° C in the hottest months of July and August. Mean temperatures in the coldest month January are between 2° C and 5° C. Summer dryness is intense and long lasting. Annual precipitation varies between 350 and 800 mm.



Other major production areas are the Aegean (27% of total in 2004/05) and Cukurova regions (21% of total) (Karademir, 2006). Here, the climate is Mediterranean, with hot, dry summers and mild, rainy winters, and annual rainfall between 600 and 1,000 mm (Turkey, 2007).

#### 4.8.2. Impact of climate change

Between 1950 and 2004, a widespread increase in summer temperatures was observed, in particular in the western and south-western regions. Winter precipitation in the western provinces has decreased significantly in the last five decades. On the other hand, fall precipitation increased in the northern parts of central Anatolia.

Future projections for the period 2071–2100 indicate that the area-averaged annual mean temperature increase will be around 2° C–3° C. In wintertime, projected temperatures are higher in the East. In summer this pattern is reversed. The western half of the country, especially the Aegean region, will experience temperature increases of up to 6° C.

Precipitation will decrease along the Aegean and Mediterranean coasts and increase along the Turkish Black Sea coast. In summer there is little change in the level of precipitation over Turkey. A slight precipitation increase is expected in fall, especially in the Euphrate-Tigris Basin – i.e. south-eastern Anatolia. However, data also show a reduction in snow water equivalent of up to 200 mm for the high plains of eastern Anatolia and the eastern part of the Black Sea mountains. Major changes may therefore occur in the stream-flow of the river basins in Turkey. Rivers are the main source of water for Turkey, not only for safe drinking water, domestic and industrial use, but also for irrigation and power generation.

Finally, it is projected that nearly 20% of the surface water in basins will be lost by the year 2030. By 2050 and 2100, these percentages go up to 35% and more than 50% respectively. The decreasing surface water potential of basins will cause serious water stress problems for users. Moreover, higher crop evapotranspiration (up to +10% in 2030 and +54% in 2100) will increase irrigation water demand enormously (Turkey, 2007).

### 4.9. Australia

#### 4.9.1. Production

Australia produces about 2% of global cotton – virtually all is for export. Over the past ten years, average cotton yields have been increasing, due to the spread of GM seed varieties and improvements in technology and crop management. Cotton production in Australia is located in New South Wales and Queensland, in particular in the Murray-Darling river basin. This basin has been subject to severe drought since 2000, adversely affecting cotton production.

Lack of irrigation water is the most limiting factor for production (Glover *et al.*, 2008), as irrigation is used on 87% of cotton farms (Australia, 2009). An estimated 20% of water used for irrigation in the Murray-Darling system is used to irrigate cotton (Zhao & Tisdell, 2009).

#### 4.9.2. Impact of climate change

Throughout cotton growing regions, average annual minimum temperatures have increased 0.9° C and maximum temperatures 0.6° C since 1950. The difference between day and night temperatures decreased, particularly in Queensland and parts of New South Wales. Since 1970, much of Eastern Australia (particularly Queensland) has seen a trend towards declining rainfall. The combination of increasing temperatures and decreasing rainfall, especially in central and southern Queensland, is likely to reduce soil-water balance (McRae *et al.*, 2007).

Projections indicate that most of Australia will warm with 0.4° C to 2.0° C by 2030, and with 1° C to 6° C by 2070. Warming is expected to be higher inland. The rate of warming will be higher in spring and summer than in autumn and winter. There will be an increase in the average number of extremely hot days and a decrease in the average number of extremely cold days and frosts (McRae *et al.*, 2007). Annual average rainfall is expected to be lower in the southwest (-20% to +5% by 2030; -60% to +10% by 2070) and the southeast and parts of Queensland (-10% to +5% by 2030, -35% to +10% by 2070), but not in the rest of Australia (-10% to +10% by 2030, -35% to +35% by 2070) (McRae *et al.*, 2007).

Climate change impacts will be complex and will vary greatly across different cropping and pasture regions. Impacts could include heat stress, drought, water-logging and changes in the distribution and severity of insect pests, pathogens and weeds. Some impacts could be positive, such as the capacity of plants to use water more efficiently, as a result of higher atmospheric CO<sub>2</sub>. However, this positive effect may be offset by the effects of increased temperatures and changes in water availability (Glover *et al.*, 2008). Climate change is likely to make water availability more variable and limited in Australia's cotton producing regions (Zhao & Tisdell, 2009). Water availability being a key limiting factor, the cotton sector has set a goal to double its water-use efficiency by 2015 (Australia, 2008).

Many cotton growing areas 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. Excessively high temperatures (greater than 35° C) during the day can reduce photosynthesis, while warm nights (above 25° C) mean that leaf temperature and plant respiration remain high. Maintenance respiration can double for every 10° C rise in temperature (Bange, 2007).

Yet, climate change may also raise minimum temperatures. 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. In some cotton producing regions in Australia, the number of 'cold shocks', i.e. days when minimum temperatures are below 11° C, is important in early cotton growth, between mid-September and the end of November, and can be significantly reduced by climate change to the benefit of cotton production (Bange, 2007).

## 5. Options to adapt to climate change

As climate change alters the economics of production, rural cotton farming communities will have to formulate different adaptation strategies including planting different crops and seeking alternative non farm income streams. This entails complex and resource intensive responses from government and international aid flows.

At the production level, the cotton plant's genetic makeup allows it to make limited adjustments to changes in climatic conditions (ICAC, 2007). Following stress, cotton responds to the loss of vegetation or fruiting parts (buds, flowers, bolls) through 'compensatory growth'. Cotton's vertical tap root provides resilience against spells of drought, but also makes it vulnerable to water-logging.

Irrigation allows half of today's cotton acreage (and three-quarters of production) to take place in areas where cotton could not normally be productively sustained. This makes cotton particularly vulnerable to the availability of freshwater or groundwater for irrigation.

The following potential adaptation measures have been identified:

- Stop any unnecessary loss of nutrients for the farming system, preventing soil erosion and abandoning the burning of cotton crop residues where still applied.
- Favour a cropland design that has plant diversity and that favours soil fertility management; for example, through the inclusion of cover crops or perennials.
- Adjust sowing dates to offset moisture stress during the warm period, to prevent pest outbreaks, and to make best use of the length of the growing season.
- Minimize the period that land lays bare, in order to slow down loss of organic matter and soil humidity, and soil erosion in general.
- Minimize soil tillage in order to prevent loss of soil organic matter – a natural source of soil fertility and a means of storing water for plant uptake.
- Breed cotton varieties that are more resistant to heat stress, drought spells, weeds, pests and diseases, etc.



- Optimize the use of sustainable, natural fertilizing sources in cotton production, including nitrogen-fixing crop rotations, compost and composted manure.
- Optimize the efficiency of additional fertilizer use where required, because of its costs and carbon fuel footprint. Synthetic fertilizer use is particularly high in irrigated agriculture.
- Optimize the water-use efficiency in the production of irrigated cotton, because of the irrigation water's costs and carbon fuel footprint.
- Optimize the use of industrial preparations such as pesticides, herbicides and defoliant because of their costs and carbon fuel footprint.

Where used, 'optimize' refers to the search for the most appropriate, most practical, least-costly option.

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