ISSN 1327-8231

ECONOMICS, ECOLOGY AND THE ENVIRONMENT

Working Paper No. 157

The Sustainability of Cotton Production in China and in Australia: Comparative Economic and Environmental Issues

by

Xufu Zhao
and
Clem Tisdell

June 2009

THE UNIVERSITY OF QUEENSLAND

ISSN 1327-8231
WORKING PAPERS ON
ECONOMICS, ECOLOGY AND THE ENVIRONMENT

Working Paper No. 157

The Sustainability of Cotton Production in China and Australia: Comparative Economic and Environmental Issues[1]

by

Xufu Zhao[2]
Clem Tisdell[3]

June 2009

[1] This is the draft of a paper for an edited book entitled "Sustainable Agriculture: Technology, Planning and Management" to be published by Nova Science Publishers, New York

[2] Professor of Agricultural Economics, Wuhan University of Science and Engineering, Wuhan, 430073, P.R. of China. Email: zhaoxufu@126.com

[3] School of Economics, The University of Queensland, St. Lucia Campus, Brisbane QLD 4072, Australia Email: c.tisdell@economics.uq.edu.au

WORKING PAPERS IN THE SERIES, *Economics, Ecology and the Environment* are published by the School of Economics, University of Queensland, 4072, Australia, as follow up to the Australian Centre for International Agricultural Research Project 40 of which Professor Clem Tisdell was the Project Leader. Views expressed in these working papers are those of their authors and not necessarily of any of the organisations associated with the Project. They should not be reproduced in whole or in part without the written permission of the Project Leader. It is planned to publish contributions to this series over the next few years.

Research for ACIAR project 40, *Economic Impact and Rural Adjustments to Nature Conservation (Biodiversity) Programmes: A Case Study of Xishuangbanna Dai Autonomous Prefecture, Yunnan, China* was sponsored by the Australian Centre for International Agricultural Research (ACIAR), GPO Box 1571, Canberra, ACT, 2601, Australia.

The research for ACIAR project 40 has led in part, to the research being carried out in this current series.

For more information write to Emeritus Professor Clem Tisdell, School of Economics, University of Queensland, St. Lucia Campus, Brisbane 4072, Australia.

The Sustainability of Cotton Production in China and in Australia: Comparative Economic and Environmental Issues

ABSTRACT

After providing some background about the importance of cotton as a fibre, this article provides information about the global relevance of China's and Australia's cotton industries and compares the structure and other significant features of their cotton industries. Attention is given to trends in overall cotton yields and the volume of production of cotton globally, in Australia, and in China as indicators of the sustainability of cotton supplies. Some simple economic theory is applied to indicate the relationship between market conditions and the sustainability of global cotton supplies. Then the environmental and economic factors that challenge the sustainability of Australian cotton production are outlined and analysed and this is done subsequently for China's cotton production. Geographical and regional features that affect the sustainability of cotton supplies in Australia and China are given particular attention. Some new economic theory is proposed to model hysteresis in Australia's supplies of cotton. Ways of coping with the sustainability difficulties that are being encountered by both these nations are compared. Many of the sustainability challenges facing these two countries are found to differ but some of their environmental obstacles to sustainable cotton production are similar.

Keywords: Australia; China; cotton production; fibre markets; hysteresis of supplies; sustainable agriculture; water resources.

JEL Codes: Q01, Q11, Q15, Q24, Q50.

The Sustainability of Cotton Production in China and in Australia: Comparative Economic and Environmental Issues

1. Introduction

Despite its reduced share of the textile fibre market, cotton still remains the major natural fibre used in textiles. The prime reason for cotton's reduced share of the textile fibre market has been increased competition from man-made fibres (Tisdell and McDonald, 1979, Ch.1). In 2007, cotton accounted for 38% of the global market by weight based on the data available from the Japan Chemical Fiber Association (2008) whereas in 1960-61 it accounted for 68% of world fibre production (Tisdell and McDonald, 1979, p.23). Nevertheless, the global volume of cotton production has continued to show a strong upward trend. Whereas just over 10 million tonnes of cotton were produced globally in 1960-61, by 2007, this had risen to 25.7 million tonnes, that is to about 2.5 times its volume in 1960-61. This can be attributed in part to technical progress in the production of cotton and improvements in the management of cotton cultivation as well as valuable attributes of cotton which sustain demand for its use in blends with chemical fibres. Whether or not growth in the global supply of cotton will continue to be maintained is not clear. Changing economic and environmental factors will constrain future changes in cotton global supply.

Other writers have also emphasised the importance of cotton for the textile industry. It represents over 90 percent of the global consumption of natural fibres by weight (Oerlikon, 2008). Plastina (2008) mentions that: over the last 5 decades, although the market share of cotton decreased from an average of 62.4% in the 1960s to 39.8% in the 2000s, cotton consumption increased one-and-a-half times during that period to reach 26.4 million tons in 2007. World textile fiber consumption more than tripled over the last 5 decades. Other fibers (wool, chemical and non-chemical synthetic fibers) increased eight times to reach 45.7 million tons in 2007. In addition to its use in the textile industry, cotton is used in many other fields. For example, the cottonseed which remains after the cotton is ginned is used to produce cottonseed oil, which after refining can be consumed by humans like any other vegetable oil. The cottonseed

meal that is left is generally fed to livestock. Nevertheless, the most valuable use of cotton is in the cotton textile industry.

Cotton has also served as an engine of economic growth and provides income to millions of farmers in both industrial and developing countries worldwide (Wang and Chidmi, 2009). In Australia, in a non-drought year, the cotton industry generates in excess of $1 billion per year in export revenue, is one of Australia's largest rural export earners and helps underpin the viability of many rural communities (Cotton Australia, 2008a). It employs 10,000 Australians and directly supports 4,000 businesses that are reliant on cotton (Cotton Australia, 2008b). In China, the value of its output accounts for 7% – 8% of the value of gross agricultural output. In 2002, China's export of cotton and cotton textile garments was $26 billion, and accounted for 35% of its total textile and garment exports by value (Mao, 2006). According to Wang and Chidmi (2009): "Cotton also does play an important part in US, the United States has produced about 20 percent of the world's cotton supply and consumed 10 percent of world cotton. It provides about 0.1 percent of U.S. Gross Domestic Product".

The purpose of this article is to focus on the sustainability of the supply of cotton by China and Australia and examine the constraints they have experienced in recent years in producing cotton, how they have fared in this regard, and the challenges they face for maintaining or increasing the level of cotton production. These two countries are of interest as cases because of differences in the socioeconomic conditions influencing their cotton industries as well as contrasts in their approaches to cultivating cotton. China is the world's major producer of cotton (ahead of the USA and India) and Australia is one of the main cotton exporting nations (noted for its export of fine cotton) and is the nation with the highest yields of cotton per ha (Zhao and Tisdell, 2009). Australia has only become a significant global producer of cotton in recent decades whereas China has been a major producer for several centuries. China regards cotton as a strategic material and this gives it particular (but not overriding) importance in relation to its agricultural policy.

By way of background, some general information is provided about the global relevance of China's and Australia's cotton industries and then sustainability issues are addressed. At a general level, the sustainability of global cotton production depends on possible shifts in the market demand and supply curves for cotton. This is

discussed briefly. The features of the geographical locations of Australia's and China's production of cotton are outlined and discussed. These locations have important implications for the sustainability of cotton production in both these countries. Cotton production in Australia occurs in a different type of economic environment to that in China and there are also differences in their farming systems and size of farms, all of which have consequences for maintaining cotton production. After discussing this, the experiences of Australia and China in sustaining cotton production are outlined and their economic and environmental challenges for future sustainability of cotton production are discussed.

2. The Global Relevance of China's and Australia's Cotton Industries.

The cotton industry is a significant contributor to China's and Australia's agricultural sector. Australia is the major cotton-producing country in the Southern Hemisphere, and has been an important cotton exporter. Table 1 provides information on the level of Australian production and export of cotton in the period 1980-2007. These levels peaked in 2000 and have declined since then due to water shortages as a result of prolonged drought, possibly a consequence of climate change. However, some rebound is expected for 2009 due to the drought easing. At its peak in 2000, Australian cotton production amounted to 819 kilotonnes (hereinafter referred to as KT), and made up 4.16% of the world total production; Australia exported 850 KT, of cotton which accounted to 14.90% of the world's cotton export trade (see Table 1).

Table 1: The volume of Australia's cotton output and exports (1980-2007) in '000 tonnes and the global share of these

Year	Production			Export		
	World	Australia	%	World	Australia	%
1980	13799	99	0.73	5719	53	0.93
1985	17450	259	1.49	6114	248	4.06
1990	18975	434	2.29	6437	299	4.65
1995	20439	429	2.10	5958	319	5.36
2000	19400	819	4.16	5705	850	14.90
2001	21491	728	3.39	6347	682	10.75
2002	19809	366	1.85	6632	579	8.74
2003	21067	371	1.77	7229	470	6.51
2004	26441	654	2.48	7624	436	5.72
2005	25383	610	2.41	9708	628	6.47
2006	26561	294	1.11	8077	464	5.75
2007	26245	133	0.52	8370	266	3.18

Sources: (1) United States Department of Agriculture(USDA), Foreign Agricultural Service(FAS), 2009;
(2) Australian Bureau of Agricultural and Resource Economics (ABARE) , 2009.
Notes: year: Aug. 1 - July 31.

China is not only the major global producer of cotton, it is its major consumer as well. In the five years from 2003 to 2007, the average output of Chinese cotton was 6,750 KT per year, which was 27% of the world total, on average. On average, China also imported annually 2,466 KT of cotton and this accounted for 30% of the world's exports of cotton. In the corresponding period, China's textile industry consumed 9,499 KT of cotton annually, accounting for 38% of the total quantity of cotton consumed in the world. Table 2 provides data on China's cotton production and its imports of cotton for the period 1980-2007.

Table 2: The volume of China's cotton production and imports (1980-2007) in '000 tonnes and the global share of these

Year	Production			Import		
	World	China	%	World	China	%
1980	13799	2700	19.57	5934	773	13.03
1985	17450	4137	23.71	6310	1	0.02
1990	18975	4507	23.76	6658	481	7.23
1995	20439	4769	23.34	5879	634	10.79
2000	19400	4420	22.79	5711	51	0.9
2001	21491	5313	24.73	6381	98	1.54
2002	19809	5487	27.7	6573	681	10.37
2003	21067	5182	24.6	7406	1923	25.97
2004	26441	6598	24.96	7283	1391	19.1
2005	25383	6184	24.37	9686	4199	43.36
2006	26561	7730	29.11	8150	2306	28.3
2007	26245	8056	30.7	8283	2511	30.32

Sources: (1) United States Department of Agriculture, Foreign Agricultural Service, 2009;
(2) The National Cotton Council, 2009.
Notes: year: Aug. 1 - July 31.

Australia and China are among the 10 major cotton-producing countries in the world, Table 3 shows the basic situation of the 10 major cotton-producing countries in the world in terms of their level of production, area planted, and yield for a .recent 5 year period (2002/03-2006/07).

Table3: Ranking of the 10 major cotton producing countries in terms of their level of cotton production, area planted and yield.

	Production		Area		Yield	
	KT	rank	1000 ha	rank	Kg/ha	rank
China	6235.73	1	5409.98	2	1150.91	5
USA	4537.15	2	5181.00	3	872.48	7
India	3677.43	3	8424.27	1	430.98	10
Pakistan	2047.51	4	3065.28	4	665.50	9
Brazil	1197.72	5	990.11	6	1206.24	4
Uzbekistan	1079.93	6	1421.03	5	758.91	8
Turkey	861.29	7	668.06	7	1288.45	3
Australia	458.54	8	242.17	9	1893.47	1
Greece	366.65	9	355.56	8	1029.50	6
Syria	280.69	10	215.78	10	1298.30	2

Source： The National Cotton Council of America（NCC）, 2009.
Note: quantitative data are on a 5-year average for 2002/03-2006/07.

From Table 3, we find that China is the major global cotton producer, Australia has the highest yield of cotton per ha (hereafter referred to simply as yield) and India has the largest planted area of cotton. In this group of the 10 major cotton producers, the

planted area of cotton in China ranks second and its yield ranks fifth. The combined effect of these two factors makes the level of gross cotton production of China the highest in the world.

3. Markets and the Sustainability of Cotton Production

The economic theory of market operations can be used to provide background on the forces affecting the sustainability of global cotton production. The theory asserts that market demand and supply conditions determine the volume of production of a commodity and the direction of change in this. Other things held equal, a rise in the demand for a product will normally increase its market supply, as will a fall in the cost of its supply. The latter increases the willingness of producers to supply the good to the market. In the case of cotton, the global demand for it appears to have increased with the passage of time as has the willingness of farmers to supply cotton. At the same time, there has been a long-term tendency for the real price obtained by growers for cotton (that is its price adjusted for price inflation) to decline. This long-term pattern of change can be analysed by means of market demand and supply relationships.

Consider the illustration in Figure 1 which is based on the assumption that the market for cotton is a purely competitive one. This implies that neither individual buyers nor sellers of cotton have any market power, they are price-takers. In an initial period, it is assumed that the market demand for cotton as a function of its price is as shown by line D_1D_1 and that its market supply (also as a function of its prices) is as indicated by line S_1S_1. The result is that market equilibrium is established at point E_1 with the equilibrium supply of cotton being X_1 and its real price being P_1. However, with the passing of time, the market demand curve for cotton shifts upwards and the supply curve moves to the right. In Figure 1, this results in a shift from D_1D_1 to D_2D_2 and from S_1S_1 to S_2S_2 respectively with the equilibrium of the market altering from E_1 to E_2. The volume of cotton production rises but its real price falls. As long as it is possible to sustain shifts in the cotton supply and demand curves in this way, cotton production will not only be sustained but will increase in volume.

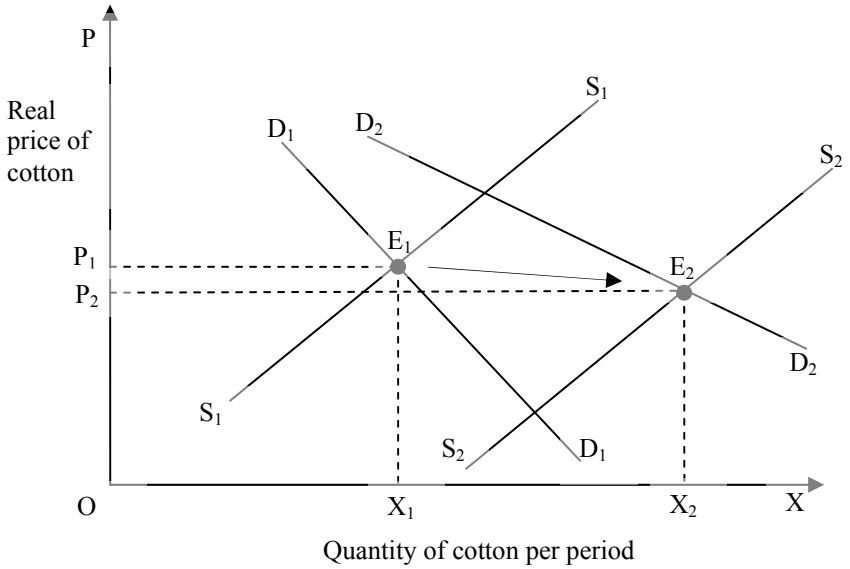

Figure 1 Globally the volume of cotton supply has shown a long-term upward trend. This is consistent with the market change illustrated above as is discussed in the text. Cotton production has not only been maintained but has grown. Whether or not this trend will be sustained is not clear.

Although chemical fibres are a substitute for cotton, they are not a perfect substitute. The qualities of many chemical fibres are improved when they are blended with cotton. Rising global population and the presence of more people with higher income have helped to raise the demand for textiles, including cotton. Hence, the demand curve for cotton has moved upwards but because there is now scope for the substitution with chemical fibres, the market demand curve (shown by D_2D_2 in Figure 1) has become flatter, that is more price elastic.

The global supply curve of cotton appears to have moved to the right more quickly than the demand curve has shifted upward. This is to a large extent due to lower real costs of producing cotton as a result of new techniques and improved management of its cultivation. The global yield of cotton per hectare has, for example, shown an upward trend since 1980 and the area planted with cotton has also risen (see Zhao and Tisdell, 2009). Cotton production has both intensified and become more extensive. Improved varieties of cotton and the introduction of genetically modified cotton seem to have played a positive role in reducing the per unit costs of producing cotton.

Whether or not past trends will continue is uncertain. Increased demand for land to supply food and for organic material to produce biofuels could, in the long-term,

result in less land being available for growing cotton. Furthermore, reduced availability of water for growing cotton may occur due to climate change and increased competition for use of water for other crops and purposes. The world's population is expected to increase by 30 per cent in the next two decades and this will place increased economic pressure on agriculture (Mann, 2008). In addition, cotton production (particularly in higher income countries, and increasingly so in less developed countries) depends to a large extent on the availability of non-renewable resources such as mineral oil. These resources are predicted to become scarcer in the future.

Another factor that could result in cotton supplies not being sustained is a reduction in its ecological fitness. For example, due to natural selection, genetically modified cotton may no longer be able to perform the functions for which it was originally intended. For instance, some types of caterpillar pests may no long be deterred by Bt cotton and new pests may emerge that are not affected by the Bt cotton. So far, however, the industry has been successful in staving off challenges to its sustainability

4. Trends in Overall Cotton Yields and Supplies as Indicators of the Sustainability of Cotton Production.

The yield of cotton per hectare and the area planted with cotton determines its aggregate level of production. As pointed out in the previous section, global yields of cotton have shown an upward trend in the period 1980-2007 and the total volume of cotton production rose. In China's case, both its yield of cotton and its total land area planted with cotton displayed a fairly steady upward trend. In Australia, cotton yields have shown a strong tendency to grow, but the volume of Australia's production of cotton has not been sustained. In the period 1980-2007, the volume of Australia's cotton production peaked in 2000 and then declined due to lack of availability of water caused by drought. Drought reduced the land area planted with cotton in Australia after 2000. Trends and factors influencing levels of China's and Australia's cotton production are outlined in Zhao and Tisdell (2009).

Zhao and Tisdell (2009) using linear regression analysis found a close statistical fit between cotton yields per ha as a function of time for the world, China, and Australia on the basis of data for the period 1980-2007. According to the relevant regression

analysis (Zhao and Tisdell, 2009), world cotton yields per ha tended to increase by 9.77kg per year, China's yields rose by 22.27kg per year and Australia's cotton yields increased by 29.93kgs per year. There is no hint from this historical data that yields per ha are going to decline nor that their absolute rate of increase is about to decline. However, projection of the historical record is risky. It is merely a mechanical exercise.

A more rewarding approach is to analyse the underlying relationships that influence yields. Amongst other things, this requires that consideration be given to the geographical location of cotton production and any changes in this as well as the nature of the farming systems used and their ecological consequences. Globally (and within some countries), there have been alterations in the location of cotton production as well as in systems for producing cotton, for example, replacement of traditional cotton varieties with genetically modified varieties.

Although globally China has retained its position as the major producer of cotton, India has edged out the United States as the second largest producer of cotton, and in recent decades Australia progressed from being of negligible importance as a global cotton supplier to being a significant supplier. Although the general location of cotton production in Australia has not changed much since 1980, the location of China's cotton production has tended to shift towards its west, particularly Xinjiang. This shift has had a positive impact on aggregate yields of cotton in China because growing conditions for cotton tend to be more favourable there than in eastern China, especially compared to areas in the Yellow River region. Improvements in farming systems have, of course, also played a role in increasing cotton yields in China and elsewhere. In considering the sustainability of cotton yields and production, it is important to take into account economic factors, the geographical location of cotton growing and the farming systems involved. This will now be done for Australia and China in order to better appreciate the challenges faced by both those countries in sustaining their cotton supplies.

5. The Geographical Locations of Cotton Production in Australia and China and the Sustainability of Supply

The cotton production of Australia is located in New South Wales (NSW) and Queensland (QLD), in the river valleys along rivers, between 23ºS and 33ºS

(Tennakoon and Milroy, 2003). The major production area in NSW stretches south from the Macintyre River on the Queensland-NSW border and covers the Gwydir, Namoi and Macquarie valleys. In NSW, cotton is also grown along the Barwon and Darling Rivers in the west and the Lachlan and Murrumbidgee rivers in the south. In Queensland, cotton is grown mostly in the south in the Darling Downs, St George, Dirranbandi and Macintyre Valley regions. The remainder is grown near Emerald, Theodore and Biloela in Central Queensland (Figure 2). Except for this cotton (which is grown in the Fitzroy River Basin), all Australian cotton is grown in the Murray-Darling Basin. Whereas the Fitzroy River flows into the Pacific Ocean, the water from the Darling and Murray rivers and their tributaries flow through inland Australia to reach the Southern Ocean.

The Murray-Darling River System has been subject to severe drought since 2000 (Draper, 2009) and this has adversely affected the supply of Australian cotton. It is estimated that approximately 20% of water used for irrigation in the Murray-Darling system is used to irrigate cotton (Draper, 2009, p.47). Apart from drought conditions, state governments have tended to issue rights to use water in the Murray-Darling basin in excess of its sustainable capacity to supply water. This over allocation has reduced water flows in the Murray River to such an extent that it no longer reaches the sea. This is a similar situation to that for the Yellow River in China.

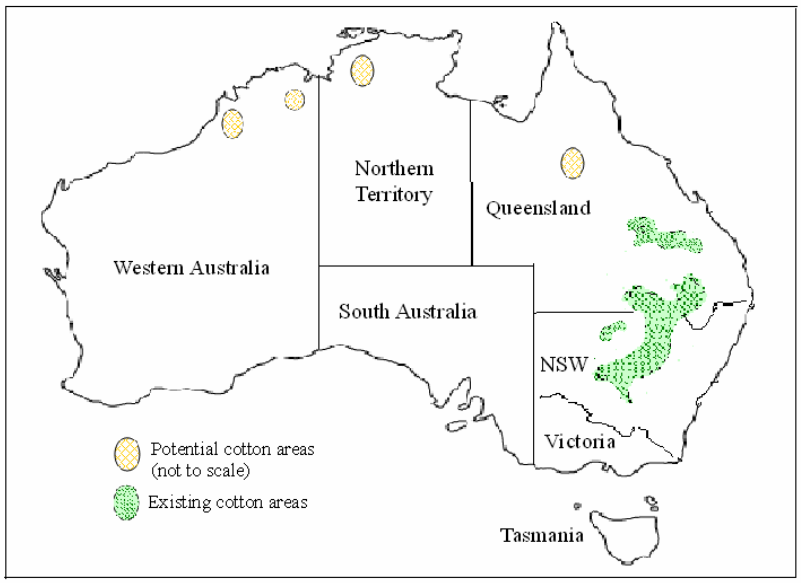

Figure 2 Map showing the general location of cotton production in Australia and potential cotton region

Because water shortages in the Murray-Darling Basin are a major constraint on the sustainability of Australian cotton supplies, consideration has been given to promoting the planting of cotton in new areas in tropical northern Australia (see Figure 2). Rainfall in these areas depends on the annual monsoon. At the present time, however, Australia's cotton fields are concentrated in its southwest in inland locations, and water availability is the main constraint on Australia's supply of cotton.

Approximately two-thirds of Australia's cotton is grown in NSW with the remainder produced in Queensland (Cotton Australia, 2008a). In 2006/07, the planted area in NSW and QLD occupied respectively 73% and 27% of the total planted area of cotton in Australia and the percentages of their production were respectively 76% and 24% (ABARE, 2009).

The geographical location of cotton growing in China is much more dispersed than in Australia. In China, the planting of cotton spreads over 25 provinces and regions. Only 6 provinces and regions do not grow cotton (Zhao, 2006). Nevertheless, China's cotton production is comparatively centralized in the three major regions (Figure 3): the Northwestern Inland Cotton Region(Xinjiang), Yellow River Watershed Cotton Region(Huang-Huai-Hai Plain) and Yangtze River Watershed Cotton Region(Middle and Lower Reaches). Significant constraints on the supply of cotton vary according to the region considered.

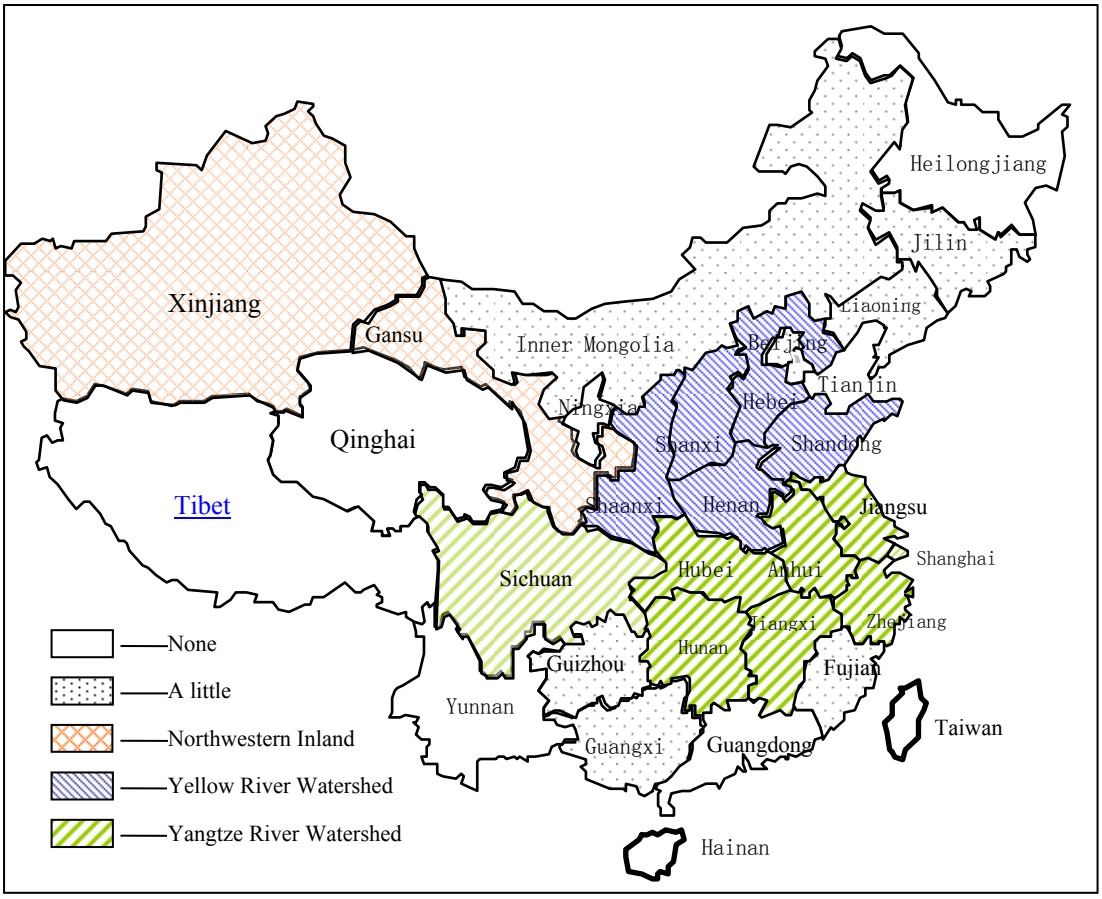

Figure 3: Map showing the general location of cotton production in China by province

Farming systems for producing cotton also differ between China's major cotton-producing regions. Xinjiang is the only cotton region with large-area plantations and with a high-level mechanization. In the Yangtze River Watershed and Yellow River Watershed, the cotton fields are small and very dispersed with low yield, high production costs and low comparative benefits. Furthermore, these two regions are China's main grain-producing areas. There is intense competition in favour of using land to grow grain and other food crops and as a result that available for cotton fluctuates considerably. (Zhao and Ding, 2008). In 2006, according to NBSC (2007), the Yangtze River Watershed, Yellow River Watershed and the Northwest accounted respectively for 26.38%, 47.12% and 25% of the area planted with cotton in China. Moreover, 24.06%, 39.82% and 34.35% of China's total production of cotton by weight in 2006 was supplied respectively by these regions. Xinjiang (located in the Northwest area) alone produces 32.4% of China's cotton, almost one-third of it.

These statistics have some interesting implications. They imply that in 2006, the three major cotton-producing regions of China accounted for 98.5% of the area planted with cotton in China and 98.23% of its production of cotton by weight. Furthermore, it can be deduced that significant difference exist in cotton yields per ha in the various regions. Yields are highest in the Northwest region, significantly lower in the Yangtze Basin and lowest in the Yellow River Watershed. In 2006, yields of cotton per ha in the Northwest were 50% higher than those in the Yangtze River region and 62.26% higher than in the Yellow River region. Therefore, as stated in the previous section, the geographical movement of China's production towards it northwest has been a major factor in increasing its overall yield of cotton since 1980.

There are great differences in climate, soil, quality, ecological conditions and the incidence of plant diseases and insect pests in the three main cotton-growing regions of China. The Yangtze River Watershed cotton region has suitable temperatures and soil fertility for growing cotton but experiences frequent summer drought; the Yellow River Watershed cotton region has abundant sunshine in the spring and fall but drought often occurs in the winter and the spring, its soil is poor and its ecological conditions are fragile. The Xinjiang cotton region has abundant sunlight in summer, a dry climate and big differences occur between day and night temperatures. These environmental conditions are favourable for the growth of cotton. Because this region has little rainfall in normal years, its cotton production depends completely on irrigation (Zhang, 2001). Due to irrigation works and its utilization of both surface water and groundwater, the irrigated area of Xinjiang expanded from 1,450 thousand ha in the early 1950s to over 4,000 thousand ha in 2007. About 2,000 thousand ha can be irrigated even in drought years. The area planted with cotton in Xinjiang in 2007 was 1,782.6 thousand ha (Guan, 2008). This means that about half the irrigated area in Xinjiang is planted with cotton and probably an even larger proportion of the area for which irrigated water supplies are assured. The construction of irrigation works and the adoption of water-saving irrigation technology make Xinjiang an important cotton producing region. Nevertheless, water availability is a constraint on the expansion of cotton production in Xinjiang.

6. The Structure and the Nature of Australia's and China's Cotton Farming Systems and the Size of Farms – Sustainability Issues

Australian cotton is produced on farms of very large size (usually 500-2000 ha in size) and individual fields of cotton also tend to be very large (see Figure 4). Australian methods of cotton production are also very capital-intensive and depend heavily on purchased material imports. On the other hand, cotton production on three-quarters of the land used for cotton in China depends on labour-intensive methods with farm sizes being extremely small. Cotton production in Xinjiang is exceptional in China because it is much more capital-intensive than cotton production in the rest of China. However, even here cotton farms employ temporary migrant labour to pick cotton and to weed the cotton crop. The difference in the culture of cotton in Australia and China is a consequence of China being a country in which agricultural labour is relatively plentiful whereas agricultural labour is relatively scarce in Australia.

Figure 4: Photo of an Australian cotton field with one of the authors in the foreground)

There are about 1,100 farms in Australia producing cotton and most are family operated (Cotton Australia, 2008a). Apart from growing cotton, most cotton growers

also produce other broadacre crops such as sorghum, maize and sunflower and some graze cattle and sheep (Cotton Australia, 2008a; Morris and Stogdon, 1995). The whole process of cotton production in Australia is mechanized. This includes land preparation, planting, irrigation, weeding and pest control, cotton defoliation prior to harvesting, harvesting (see Figure 5), transport to the cotton gin, (see Figure 6) and processing and packaging.

Figure 5: Machinery harvesting cotton on the Darling Downs in Australia

Figure 6: Transport of cotton to the gin in Australia is completely mechanized. This shows cotton being compacted on a farm for transport to the gin.

A huge number of families in China produce cotton and each on average cultivates only a small amount of land for this purpose. According to Lei (2004), about 45 million Chinese families are engaged in the planting of cotton with an average area of 0.13 ha of cotton being planted by each family growing cotton. For most of the families who plant cotton, especially the ones in the non-major cotton regions, their cotton plots are scattered and are unsuitable for planting food crops. They plant cotton just as a supplement to their principal crops (mostly food crops). In these regions, the planted varieties and acreage of cotton vary greatly between years (Du, 2005). Most cotton is tended and picked by hand because it is impractical to use machines of even moderate size on small scattered cotton plots.

Australian production of cotton involves a high level of yield but also a high level of non-labour input per unit of output. In fact, Australian cotton yields per ha exceed that of other countries. By contrast most Chinese cotton growers depend much less on purchased imports for their production but their cotton yield per ha is lower than in Australia.

Because of the high intensity of Australian cotton production, Australian cotton growers have to give considerable attention to the best practice to sustain and increase their yields. The problems which they have in sustaining yields differ in many respects for those experienced by farmers who have small plots of cotton in China. In Australia's case, there is a risk of soil compacting due to use of heavy machinery in cotton cultivation and deterioration in soil quality due to substantial use of chemicals applied in cultivating cotton. These problems appear to be less acute in China because of most of its production does not depend on the use of heavy machinery and in most cases less use is made of chemical fertilizers and pesticides. However, some problems involved in sustaining levels of cotton production and cotton yields are the same in China and Australia. Let us further consider the challenges facing each country in sustaining their levels of cotton production. In doing this we concentrate on economic and ecological challenges but to some extent the economic challenges reflect sociological challenges. The sustainability of agricultural supplies has been claimed to depend on economic ecological (including environmental) and sociological factors (Tisdell, 1999; see also Conway, 1985, 1987).

7. Challenges being faced in Sustaining Australia's Cotton Production.

7.1 Economic challenges and economic phenomena affecting the sustainability of Australia's cotton supply

The nature of cotton production in Australia has important economic consequences for Australia's supply of cotton and its sustainability. As in the United States, cotton is a high input crop requiring sustained careful management. It requires high levels of fixed investment as well as a high level of investment in each crop sown. In the Australian case, fixed capital investment is needed in machinery (much of which is specific to cotton) and irrigation infrastructure, such as dams (See Figure 7). However, some of the investment in machinery specific to cotton can be avoided by individual cotton growers by hiring equipment or contractors to undertake some of the processes involved in cultivating cotton. Nevertheless, this also involves market risks because it depends on the availability of such contractors. In addition, for these farmers who have not previously grown cotton, they have to learn a great deal about how to optimally cultivate the crop. These factors tend to reduce the elasticity of the supply curve for cotton in Australia and result in a degree of lock-in to the growing of cotton

by farmers who have begun to grow it successfully. The latter means that, to some extent, path-dependence exists in cotton supplies in the Australian industry.

Figure 7: A large earthen dam on a cotton farm in Southwest Queensland, Australia

Theoretically, this phenomena means that the supply curve of Australian cotton exhibits hysteresis which implies that it lacks perfect reversibility. This is illustrated in Figure 8. There, the line AS_1 represents the aggregate supply of Australian cotton in response to a sustained level of its price, other things (such as water availability) held constant. If the price of cotton should rise from P_0 to P_1 in a way that appears as though it will be sustained the supply of cotton expands from X_0 to X_2. Suppose, however that after remaining at P_1 for some considerable time the price of cotton falls back to P_1. The supply of cotton does not return to X_0 but may only fall back to X_1 because market equilibrium has been at E_1 and many investments specific to cotton supply have been made. The effective supply curve after such investments may then be the kinked line BE_1S_1. The lock-in effect due to path-dependence is, therefore, equivalent to $X_1 - X_0$. This means that because of past economic decisions, cotton production is sustained at a higher level than would otherwise occur. Of course in the

very long run, this lock-in effect will diminish. However, it results in supply being reduced at a slower rate with the efflux of time when the price of the product is reduced than occurs for a comparable increase in its price.

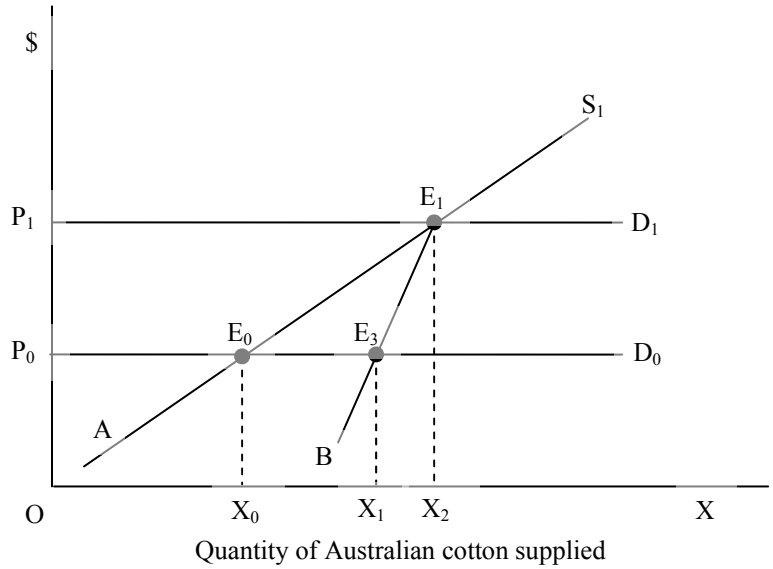

Figure 8: An illustration of hysteresis in the Australian supply of cotton. In this case, there is a lock-in effect on supply of $X_1 - X_0$ due to the historical occurrence of an equilibrium at E_1, as is explained in the text.

Because of differences in the nature of cotton production in more developed countries (such as Australia and the United States) one expects the lock-in phenomenon in supply to be more important in such countries than in less developed countries, such as China, because the latter have lower levels of specific investment in cotton production. However, in China's case this phenomenon has more relevance to its production of cotton in Xinjiang than in its other provinces.

7.2 Environmental factors affecting the sustainability of Australian cotton production.

Given the above-mentioned considerations, the elasticity of supply of Australian cotton in relation to its price can be expected to be relatively inelastic, more so than in the case of alternative summer crops such as sorghum, sunflower and maize. These crops (especially sorghum) require less investment than cotton and less intensive management. Sorghum is also more drought-tolerant. As Commins (2008) points out, growing cotton in Australia is risky because of the considerable sunk investment involved. Financial losses are high if there is crop failure or a partial crop failure or if

prices are low. Therefore, many farmers will not risk growing cotton, especially if they have no previous experience with growing it. Furthermore, in Australia cotton must be grown on a large-scale and intensively if it is to be profitable (economic) unlike in China.

The prices received by Australian farmers for cotton can vary considerably because they are world prices (Carpio, 2002). There is no government intervention to help stabilize prices paid to Australian farmers for their cotton and no subsidies for Australian cotton. This contrasts with the situation in the United States where the government guarantees cotton growers a minimum price for their cotton. Also, the Chinese government attempts to moderate fluctuations in prices paid to Chinese farmers for cotton. When global cotton prices are depressed, the Chinese government reduces the amount of cotton that can enter China duty free and also it increases its level of tariffs on cotton imports. This helps maintain the price paid for domestic cotton. Furthermore, the Chinese import system often requires that Chinese cotton importers buy a specified amount of cotton from Xinjiang to qualify for their import quotas. This is a way of giving financial preference to Xinjiang cotton-growers who are financially much more dependent on cotton than most growers of cotton elsewhere in China. Despite these interventions, the prices paid to Chinese growers of cotton still fluctuate considerably.

Given that most Australian producers of cotton are relatively efficient (compare Chan and Zepeda, 2001) and are relatively well informed about price trends, economic factors are not the major constraint on Australian cotton supplies. The availability of water has become the major challenge in recent times to sustaining supplies of Australian cotton.

Due to drought in the Murray-Darling Basin, there was a major decline in the quantity of cotton produced in Australia in the period 2000-20007. In 2000, Australian production of cotton peaked at 819 kilotonnes and declined to 133 kilotonnes in 2007. This was mainly due to the reduced area planted with cotton. This fell from 527 thousand ha in 2000 to 63 thousand ha in 2007; a reduction of about 88 per cent in the area planted with cotton. Nevertheless, yields continued to show an upward trend in this period. There are fears that due to climate change water availability is likely to

become more variable and lessen in Australia's regions that now grow most of its cotton crop.

While water availability increased to some extent in 07/08 and in 08/09, Commins (2008) reports that some cotton farmers are wary about increasing their exposure to cotton. They continue to be worried about the availability of water and think it will become more valuable in the future. There is a possibility that government restrictions on the use of water for agriculture will increase in Australia.

A consequence of the sharp reduction in Australian production of cotton has been that many cotton gins have excess capacity. Instead of working three shifts per day, most now only work a single shift and operate for fewer months of the year. Given the considerable fixed costs incurred by gins, their costs per unit of cotton ginned have tended to rise because Australian cotton production has not been maintained. Their continuing economic viability depends on Australian farmers supplying more raw cotton than in recent years. Lack of sustainability of primary cotton production has flow-on consequences (see Figure 9).

Figure 9: Baled ginned cotton at a cotton gin near Dalby Queensland, awaiting export to China.

A continuing challenge for Australian cotton production has been managing the pressure of diseases, weeds and insect pests in cotton in order to maintain the profitability of growing cotton. This is, however, not a problem peculiar to the Australian cotton industry – it is a global challenge. The problem is that biological systems adapt to control measures and evolve so that particular pest control measures usually only have a limited effective life and repeatedly new measures need to be developed. While transgenic varieties of cotton have boosted the effectiveness of pest control in Australia, it is too optimistic to think that particular genetic variations will be fit for their purpose forever because nature is very adaptable. Despite all such challenges, yields per ha of Australian cotton have displayed a strong upward trend, even though the volume of Australian cotton production fell sharply between 2000 and 2007. Reduced yields were not the reason for the slump in production of Australian cotton. Its main cause was lack of water availability due to drought which resulted in a severe reduction in the area planted with cotton in Australia. Once water supplies in the Murray-Darling Basin increase again, the area planted with cotton will

increase but the indications are that the response will be damped given recent experiences of farmers with drought and long-term prognosis about water availability.

8. Challenges Being Faced in Sustaining China's Cotton Production.

8.1 Economic factors affecting the sustainability of China's cotton supply.

In its agricultural policy, China gives top priority to the production of food. Consequently, the allocation of land for growing non-food crops (such as cotton) is limited to some extent (Guan, 2008). Nevertheless, there are fewer limitations on agricultural land-use in China than in the pre-reform period, even though market and related government interventions are still of importance. Farmers now have the right to decide which crops to plant, but the State can regulate this indirectly according to need, by such means as altering the price between cotton and grain, granting different subsidies for different crops and so on.

A new issue that is affecting the economics of China's agricultural production is a relative shortage of agricultural labour. This contrasts with the earlier situation in China when China had surplus of agricultural labour (Cao and Tisdell, 1992; Cao, 2005). Because many young and middle-aged people leave rural areas and agricultural industry for jobs in urban areas, all agricultural production, including cotton production, faces new challenges. According to the survey made in 2006 in 17 provinces (municipalities and autonomous regions) (Zhang, 2009), 74.3% of villages responded that nearly all young and middle-aged people went out to work and more than 80% of young and middle-aged labour force in approximately one third of the investigated villages had transferred to cities. On average, 48 young and middle-aged people per village stayed at home; the proportion was 17.82% (Xia, 2009). The aged rural labour force without much education and with little enthusiasm for farming not only influences the input of farmers, but is also unfavourable to the adoption of modern agricultural technologies.

Returns from growing cotton are very unstable in China these days and economic returns tend to be low. Economic returns fluctuate because the cotton price fluctuates all the time and production costs, due to variations in the prices of pesticides and chemical fertilizers, change constantly (Zhang, Wang, and Tuo, 2008). Furthermore,

labour costs have risen, so the gains from cotton production are unstable and have declined sharply in recent years, thereby lowering farmers' willingness to plant cotton.

Because of the very small scale of most Chinese farms growing cotton, mechanization and capital-intensive methods of cotton production tend to be uneconomic in China. In fact, most techniques used for cotton production on a large scale in Australia and in the United States are uneconomic in China, except (to a certain extent) in Xinjiang Autonomous Region. The most frequent situation is that all processes involved in cotton production are done manually (see Figure 10). The undersupply of cotton pickers in Xinjiang becomes a pressing problem when the picking season comes and these workers must be introduced from the inland on a large scale. Picking cotton by hand is of low efficiency with a long-time required to complete the harvest, and a large amount of labour is used at a high cost. This hinders the expansion of cotton production in China.

Figure 10: Cotton seed being planted by hand on a small plot in Hubei Province, China. All operators involved in growing cotton on this farm are done by hand.

Given the rapid economic development of China in the last three decades, and the major movement of rural labour to off-farm work and its drift to cities for work, it has become more difficult for China to sustain its level of agricultural production using traditional labour-intensive methods. This, together with China's preference for agricultural production of food, is making it more difficult for China to sustain

increases in its level of cotton production. Nevertheless, China's trend in total cotton production has remained an upward one (see Table 2). However, further economic growth in China's economy can be expected to add to the difficulty of sustaining growth in China's cotton production and may increase pressures for the amalgamation of farms. Larger sized farms could make the use of more capital-intensive techniques more economic. However, much institutional change would be needed to make farm amalgamations possible in China and the reform process may be slow. The general pattern of economic development in Western economies has been for farm sizes to become larger and for farms to become more specialized in their production but this adjustment problem is more difficult in transitional economies, such as China and Vietnam (see Tisdell, 2010 in this volume)

8.2 Environmental factors influencing the sustainability of China's cotton production

The main regions in which cotton is grown in China experience different agro-climatic conditions. While some environmental problems are common to all of China's cotton growing areas, there are also regional differences in the nature and severity of these problems. These differences are much greater than in Australia's case. In Australia, there is less dispersion of the areas in which cotton is grown and greater similarity of environmental conditions experienced in these areas than in China, even though the land in which cotton is grown in Australia is from north to south over a 1000 kms in length.

Water availability exerts a major influence on the sustainability of China's cotton supplies and the issues involved varying according to the region in China where cotton is grown. Drought, floods and the unsustainable use of available water supplies (especially groundwater) are of concern.

The Yangtze River Watershed Cotton Region has a relatively sufficient water supply but experiences floods and droughts (Xu, 2007). In the Yellow River Watershed Cotton Region drought prevails, and Xinjiang Cotton Region is characterized by "drought in spring, flood in summer, water shortage in fall and low water in winter" (Ouyang, 2008). Almost all the surface water resource of Xinjiang have been used for irrigation. Although only 20% of water resources of Ertix River and Ili River are developed and utilized, nearly 85% of water in most middle and small rivers is

diverted (Ouyang, 2008). According to research by Chen, Chen, and Wang (2007) and Zhang (2004), groundwater is the main water source for northern China. Taking Hebei, Shanxi and Henan in the Yellow River Basin Cotton Region for example, in 2004, the proportions of groundwater use to the total water use were respectively 74.3%, 66.8% and 55% for the three provinces. The percentages of groundwater used for agricultural production were 75% in Hebei province and over 50% in Shanxi and Henan. The groundwater exploitation rates are 128%, 78.1% and 83.2% respectively. This means that in Hebei province the rate of withdrawal of underground water exceeds its rate of replacement and therefore the watertables are falling. Such a situation is unsustainable. Even in other provinces, this is a problem in some areas. Falling underground watertables add to the cost of extracting water and lower the availability of surface water. The overuse of groundwater (as well as surface water) can have many adverse ecological consequences.

In addition, while China has a many irrigation works (reservoirs and canals etc.), most of these were built in 1950s and 1960s with low standards of construction. Most have not been maintained, renovated and transformed for a long time and are ageing. According to the statistics (Yu, Zhang, and Fang, 2008), 10% of irrigation projects fail to function and 60% are damaged to some degree. From 1999 to 2008, 20 reservoirs in China collapsed because of defects or other quality problems. In 2009, there are estimated still to be 37,000 dangerous reservoirs, 43.3% of all reservoirs in China (Chen, 2009).

Cotton cultivation methods used in many places in China are reducing soil quality. First, the practice of continuous cropping with cotton is a problem. Generally speaking, cotton plots are continuously cropped with cotton for more than 10 years, and even some are continuously cropped for up to 20 years (Bai, 2008). Secondly, plastic film is used to mulch many cotton crops and suppress weeds but its use leaves plastic residues in the soil（Ma, 2008）. As is indicated by an investigation completed by Wan and Wang (2006), one year of plastic mulching leaves 46.2% of plastic residues in the soil; if plastic mulching occurs for five consecutive years, the cotton yield is reduced by 10% to 23%. Third, increasing application of chemical fertilizers and a relative decrease in the use of organic fertilizers has reduced the organic matter (humus) in some cultivated land and the soil structure has deteriorated.

Diseases in cotton plants, insect pests and weeds, make it difficult to maintain cotton yields. While the broadacre planting of cotton (as in Xinjiang) can yield economies of scale, it provides favourable ecological conditions for the spread of plant diseases and insect pests. For example, in the Xinjiang Cotton Region, commonly 20% to 30% of plants in cotton plots are diseased and the proportion is over 80% for a few plots (Bai, 2008). Furthermore, continuous cropping adversely affects the balance of soil nutrients and provides suitable conditions for the multiplication of insect pests (Ma, 2008).

China finds it to be difficult to achieve and maintain a high uniform quality in its supply of cotton because of the lack of uniformity in the varieties of cotton sown. Even in the same plot of land, multiple varieties of cotton are often sown. When multiple varieties are planted in the same plot, they cross pollinate, leading to variety variation and lower cotton quality and fibre strength, dull lustre, big differences between the quality of bales and poor spinnability. By contrast, the quality of cotton in each Australian bale is virtually uniform.

Nevertheless, despite all these difficulties, the yield and supply of Chinese cotton has displayed an upward trend since 1980. In part, however, this can be attributed to the shift in cotton production towards China's Northwest Region. It seems likely that China will face greater difficulties in sustaining its production of cotton in the future than in the past.

9. Discussion of Some Measures to Counter Lack of Sustainability of Cotton Supplies in Australia and China

China and Australia are both aware of the sustainability challenges facing their supply of cotton. Several initiatives have been adopted in Australia's cotton industry to help secure the sustainability of its cotton supplies. These include the following:

(1) The Best Management Practices (BMP) program has been adopted. This is designed to help cotton growers identify and manage the risks associated with their use of pesticides and petrochemicals, and to improve the management of their soil, water and vegetation (Williams, 2008). As a result of the BMP Program, it is claimed that Australia's cotton industry is at the forefront of sustainable practices,

thereby fostering a positive future for the industry and the natural systems that support it (Cotton Australia, 2008c).

(2) Progress in agricultural technology development, especially in transgenic technology and its application in cotton production, many contribute to the sustainability of yields. In 2006, 95 per cent of Australia's cotton growers planted transgenic varieties, and these account for 80 per cent of the total area planted with cotton (Cotton Australia, 2008a).

(3) Fallow and rotation of cotton plots are recommended so that the soil fertility can be maintained.

(4) There is increased emphasis on the more efficient use of water in cultivating cotton.

These measures are of great importance for the future sustainability of cotton production in Australia and they need to be adhered to for a long period and to be continuously perfected. In the long run, Australia may have an opportunity to increase its area planted with cotton. Although yield may be approaching its maximum, Australia still has land resources that are suitable for planting cotton. It may be possible to expand the planted area:

(1) by replanting areas previously planted in NSW and QLD with cotton in 2000/01; and

(2) as mentioned by the Office of the Gene Technology Operator (OGTR, 2008), several regions in the north of QLD might be developed for cotton production and the cropping area could even be extended to other states.

However, unless water availability increases considerably and reliably in the Murray-Darling Basin or new types of cotton requiring much less water are developed, the recovery mentioned in (1) seems unlikely.

A study by the Australian Cotton Cooperative Research Centre (ACCRC), based on average temperatures during the growing season, timing of rainfall, and the suitability of the soil for cotton cultivation, indicates considerable potential for expansion into northern Australia in particular areas of WA, the NT and QLD. The ACCRC study

examined potential regions for cotton growing in northern Australia and suggested at least 200,000 ha of potential irrigation-areas that could be developed over the next ten years (OGTR, 2008).

China has also been giving consideration to how it can sustain its supply of cotton given current demands on the use of its agricultural land, particularly to grow food. One strategy has been to increasingly locate its cotton production in its northwest, especially Xinjiang (Zhao and Tisdell, 2009). However, there appears to be little scope for increasing the area planted with cotton in the northwest, unless new varieties of cotton that are less water dependent are developed or significant increases in the efficiency of water use can be achieved. A second strategy has been to adopt transgenic technologies to raise yields and to maintain these for longer than otherwise. In 2007, 67% of the area under cotton in China was said to be planted with transgenic cotton (ISAAA, 2007).

If the Chinese economy continues to grow and develop at a fast pace, this is likely to result in significant structural change in Chinese agriculture as rural-to-urban migration continues. In turn, this may result in changes that favour the merging of farms and greater mechanization in agriculture, that is a trend towards more industrial-type specialized farms. The long-term implications of such changes for China's cotton industry are unclear but they may result in a decline in cotton production in all regions of China, except in its northwest. Nevertheless, it is theoretically possible for China to increase its cotton yields which on average are much lower than those in Australia.

10. Conclusion

Global supplies of cotton have shown a persistent upward trend despite the increasing share of the market for textile fibres occupied by chemical fibres. In addition, yields of cotton globally have tended to rise partly as a result of new techniques for the cultivation of cotton (such as the introduction of transgenic cotton) and because new areas have been opened up for growing cotton some of which are more suitable for its growth than areas where cotton was previously established as a crop. The latter has happened in China as a result of an increasing proportion of its cotton being grown in its northwest, mostly Xinjiang. Whether or not these past trends in cotton supply will

continue is unclear but it was argued that projecting past trends is risky and that disaggregation of the statistics on cotton supply is needed to obtain a better picture of the sustainability issues faced by the cotton industry. In order to progress with this aspect, Australia and China were selected for case studies. Both countries are globally important producers of cotton. While the volume of China's cotton production far exceeds that of Australia, Australian cotton is much superior in quality and is mainly exported.

Both economic and environmental factors were shown to have important implications for the sustainability of China's and Australia's cotton supplies. In recent times, lack of water has been the main constraint on Australian cotton production. This has resulted in a dramatic reduction in the area planted with cotton in Australia and a large fall in its volume of production, even though Australian cotton yields per hectare have continued to rise strongly due to improved techniques and methods of production.

On the other hand, China's supply of cotton has continued increasing despite the economic and environmental difficulties which its cotton-growers face. The depth and nature of these difficulties vary between the major cotton-producing regions of China. Water is in short supply in the Yellow River Region and almost all the available water resources have been utilized in China's Northwest Region. Increasing production in these regions (as in Australia) may depend on the development of varieties of cotton that need less water to flourish and on the more efficient use of water. In the Yangtze River Region and the Yellow River Region, government policies favouring the growing of grain and other food crops are edging out cotton production. Furthermore, some cultivation methods, such as the use of plastic sheeting for mulching cotton, are reducing yields.

Labour availability is emerging as another problem for China's agricultural production. As a result of China's economic growth, rural-to-urban migration and increased off-farm work rose in importance thereby creating an agricultural labour shortage compared to the past. Consequently, it is no longer possible to maintain many of the labour-intensive techniques used in the past for cultivating crops, including cotton. As discussed, the bulk of China's cotton supply is obtained by the use of labour-intensive methods. If China continues on the path of economic development which it has experienced in the last thirty years (see Tisdell, 2009)

structural change in the nature of its agricultural sector is likely to be unavoidable. With less agricultural labour available in China, there are likely to be economic pressures to increasingly mechanize and adopt more capital-intensive techniques for agricultural production, raise the size of farms and import more agricultural produce rather than rely as heavily as in the past on domestic production. These complex economic changes may make it very difficult for China to sustain the level of its cotton production in the long term.

11. References:

ABARE. (2009). Australian crop report. The Australian Bureau of Agricultural and Resource Economics, Report No.149, February 17, 2009.

Bai, Y. (2008). Research on the sustainable development of cotton planting by the Xinjiang Production and Construction Corps(XPCC). *Xinjiang State Farms Economy*, (5), 27-36. [In Chinese]

Cao, Yang (2005). Rural-urban labour mobility and income inequality in China against the background of globalisation. Pp. 354-373 in C. Tisdell (ed.) *Globalisation and World Economic Policies*. Serials Publications, New Delhi.

Cao, Yang and Tisdell, C. (1992). China's surplus agricultural labour force: its size, transfer, prospects for absorption and effects of the double-track economic system. *Asian Economic Journal,* 6, 149-182.

Carpio, C.E. (2002). *Production Response of Cotton in India, Pakistan and Australia*. Submitted to the Graduate Faculty of Texas Tech University for the Degree of Master of Science. Accepted in May, 2002.

Chang, H.S., and Zepeda, L. （2001）. Agricultural productivity for sustainable food security in Asia and the Pacific: The role of investment. In: Lydia Zepeda: (ed). *Agricultural Investment and Productivity in Developing Countries*. FAO, Viale Delle, Rome.

Chen, L. (2009). Giving an alarm: still relying on beating gongs and setting off firecrackers in China if reservoirs were to suffer major problems. http://politics.people.com.cn/GB/index.html. [In Chinese]

Chen, X, Chen, D.H., and Wang, Z. (2007). Some opinions about the groundwater exploitation for agricultural production in Northern China. *Acta Geoscientica Sinica*, 28(3), 309-314. [In Chinese]

Commins, R. (2008). Responding to drought - Industry growth regions: expansion in Southern NSW and a move north in the Burdekin. 14th Australian Cotton Conference, Gold Coast, Queensland. August 12-14 2008.

Conway, G. (1985). Agrosystem analysis. *Agricultural Administration,* 20, 31-55.

Conway, G. (1987). The properties of agrosystems. *Agricultural Systems*, 24, 95-117.

Cotton Australia. (2008a). Facts and Figures/ General. From http://www.cottonaustralia.com.au/facts/factsandfigures.aspx?id=18. Accessed December 1, 2008.

Cotton Australia. (2008b). Facts and Figures/ Natural Resource Management Issues. from http://www.cottonaustralia.com.au/facts/factsandfigures.aspx?id=17. Accessed December 1, 2008.

Cotton Australia.(2008c). Growers' Toolkit / Best Management Practices. http://www.cottonaustralia.com.au/toolkit/bmp/

Draper, R. (2009). Australia's dry run. *National Geographic,* 215(4), 34-59.

Du, M. (2005). Analysis on the present situation and countermeasures of cotton production supply and demand in China. *China State Farms*, 7, 26-29. [In Chinese]

Fitt, G., Mares,C., and Constable G.(2002). Enhancing host plant resistance of Australian cotton varieties. Australian Cotton CRC, Narrabri.

Guan, R.J. (2008). *Xinjiang and National Cotton Industry Security*. China Agricultural Press, Beijing, China. [In Chinese]

ISAAA. (2007). Global Status of Commercialized Biotech/GM Crops: 2007. *The International Service for the Acquisition of Agri-biotech Applications.* No. 37.

Japan Chemical Fiber Association (2008). http://www.textileinfo.com/en/news/2008_01/0127_03.html

Lei, J.X. (2004). The influence of China's development of cotton industry on the international cotton market. *The Marketing of Cotton and Jute of China*, (4), 7-9. [In Chinese]

Ma, H.X. (2008). Predicaments for the sustainable development of Xinjiang's cotton industry – a research based on the household economy. *Finance and Economics of Xinjiang*, (6) 24-29. [In Chinese]

Mann, C.C. (2008). Our good earth. *National Geographic,* 214(8), 80-107.

Mao, S.C. (2006). *Report on Prosperity of China's Cotton Production 2005*. China Agricultural Press, Beijing, China. [In Chinese]

Morris, D., and Stogdon, A. (1995). World markets for cotton: forecasts to 2000. Textiles Intelligence Limited and the Economist Intelligence Unit, *Special Report* No.2640.

NBSC, National Bureau of Statistics of China (2007). *China Statistical Yearbook 2007,* China Statistics Press, Beijing.

Oerlikon.(2008). The fiber year 2007/08---A world survey on textile and nonwovens industry. Oerlikon textile Gm.bH and KG. Remscheid Germany, http://www. Oerlikontextile.com. 72-73.

OGTR. (2008). The Biology of *Gossypium hirsutum* and *G. barbadense*, (Cotton), Ver. 2.Office of the Gene Technology Regulator, Australian Government Department of Health and Ageing, Canberra. 11 pp.

Ouyang, J.Q. (2008) Analysis and countermeasure of the supply and need of water resources in Xinjiang. *Economic Tribune*, (24), 40-42. [In Chinese]

Plastina, A. (2008). Cotton's share of world textile fiber use to decline in 2008 and 2009. Presented at the IFCP Session on Cotton Promotion: A Call to Action, 67th ICAC Plenary Meetings, November 19, 2008.

Tennakoon, S.B., and Milroy, S.P. (2003). Crop water use and water use efficiency on irrigated cotton farms in Australia. *Agricultural Water Management*, 61(03), 179–194.

Tisdell, C.A. (1979). *Economics of Fibre Markets*. Pergamon Press, Oxford and New York.

Tisdell, C.A. (1999). Economic aspects of ecology and sustainable agricultural production. Pp 37-56 in A.K. Dragun and C.Tisdell (eds.), *Sustainable Agriculture and Environment*. Edward Elgar, Cheltenham, UK and Northampton, MA, USA.

Tisdell, C.A. (2009). Economic reform and openness in China: China's development policies in the last 30 years. *Economic Analysis and Policy* (in press)

Tisdell, C.A. (2010). The survival of small-scale agricultural producers in Asia, particularly Vietnam: General issues illustrated by Vietnam's agricultural sector, especially its pig production. In this volume, *Sustainable Agriculture: Technology, Planning and Management,* Nova Science Publishers, New York.

Wan, S.M., and Wang, L.X.(2006). Give full play to regional resources superiority for promoting the sustainable development of cotton production in Xinjiang. *Journal of Tarim University*, (1), 98-101. [In Chinese]

Wang, Q.Z., and Chidmi, B. (2009). Cotton price risk management across different countries. Presented at the Southern Agricultural Economics Association Annual Meeting, Atlanta, Georgia, January 31-February 3, 2009.

Williams, A. (2008). Managing the environmental impacts of cotton growing – An Australian perspective. Cotton Research and Development Corporation(CRDC). http://www.crdc.com.au/uploaded/File/E-Library/E-ENVIRO/Mging_Envir_Impacts_Cotton_Growing.pdf.

Xia, L.Y. (2009). Negative effects of labor force drain on rural economy. *Journal of Nanjing Agricultural University,* (1), 14-19. [In Chinese]

Xu, L.H.(2007). Status quo and development ideas for sustainable development of cotton production in Jiangsu Province. *China Cotton*, (4), 4-7. [In Chinese]

Yu, Q., Zhang, H.X., and Fang, J. (2008). Discussion on sustainable utilization of agricultural water resource in China. *Journal of Hebei Agricultural Sciences*, 12 (10), 87 – 89. [In Chinese]

Zhang Z.H., Li L.R.(2004). *Ground Water Resources in China*.: Sino-Map Press, Beijing. 206-214. [In Chinese]

Zhang, C.X. (2001). *Cotton Disaster and Disaster Prevention and Reduction Techniques*. China Agricultural Scientech Press, Beijing. [In Chinese]

Zhang, P.Z., Wang, X.J, and Tuo, H.T. (2008). Status quo, existing problems and countermeasures of the development of Xinjiang's cotton industry. *Xinjiang Agricultural Sciences*, 45 (S2), 174 – 176. [In Chinese]

Zhang, Z.Z.(2009). Agricultural labor shortage – A new challenge for the new socialist countryside construction. *Agricultural Outlook*, (1), 36-40. [In Chinese]

Zhao, X.F. (2006). *Development of China's Agricultural Textile Materials in Relation to Industrial Chains.* Wuhan University Press, Wuhan. [In Chinese]

Zhao, C.H., and Ding, J.G. (2008). "Soft cotton" in Xinjiang with increasing "hard strength". *Economic Information Daily*, Feb.19. [In Chinese]

Zhao, X.F. and Tisdell, C. (2009). A comparative economic study of China's and Australia's cotton production. *Economic Theory, Applications and Issues,* Working Paper No. 53. School of Economics, The University of Queensland, Brisbane 4072.

PREVIOUS WORKING PAPERS IN THE SERIES
ECONOMICS, ECOLOGY AND ENVIRONMENT

For a list of working papers 1-100 in this series, visit the following website: http://www.uq.edu.au/economics/PDF/staff/Clem_Tisdell_WorkingPapers.pdf or see lists in papers 101 on.

101. Knowledge and Willingness to Pay for the Conservation of Wildlife Species: Experimental Results Evaluating Australian Tropical Species, by Clem Tisdell and Clevo Wilson, May 2004.
102. Antarctic Tourists, Wildlife and the Environment: Attractions and Reactions to Antarctica, by Clem Tisdell, May 2004.
103. Birds in an Australian Rainforest: Their Attraction for Visitors and Visitors' Ecological Impacts, by Clem Tisdell and Clevo Wilson, May 2004.
104. Nature-Based Tourism and the Valuation of its Environmental Resources: Economic and Other Aspects by Clem Tisdell, May 2004.
105. Glow Worms as a Tourist Attraction in Springbrook National Park: Visitor Attitudes and Economic Issues, by Clem Tisdell, Clevo Wilson and David Merritt, July 2004.
106. Australian Tropical Reptile Species: Ecological Status, Public Valuation and Attitudes to their Conservation and Commercial Use, by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, August 2004.
107. Information and Wildlife Valuation: Experiments and Policy, by Clem Tisdell and Clevo Wilson, August 2004.
108. What are the Economic Prospects of Developing Aquaculture in Queensland to Supply the Low Price White Fillet Market? Lessons from the US Channel Catfish Industry, by Thorbjorn Lyster and Clem Tisdell, October 2004.
109. Comparative Public Support for Conserving Reptile Species is High: Australian Evidence and its Implications, by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, October 2004.
110. Dependence of public support for survival of wildlife species on their likeability by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, October 2004.
111. Dynamic Processes in Contingent Valuation: A Case Study Involving the Mahogany Glider by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, November 2004.
112. Economics, Wildlife Tourism and Conservation: Three Case Studies by Clem Tisdell and Clevo Wilson, November 2004.
113. What Role Does Knowledge of Wildlife Play in Providing Support for Species' Conservation by Clevo Wilson and Clem Tisdell, December 2004.
114. Public Support for Sustainable Commercial Harvesting of Wildlife: An Australian Case Study by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, December 2004.
115. Endangerment and Likeability of Wildlife Species: How Important are they for Proposed Payments for Conservation by Clem Tisdell, Hemanath Swarna Nantha and Clevo Wilson, December 2004.
116. How Knowledge Affects Payment to Conserve and Endangered Bird by Clevo Wilson and Clem Tisdell, February 2005.
117. Public Choice of Species for the Ark: Phylogenetic Similarity and Preferred Wildlife Species for Survival by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, March 2005.
118. Economic Incentives for Global Conservation of Wildlife: New International Policy Directions by Clem Tisdell, March 2005.
119. Resource Entitlements of Indigenous Minorities, Their Poverty and Conservation of Nature: Status of Australian Aborigines, Comparisons with India's Tribals, Theory and Changing Policies Globally by Clem Tisdell, March 2005.

120. Elephants and Polity in Ancient India as Exemplified by Kautilya's *Arthasastra* (Science of Polity) by Clem Tisdell, March 2005.
121. Sustainable Agriculture by Clem Tisdell, April 2005.
122. Dynamic Processes in the Contingent Valuation of an Endangered Mammal Species by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, April 2005.
123. Knowledge about a Species' Conservation Status and Funding for its Preservation: Analysis by Clem Tisdell, June 2005.
124. Public Valuation of and Attitudes towards the Conservation and Use of the Hawksbill Turtle: An Australian Case Study by Clem Tisdell, Hemanath Swarna Nantha and Clevo Wilson, June 2005.
125. Comparison of Funding and Demand for the Conservation of the Charismatic Koala with those for the Critically Endangered Wombat *Lasiorhinus krefftii* by Clem Tisdell and Hemanath Swarna Nantha, June 2005.
126. Management, Conservation and Farming of Saltwater Crocodiles: An Australian Case Study of Sustainable Commercial Use by Clem Tisdell and Hemanath Swarna Nantha, August 2005.
127. Public Attitudes to the Use of Wildlife by Aboriginal Australians: Marketing of Wildlife and its Conservation by Clem Tisdell and Hemanath Swarna Nantha, August 2005.
128. Linking Policies for Biodiversity Conservation with Advances in Behavioral Economics by Clem Tisdell, August 2005.
129. Knowledge about a Species' Conservation Status and Funding for its Preservation: Analysis by Clem Tisdell, August 2005.
130. A Report on the Management of Saltwater Crocodiles (*Crocodylus porosus*) in the Northern Territory: Results of a Survey of Pastoralists by Clem Tisdell, Clevo Wilson and Hemanath Swarna Nantha, September 2005.
131. Crocodile Farms and Management of Saltwater Crocodiles in Northern Territory: Results of a Survey of NT Crocodile Farmers Plus Analysis of Secondary Information by Clem Tisdell, September 2005.
132. The Environment and the Selection of Aquaculture Species and Systems: An Economic Analysis by Clem Tisdell, October 2005.
133. The History and Value of the Elephant in Sri Lankan Society by Ranjith Bandara and Clem Tisdell, November 2005.
134. Economics of Controlling Livestock Diseases: Basic Theory by Clem Tisdell, November 2006.
135. Poverty, Political Failure and the Use of Open Access Resources in Developing Countries by Clem Tisdell, November 2006.
136. Global Property Rights in Genetic Resources: An Economic Assessment by Clem Tisdell, November 2006.
137. Notes on the Economics of Fish Biodiversity: Linkages between Aquaculture and Fisheries by Clem Tisdell, November 2006.
138. Conservation of the Proboscis Monkey and the Orangutan in Borneo: Comparative Issues and Economic Considerations by Clem Tisdell and Hemanath Swarna Nantha, March 2007.
139. Economic Change and Environmental Issues: Policy Reforms and Concerns in Australian Agriculture, by Clem Tisdell, April 2007.
140. Institutional Economics and the Behaviour of Conservation Organizations: Implications for Biodiversity Conservation by Clem Tisdell, March 2007
141. Poverty, Policy Reforms for Resource-use and Economic Efficiency: Neglected Issues by Clem Tisdell, May 2007.
142. The State of the Environment and the Availability of Natural Resources by Clem Tisdell, May 2007.
143. Economics of Pearl Oyster Culture by Clem Tisdell and Bernard Poirine, July 2007.
144. The Economic Importance of Wildlife Conservation on the Otago Peninsula – 20 Years on by Clem Tisdell, November, 2007.

145. Valuing the Otago Peninsula: The Economic Benefits of Conservation by Clem Tisdell, November 2007.
146. Policy Choices about Agricultural Externalities and Sustainability: Diverse Approaches, Options and Issues by Clem Tisdell, November, 2007.
147. Global Warming and the Future of Pacific Island Countries by Clem Tisdell, November 2007.
148. Complex Policy Choices about Agricultural Externalities: Efficiency, Equity and Acceptability by Clem Tisdell, June 2008.
149. Wildlife Conservation and the Value of New Zealand's Otago Peninsula: Economic Impacts and Other Considerations by Clem Tisdell, June 2008.
150. Global Property Rights in Genetic Resources: Do They Involve Sound Economics? Will They Conserve Nature and Biodiversity? By Clem Tisdell, August 2008.
151. Supply-side Policies to Conserve Biodiversity and Save the Orangutan from Oil Palm Expansion: An Economic Assessment. By Clem Tisdell and Hemanath Swarna Nantha, September, 2008.
152. The Orangutan-Oil Palm Conflict: Economic Constraints and Opportunities for Conservation by Hemanath Swarna Nantha and Clem Tisdell, October 2008.
153. Economics, Ecology and the Development and Use of GMOs: General Considerations and Biosafety Issues by Clem Tisdell, October 2008.
154. Agricultural Sustainability and the Introduction of Genetically Modified Organisms (GMOs) by Clem Tisdell, February, 2009.
155. Notes on Biodiversity Conservation, The Rate of Interest and Discounting by Clem Tisdell, April, 2009.
156. Is Posner's Principle of Justice an Adequate Basis for Environmental Law? by Clem Tisdell, June 2009.