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CLIMATE CHANGE AND AGRICULTURE RESEARCH PAPER

Reconfiguring agriculture through the relocation of production systems for water, environment and food security under climate change

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SUMMARY

The prospect of climate change has revived both fears of food insecurity and its corollary, market opportunities for agricultural production. In Australia, with its long history of state-sponsored agricultural development, there is renewed interest in the agricultural development of tropical and sub-tropical northern regions. Climate projections suggest that there will be less water available to the main irrigation systems of the eastern central and southern regions of Australia, while net rainfall could be sustained or even increase in the northern areas. Hence, there could be more intensive use of northern agricultural areas, with the relocation of some production of economically important commodities such as vegetables, rice and cotton. The problem is that the expansion of cropping in northern Australia has been constrained by agronomic and economic considerations.

The present paper examines the economics, at both farm and regional level, of relocating some cotton production from the east-central irrigation areas to the north where there is an existing irrigation scheme together with some industry and individual interest in such relocation. Integrated modelling and expert knowledge are used to examine this example of prospective climate change adaptation. Farm-level simulations show that without adaptation, overall gross margins will decrease under a combination of climate change and reduction in water availability. A dynamic regional Computable General Equilibrium model is used to explore two scenarios of relocating cotton production from south east Queensland, to sugar-dominated areas in northern Queensland. Overall, an increase in real economic output and real income was realized when some cotton production was relocated to sugar cane fallow land/new land. There were, however, large negative effects on regional economies where cotton production displaced sugar cane. It is concluded that even excluding the agronomic uncertainties, which are not examined here, there is unlikely to be significant market-driven relocation of cotton production.

INTRODUCTION

Climate change has the potential to change the rainfall distribution and conditions for crop production significantly, with important implications for food security (Rosenzweig & Hillel 1998; Ingram *et al*. 2008; Carberry *et al*. 2011; Risbey 2011; Steffen *et al*. 2011; Smith *et al*. 2013). Regional differences in rainfall distribution and crop productivity are likely to emerge (Olesen & Bindi 2002). For example in Australia, where climate change poses significant challenges, it is expected that the southern part of Australia will generally become drier, while there is a likelihood of increases in rainfall and in the frequency and intensity of extreme events in parts of the north (IPCC 2007; CSIRO & Bureau of Meteorology 2010; Potgieter *et al*. 2013).

The possibility of conditions more favourable to agricultural production in northern Australia has generated renewed interest in northern irrigation projects, with proposals to reconfigure the geography of intensive agriculture (Camkin *et al*. 2007; Shanahan 2007;

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Northern Australian Land and Water Taskforce 2009). A key driver of this renewed interest in northern agriculture was to secure a 'potential new food basket' in the face of climate change (Shanahan 2007). Furthermore, and importantly, this expansion could then offset possible decreases in the irrigated area and output of the Murray Darling Basin as a result of decreased inflows, buybacks of environmental water under the Murray Darling Basin Plan (Murray-Darling Basin Authority 2010) and water trading, possibly to non-agricultural uses (National Water Commission 2009). The Office of Northern Australia, which in one form or another is cyclically revived whenever there are potential interests (based on politics or climate) in northern Australia development, has commissioned a study of the potential for expansion of irrigation in North Queensland (CSIRO 2013), to the west of the site of the present study.

The Burdekin area was chosen for the present study to avoid considering the cost of additional irrigation infrastructure, given the existing dam, in line with an overall approach of examining just the economics at farm and regional level, assuming future studies of the agronomic factors. In addition, the Burdekin region is reasonably close to a major centre and port (Townsville), which could minimize some of the costs and logistical problems that have constrained other northern developments. The regional impacts are important both economically and politically because agricultural production has for many years been a mainstay of regional development (Davison 2005; Thiene & Tsur 2013) and there are many communities highly dependent on irrigation systems. There is a great deal of uncertainty in the community with regard to the potential implications of major structural reforms in the irrigation sector and there is a risk of over-investment in infrastructure renewal if the likely extent of future structural adjustment is not adequately recognized (National Water Commission 2009).

For such a transformation to be successful, it is imperative that changes in yield in relation to shifts in climate, associated farm returns and regional impacts are identified clearly, particularly when there have been many attempts to develop intensive crop production in northern areas with a number of notable failures (for critical reviews see Davidson 1966; Graham-Taylor 1982; Breustedt & Glauben 2007; Ingram *et al*. 2008; Wooding 2008). Major biophysical constraints have included extreme (wet and dry) weather events, unanticipated crop pests and lower than expected yields, with broad-scale production not matching the performance in limited field trials. The economic constraints have included low returns, highly variable production, additional costs of production from combating the agronomic constraints and including the imposts incurred due to distance from inputs and markets. These agronomic and economic constraints are acknowledged, but for the present study the focus is on regional and farm income potential as a first stage of analysis.

The present paper examines cotton production systems in the Burdekin region as part of a sustainable and profitable rotation system. This will be investigated at three spatial scales (paddock, farm, region) and across time (baseline, 2030 and 2070). Cotton was selected because it is a major irrigated crop in Australia, somewhat vulnerable to reduced water availability in current growing areas, and has been shown to have potential in the Burdekin area through trials and some medium-scale production (>100 ha) over at least 3 years. Importantly, the present paper will also consider the net effects of shifting agricultural production by examining possible structural adjustment in cotton growing areas, given shifts in rainfall distribution and conditions for crop production.

The study began with an examination of the national and regional significance of the cotton industry and the significance and impact of climate change in order to show how water policy and future climate could constrain the cotton industry and affect the regional economy.

COTTON INDUSTRY SIGNIFICANCE AND CLIMATE CHANGE IMPACTS

Significance

Cotton is grown largely on fertile soils near waterways of the upper Murray-Darling Basin from central inland Queensland to southern New South Wales (NSW), with two-thirds of Australia's cotton grown in NSW. The production 'contraction' site considered in the present study is in the Darling Downs region of Queensland, in the northern part of the Basin. About 80% of cotton farms are irrigated and, as part of the enterprise mix, generally produce other crops such as wheat and sorghum, and/or graze sheep and cattle. The area of cotton varies each year (Fig. 1), depending on water availability and price (McRae *et al*. 2007). In general, the area of cotton production increased from 1975/76 to 2000, but has declined since 2001 due to major drought conditions and

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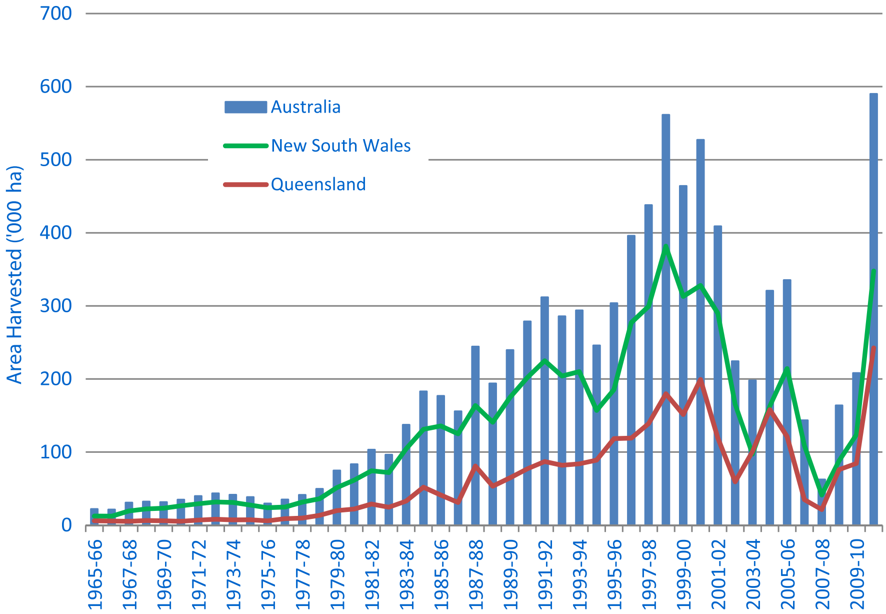

Fig. 1. Cotton harvested area: Australia, New South Wales and Queensland (colour online).

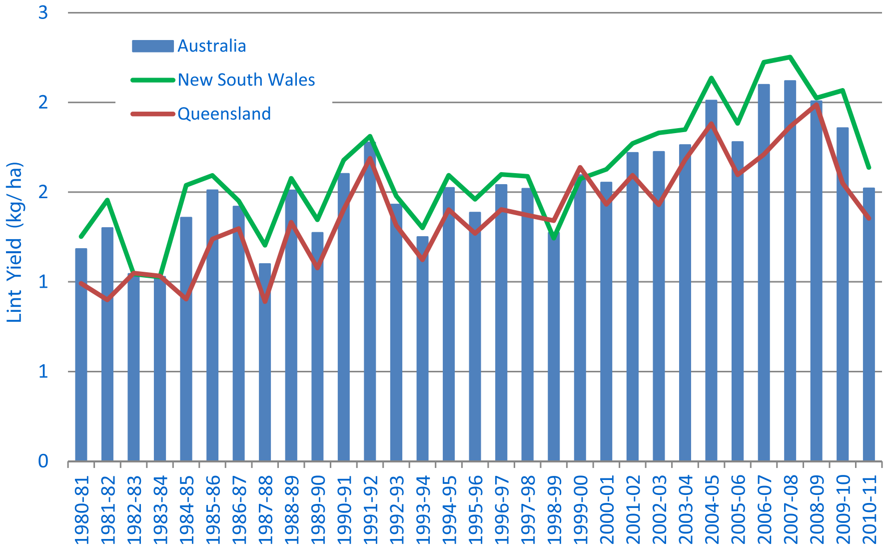

Fig. 2. Cotton lint yield: Australia, New South Wales and Queensland (colour online).

water shortages in both Queensland and NSW. The drought effects peaked in 2006/07 and 2007/08 with almost zero water allocations, which coincided with poor cotton prices, resulting in the smallest harvest in the last 25 years (Roth 2010). Despite yearly and seasonal climate variation, Australian cotton yields have improved steadily. Australian average lint yields are now the highest of any major cotton-producing country in the world and have increased at an average rate of 32·9 kg lint/ha/year over the last 20 years (Fig. 2) (Roth 2010).

Australia is a relatively small producer with 3% of the world's cotton, although it has a reputation for producing high-quality cotton, and virtually all is exported. The gross value of production peaked at AUS$1.9 billion and AUS$2.5 billion in 2000/01 and 2010/11, respectively (Fig. 3), but during the last decade generally declined due to extremely low water availability and poor seasonal conditions. In 2007/08 the gross value was at a 34-year low of AUS$259 million. Hence, an expansion of production into other areas with greater water availability could increase net exports.

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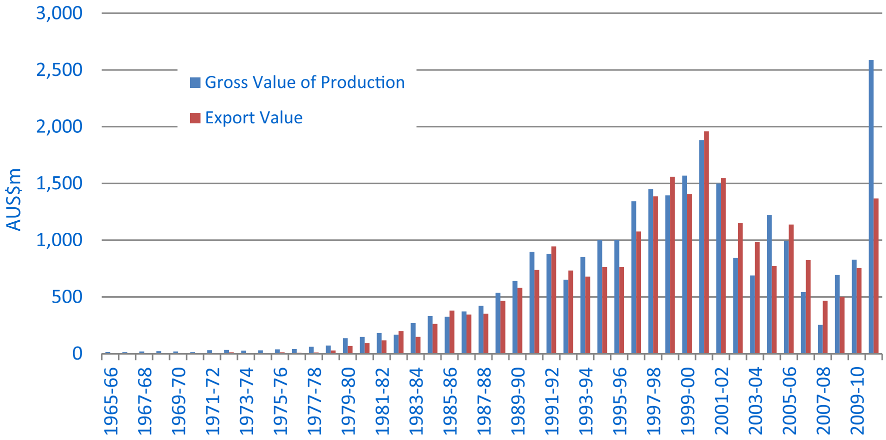

Fig. 3. Gross values of production and export values in Australia (colour online).

Climate change and water availability

While the Australian cotton industry is a major success story, in terms of increased productivity and water use efficiency, it is still highly dependent on climate: temperature, light and water are the main drivers of crop growth. Cotton has a level of resilience to high temperatures and drought due to its vertical tap root but is sensitive to water availability, particularly at the height of flowering and boll formation. With climate change, increased carbon dioxide (CO_2) has the potential to increase photosynthesis and water use efficiency leading to higher crop yields but the benefits may be offset by decreases in rainfall, increases in temperature and/or increases in atmospheric evaporative demand (McRae *et al.* 2007). These changes could reduce the water available for irrigated cotton which would result in increased competition between irrigated cotton, other crops and environmental uses, with the latter being a major focus of government policy on water allocations.

MATERIALS AND METHODS

The methodology involved crop and farm-level estimates of productivity and responses to water scarcity integrated with regional economic models. The framework assumed that the decisions made by farmers could impact on industries (and vice versa), and local and regional communities. Relocation decisions were driven by expectations about the future profitability of cotton farming based on a range of market, social, technological, government policy and environmental considerations. At the regional level, the study used the ACIL Allen General Equilibrium model, Tasman Global. This is an analytical tool that can capture these linkages at regional, state, national and global scales. The model enables the analysis of issues at these scales and the determination of the impacts of various economic changes on production, consumption and trade at the macroeconomic and industry levels. In the case of the regional cotton model, a reference case simulation will be developed (business-as-usual) with which various scenarios will be compared.

Details of the crop modelling, farm and regional assessments are presented below.

Crop and farm-level assessment

Crop and farm scale modelling was undertaken using the Agricultural Production Systems sIMulator (APSIM) (McCown *et al.* 1995) and the APSFarm framework (Power *et al.* 2011). These simulations provide an assessment of the response of cotton as a stand-alone crop and as part of a farm enterprise, which then guide the development of the regional-scale scenarios.

The effect of climate change with and without CO_2 fertilization was examined for cotton grown on the Darling Downs under the A1FI scenario in 2030 and 2050 (IPCC 2000). The present value of CO_2 was set at 350 and 449 ppm for 2030 and 555 ppm for 2050, as prescribed by the Consistent Climate Change Scenario data (Burgess *et al.* 2012). These simulations were undertaken using the Commonwealth Scientific and Industrial Research Organisation (CSIRO) MK 3·5 projections such that nitrogen stress does not occur and irrigation provides at least 0·65 of available soil water (ASW). These simulations were designed to provide information on the impact of climate change on yield and irrigation water requirements.

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Table 1. *Growth targets (with growth stages (GS) according to the BBCH scale,* Meier 1997*) for cotton measured in cumulative day degrees from sowing*

Growth target	Day degrees required for growth target	Description
Emergence (GS 09)	80	Appearance of cotyledons
5th True leaf (GS 15)	330	
1st Square (GS 51)	505	The flower bud of a cotton plant. These are often the preferred site of insect damage.
1st Flower (GS 60)	777	
Peak flower (GS 65)	1302	
Open boll (GS 80)	1527	Cotton boll is the name of the rounded seed pod of the cotton plant. The fibres harvested for cotton develop within the boll. As the boll matures the cotton boll opens. This would release the seed in normal growth
60% Open (GS 86)	2050	When 60% of the cotton bolls have opened the crop is defoliated prior to harvesting.

APSIM modelling

The cotton model used in APSIM is based on the OZCOT model developed by CSIRO, which has been used extensively throughout the cotton-growing regions in Australia. Compared with alternative modelling platforms tested for the present study, such as Decision Support System for Agrotechnology Transfer (DSSAT), APSIM provided the best pathway to understand the impact of climate change on cotton production because it had relevant cultivars available and has been tested extensively in the traditional growing areas throughout Australia. It also provided direct access to information on Australian soils and to over 4000 weather stations via the SILO data bank (Jeffrey *et al*. 2001).

While the performance of the APSIM cotton model for the Darling Downs is well understood and it is very capable of predicting yield for this system (Keating *et al*. 2003; Power *et al*. 2011; Zhang *et al*. 2013), it did not produce realistic results for the Burdekin region because of its inability to properly model the leaf area under the very different light regime for that region. Attempts to use the DSSAT cotton model were also problematic due to a lack of suitable cultivars and a different environment; even though initial trials produced yields in the correct range this was not necessarily for the correct reasons. Therefore, using the model to predict changes in yield under climate change in these conditions was not advisable.

Since neither model performed reliably in the Burdekin region, a simple day-degrees model was used to simulate crop growth here.

Growing degree day model

The model used was the same as that found within OZCOT and therefore APSIM, and used on the CottASSIST web site (https://www.cottassist.com.au/CottBASE/Default.aspx: a group of web tools designed to deliver the latest cotton research, integrate up-to-date information and assist with cotton management decisions). The number of heat units or growing degree days (GDD) required for various stages of plant development (Table 1) is a simple means of predicting and monitoring the progress of a crop. Growing degree days are accumulated by calculating the number of days in which the temperature is above a given threshold. For cotton the threshold temperature is 12 °C, so a day in which the average temperature was 18 °C would accumulate 6 GDD. In practice the calculation is done using hourly temperature accumulated over a 24-h period (Grundy *et al*. 2012). A cold shock delay is incorporated when the minimum temperature is below 11 °C. This increases the GDD requirement for a growth stage by 5·2. Sowing dates of 15 October and 20 December were used for the Darling Downs and Burdekin, respectively. Growth targets for cotton are shown in Table 1.

The GDD model was calculated for the present climate and future climates at 2030 and 2050 using the A1FI and AIB climate change scenarios (IPCC 2000) and the following climate models: (i) CSIRO-MK 3·5, (ii) the Model for Interdisciplinary Research on Climate (MIROC-H) developed by the Center for Climate Research in Japan, (iii) the Geophysical Fluid Dynamics Laboratory's model GFDL-21 and

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Table 2. *Details of cropping system used in the APSFarm modelling on the Darling Downs*

Description	Wheat	Maize	Sorghum	Cotton (1 m)	Strategy 1	Strategy 2
Cultivar	Hartog	Dekalb × 182	Early	SR71BR		
Sowing depth (mm)	30			50		
Plant density (no./m^2)	120	8	4·5	10		
Row spacing (mm)				1000	200	200
Fertilizer amount (kg/ha)	200	220	50	240	170	170
Fertilizer depth (mm)	50					
Fertilizer type	NH_4					
Irrigation threshold (% ASW)	0·4	0·4	0	0·65		
Water requirement (ML/ha)	4	3	0	4	2	0
Max. in-crop irrigations	2		0	4	2	2
Planting window	1–30 Jun	15–30 Sep	1–15 Nov	1 Oct–15 Nov as single crop 1–30 Oct when planted with cotton (2 m)	1–15 Nov	
Other	Up to 80 ha	Up to 40 ha	>80 ha fallow available	Up to 200 ha		

(iv) the Canadian Centre for Climate Modelling and Analysis' model CCCMA-47.

APSFarm modelling

APSFarm is a whole-farm systems model composed of multiple simulations of a paddock-scale model, APSIM, combined with a set of rules for crop rotation, machinery and labour availability, and cost of management operations set against the background of climate variability. In this way the impact of climate change can be modelled such that changes in rainfall, temperature and CO_2 are reflected in crop growth and yield, and changes in water policy influence the decision on which crops to plant within a rotation.

A detailed analysis of a typical farm enterprise was undertaken for the Darling Downs using the approach of Power *et al.* (2011). The approach differs from the traditional APSIM methodology in that APSFarm is a dynamic framework that integrates multiple biophysical models that operate at the paddock, farm and sub-catchment level. The baseline for the model enterprise consisted of solid (1 m rows) planting of cotton with full irrigation, with irrigated wheat and maize and 'dryland' sorghum. The farm consisted of 12 management units, effectively proxies for paddocks, with a total area of 446·5 ha. Irrigation water was supplied via two on-farm storage containers filled via captured on-farm runoff, off-farm overland flow and access to a bore (200 million litres/year). The water allocation was reduced by 14% to 172 million litres/year in both 2030 and 2050 to simulate possible reductions that might occur. The draft Murray Darling Basin plan provides a wide range of estimates for reductions in water allocation for the Condamine catchment and the figure used in the present study was selected to cause an impact on water allocation that was neither negligible nor too extreme.

In response to climate change, two adaptation strategies were considered. The baseline scenario was to continue with the current production system and document how the farm profit changed in response to changes in climate and water allocation policy. Adaptations were considered that were aimed at keeping cotton as part of the cropping mix based on discussions with industry representatives. The first option was to allow for partially irrigated cotton planted with 2 m spacing and the third option was to allow for 'dryland' cotton to be used with 2 m row spacing. This was achieved in the model by allowing planting without checking whether there was sufficient irrigation water available. Details of the cropping system are shown in Table 2.

Regional modelling approach

The computable general equilibrium (CGE) model from ACIL Allen, Tasman Global, was used to estimate the regional economic impacts of the different scenarios. Tasman Global is an iterative dynamic CGE

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model that estimates relationships between variables at different points in time. This is in contrast to comparative static models, which compare two equilibria (one before a policy change and one following). A dynamic model such as Tasman Global is beneficial when analysing issues where both the timing of the adjustment and the path that economies follow are relevant in the analysis. The Tasman Global models provide a representation of the whole economy, set in a national and international trading context, starting with individual markets, producers and consumers and building up the system via demands and production from each component. When an economic shock or change is applied to a model, each of the markets adjusts according to the set of behavioural parameters that are underpinned by economic theory. A key advantage of CGE models is that they capture both the direct and indirect impacts of economic changes while taking account of economic constraints (such as land and labour supply). Another key advantage of CGE models is that they are able to capture a wide range of economic impacts across many varied industries in a single consistent framework that enables rigorous assessment of a range of policy scenarios.

For the current analysis the model was aggregated with:

- Four economies, namely the Darling Downs statistical division (S.D.) region, the Burdekin local government area (LGA), the Rest of Australia and the Rest of the World
- 34 industries/commodities to provide the maximum detail possible for the key industries related to this analysis.

The impact of cotton relocation has been measured in terms of gross domestic product (GDP). At the state level, the GDP equivalent is called the Gross State Product (GSP) while changes at the regional level are called Gross Regional Product (GRP). Although changes in real GDP are useful measures for estimating how much the output of an economy may change, changes in the real income of a region are more important since they provide an indication of the change in economic welfare of the residents of a region. Indeed, it is possible that real GSP can increase with no, or possibly negative, changes in real income. In Tasman Global, changes in real income at the national level are synonymous with real gross national disposable incomes (RGNDI) reported by the Australian Bureau of Statistics. To reduce the potential confusion with the various acronyms, the term 'economic output' has been used in the discussion of the results presented in the present paper.

Importantly, to eliminate the impact of nominal price movements in the results, economic variables such as the change in economic output are reported as deviations from their real rather than nominal values. Similarly, all aspects not directly related to the assumed changes in the cotton industry have been kept constant across all the scenarios (including, e.g. productivity growth, national population and all demand and supply elasticities).

Cotton relocation scenarios

Baseline scenario

For the baseline scenario, long-term average rainfall and water availability was selected against which climate change, water buy-back and a new Murray Darling Basin cap (through the Murray Darling Basin Plan) scenarios are compared. The baseline scenario assumes, with average rainfall and water availability, cotton farmers will operate close to historically average levels of cotton area and production.

Scenario 1: Cotton grown in fallow sugar cane land

This scenario assumes that there is no displacement of sugar cane by cotton in the Burdekin region. Sugar cane is currently a high value crop and consultations with industry advisors suggested that farmers would be reluctant to replace the relatively certain production of sugar cane with cotton. However, there is a window of opportunity to grow cotton on fallow sugar cane land every 5 years.

Part A: 2030 climate with new Murray Darling Basin cap in place

For the Darling Downs: Based on climate modelling using CSIRO MK3·5 under A1F1 emission scenario, annual rainfall is expected to decrease by 20·5% by 2030. At the same time, another 100 billion litres or 14% water reduction is planned under a new Murray Darling Basin cap. Using a simple parsimonious regression model involving pre-season rainfall and area relationship (Cotton Area (Oct_t) = Pre-season Rain (May_t–Oct_t) = 25493 + 98·6 × (Pre-season Rain)), it is estimated that there will be an 18·4% (8449 ha) reduction in cotton area compared with the baseline scenario. Support from APSIM crop

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and APSFarm level modelling and discussions with key informants from the cotton industry suggest the reduction in the irrigated cotton area could be replaced with:

- Partial irrigated cotton (2 m spacing with pre-irrigation): 2112 ha or 25% of the 8449 ha
- Partial irrigated cotton (2 m spacing without pre-irrigation): 2957 ha (35%)
- Dryland cotton: 1690 ha (20%)
- Sorghum: 1690 ha (20%)

For the Burdekin: Based on the data from the ABS on sugar cane area and considering four sugar cane rattoons followed by fallow land, about 20 000 ha of fallow sugar cane land is available each year (ABS 2012).

Part B: 2050 climate with new Murray Darling Basin cap in place.

For the Darling Downs: Based on climate modelling using CSIRO MK3·5 under the A1F1 emission scenario, rainfall is expected to decrease by 42·2% by 2050 and there is a 14% reduction in available water planned under the Murray Darling Basin cap. Using the same model as above, it is estimated that a reduction of 28·1% (12 892 ha) may occur in the cotton area, compared with the baseline scenario. It is estimated that the reduction in the irrigated cotton area will be converted to:

- Partial irrigated cotton (2 m spacing with pre-irrigation): 1934 ha (15%)
- Partial irrigated cotton (2 m spacing without pre-irrigation): 3868 ha (30%)
- Dryland cotton: 3868 ha (30%)
- Sorghum: 3223 ha (25%)

For the Burdekin. As with the 2030 scenario, it is estimated that 20 000 ha of fallow land will be available each year for cotton because of the 4 year sugar cane rattoon cycle.

Scenario 2: Cotton grown in displaced sugar cane land in competition with sugar cane

In this scenario it is assumed that there is competition between cotton and sugar cane, with no additional land available. Any additional cotton grown will displace sugar cane. On a 'dollars per hectare' basis, a hectare of land dedicated to sugar cane production is generally of higher value than a hectare dedicated to cotton.

Part A: 2030 climate with new Murray Darling Basin cap in place

For the Darling Downs: This is the same as Scenario 1.

For the Burdekin: This assumes that there is competition between cotton and sugar cane and any additional cotton displaces the sugar cane crop. As a result, assuming additional water availability, 8449 ha of cotton will displace 8449 ha of sugar cane.

Part B: 2050 climate with new Murray Darling Basin cap in place.

For the Darling Downs: This is the same as Scenario 1

For the Burdekin: This assumes that there is competition between cotton and sugar cane and any additional cotton displaces the sugar cane crop. As a result, assuming additional water availability, 12 892 ha of cotton will displace 12 892 of sugar cane.

RESULTS

APSIM crop model of cotton in Darling Downs

A deeper understanding of the impact of climate change can be gained using the APSIM crop model, as discussed earlier. Using this model for the Darling Downs the impact of CO_2 fertilization and climate change on yield and water use can be examined.

The effect of climate change with and without CO_2 fertilization was examined for the Darling Downs under the A1FI scenario in 2030 and 2050. The present level of CO_2 was set at 350 ppm with 449 ppm for 2030 and 555 ppm for 2050 as prescribed by the Consistent Climate Change Scenario data and using the CSIRO MK 3·5 model. The effect of climate change is complicated by the interaction of increased temperature and CO_2 fertilization. If CO_2 is increased to 449 ppm using the present historical weather data then the median yield is increased by 8%. Under the 2030 scenario with CO_2 at the level of 350 ppm, yield decreases by 3%; however, CO_2 fertilization provides an increased yield of nearly 6%. By 2050 there is a decrease in yield of 17·8% without CO_2 fertilization and a 3·6% decrease with CO_2 fertilization when compared to the present (Fig. 4). These simulations were undertaken so that nitrogen stress did not occur and irrigation resulted in at least 65% ASW. To cope with the decreased in-crop rainfall (4·5% by 2030 and 15·8% in 2050) and an initial increase in evapotranspiration during crop growth of 2% in 2030, and a 10% decrease in

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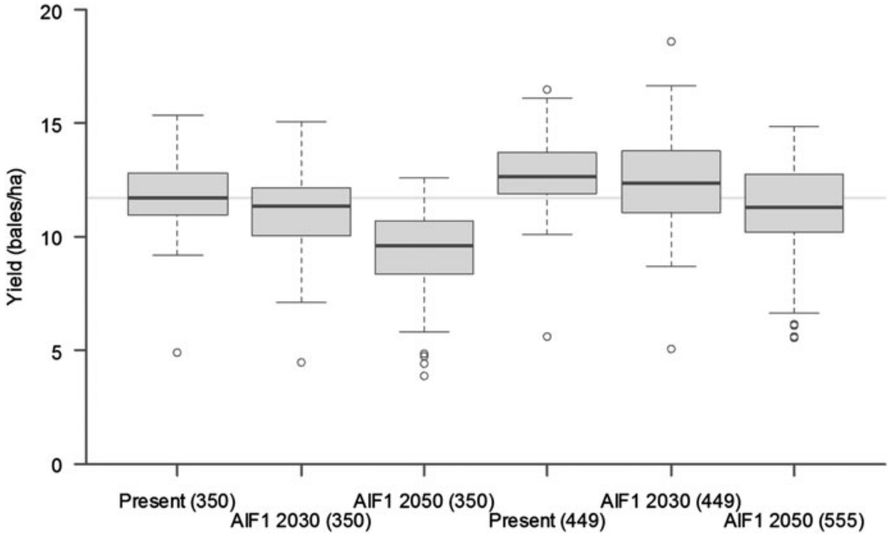

Fig. 4. Cotton yield response to CO_2 under climate change at Dalby, Darling Downs with irrigation at 65% water deficit. Values in brackets refer to ppm CO_2. Cotton planted at 1 m row spacing, planted on 15 October.

2050 due to faster crop maturation caused by increased heat, irrigation increased by 47·4 and 48·7%, respectively, in order to maintain the 65% target.

These simulations demonstrate the complex interactions that exist and highlight the importance of enhancing the cotton model so that the response of the crop in potential growing regions such as the Burdekin, the Flinders and Gilbert Rivers (north-east of the Burdekin region), the Ord River scheme (in northern Western Australia), and Katherine (Northern Territory) can be properly assessed. Without access to models that can be adapted to tropical environments, it will be difficult to provide good information for long-term policy and investment decisions under changes in water policy, control of excess nutrients loads and the complex changes to the way in which the climate behaves under global warming.

Day degree model of cotton in the Burdekin

Growing degree day models were calculated for the Burdekin region in lieu of a suitable crop model. The crop growth target of 60% open bolls was used as an indicator of the timing of farm operations that would require access to the paddock and when the crop is likely to be damaged by rain.

The calculation of GDD for Ayr with a planting date of 20 December showed that the crop reached the 60% open growth stage 146 days after sowing, i.e. 15 May (Table 3). This is from the average of sowing dates from 1957 to 2009. Using climate change projections from the version 1.1 data provided by the Queensland Climate Change Centre of Excellence (QCCCE) Consistent Climate Change Scenarios, the reduction in number of days after sowing to reach 60% bolls open (Table 3) and the year to year variation can be seen easily.

The wet start to the growing season and low radiation levels often experienced in February/March has led researchers to consider a later planting opportunity. This has been difficult to achieve from an agronomic standpoint and the crop is likely to reach a critical stage during the onset of the summer rains. Under current climatic conditions, sowing cotton on 1 May, in order to avoid the wet season during the early stages of development, results in a crop that is not due for harvest until 10 December. This risks the cotton being subject to rain when the fibres are exposed, or it would be too wet to harvest the crop successfully. Under climate change the expected harvest dates occur sooner, in early to late November, which may provide an opportunity to sow in early May (Table 4).

Without access to suitable modelling of cotton production in the Burdekin area, the present study relied heavily on information from experimental and limited commercial plantings. Trials have been undertaken in the Burdekin region and commercial crops grown that provide an indication of yield. In discussions with experienced growers originating from the Darling Downs, the yields have tended to be about 70% of the yield expected on the Darling Downs under irrigation, i.e. *c.* 7–8 bales/ha (Table 5). Yields for cotton in the Burdekin region for 2030 and 2050 are as yet

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Table 3. *Mean days after sowing to reach 60% open bolls in the Burdekin region under two climate change scenarios for a sowing date of 20 December*

	Days after sowing	Date		Days after sowing	Date
Present	146	15 May			
A1B 2030			A1FI 2030		
CSIRO-MK35 (M)	135	4 May	CSIRO-MK35 (M)	135	4 May
MIROC-H (H)	132	1 May	MIROC-H (H)	132	1 May
GFDL-21 (L)	137	6 May	GFDL-21 (L)	137	6 May
CCCMA-47 (L)	138	7 May	CCCMA-47 (L)	138	7 May
A1B 2050			A1FI 2050		
CSIRO-MK35 (M)	129	28 Apr	CSIRO-MK35 (M)	126	25 Apr
MIROC-H (H)	124	23 Apr	MIROC-H (H)	121	20 Apr
GFDL-21 (L)	132	1 May	GFDL-21 (L)	130	29 Apr
CCCMA-47 (L)	134	3 May	CCCMA-47 (L)	132	1 May

Table 4. *Mean days after sowing to reach 60% open bolls in the Burdekin region under two climate change scenarios for a sowing date of 1 May*

	Days after sowing	Date		Days after sowing	Date
Present	223	10 Dec			
A1B 2030			A1FI 2030		
CSIRO-MK35 (M)	208	25 Nov	CSIRO-MK35 (M)	209	26 Nov
MIROC-H (H)	204	21 Nov	MIROC-H (H)	205	22 Nov
GFDL-21 (L)	213	30 Nov	GFDL-21 (L)	213	30 Nov
CCCMA-47 (L)	212	29 Nov	CCCMA-47 (L)	213	30 Nov
A1B 2050			A1FI 2050		
CSIRO-MK35 (M)	199	16 Nov	CSIRO-MK35 (M)	194	11 Nov
MIROC-H (H)	193	10 Nov	MIROC-H (H)	189	6 Nov
GFDL-21 (L)	207	24 Nov	GFDL-21 (L)	203	20 Nov
CCCMA-47 (L)	204	21 Nov	CCCMA-47 (L)	202	19 Nov

Table 5. *Cotton yields recorded from field trials in the Burdekin region*

Harvest Year	Yield (bales/ha)	Planting and harvest dates	Source
2008	6·5–7·2	3 Jan 2008–25 Jun 2008	CSD web site*
2009	5·6–6·49	27 Dec 2008–12 Jul 2009	CSD web site
2009	3·0–9·5, average = 6·5	Late Dec planting	Grundy & Yeates (2009)
2009	8–9 ~12	Early and late Dec Planting 8 Jan	Grundy *et al.* (2009)
2010	6·6–7·5	Not recorded	CSD web site

*http://www.csd.net.au/trials/variety/

unlikely to be affected by water restrictions, so the impact on yield is likely to be positive because of CO_2 fertilization and warmer temperatures, but at this stage it is difficult to predict the extent of increases without a reliable crop model.

From the trials and experimental work undertaken by researchers and commercial growers in the district, cotton could play a role as a complementary crop to sugar cane in the Burdekin Delta. Major determinants of viability for cotton will be the success of commercial-scale cotton planting and the extent and spread of agronomic knowledge and range of socio-economic factors. Modelling the impact of climate change needs to be undertaken using models that

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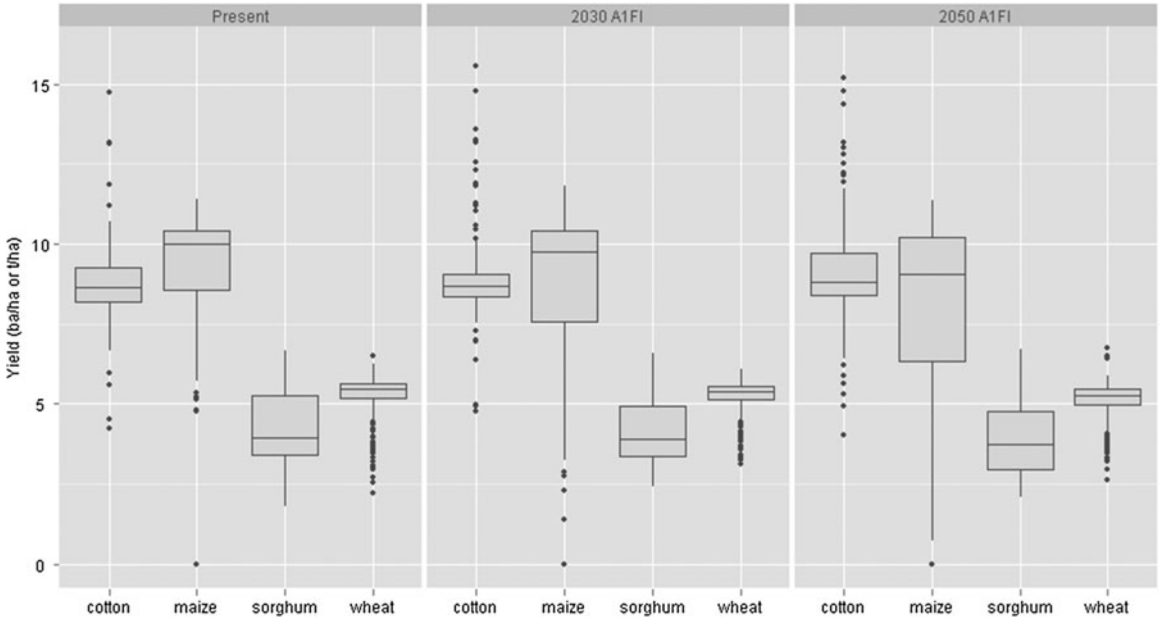

Fig. 5. Yield for cotton using 1 m planting and full irrigation under present and future conditions with the A1FI scenario and a 14% reduction in water allocation.

can consistently and reliably simulate the very different suite of conditions that will be faced by growers in the tropics. Changes to the model need to be supported and this will require some additional experimental work to understand the interaction of light, temperature and CO_2 fertilization. Additionally a more robust procedure for the provision of climate change data needs to be found that can shed light on the change in intensity of rainfall and other extreme events. This needs to include a suite of GCMs and this will hopefully be addressed when the next round of the IPCC reports become available.

Farm-level assessment

Analyses undertaken at the farm level using APSFarm (Power *et al.* 2011) take crop modelling a step further by integrating the production of cotton with decisions that have to be made about the allocation of limited resources. The main limitation that was considered in the present study was the use of water, given that restrictions would be placed on this in the future. A modest 14% reduction in bore allocations for the Darling Downs model farm sites was coupled with modelled changes in overland flow, with maize and wheat also used as irrigated crops within the rotation. A mechanism by which cotton was preferentially retained in the mix of crops was also included, because an enterprise that is built around cotton is likely to remain so unless very strong forces act upon it; because of this the approach of the present study differs from that of Power *et al.* (2011) in that water allocation was not optimized across all crops.

Adaptation to climate change and reduced water allocation as a result of national policy was introduced into the simulation by considering opportunities for partial irrigation and dryland planting of cotton at wider row spacing. The other crops (wheat, maize and sorghum) retained the present agronomic conditions and water requirements. This approach was similar to that taken by Power *et al.* (2011) in that the farm comprises a set of paddocks or management units, a suite of crops and water storage facilities (on-farm dams) that are supplemented from bore water. A gross margin analysis is therefore possible that takes into account the cost of producing a crop including planting, harvesting, value of the product and irrigation. Details of the simulation methodology were discussed earlier.

Crop yield

The simulations using the APSFarm approach, without any adaptation (solid planting with full irrigation), showed that cotton yield at the Darling Downs site would increase slightly in the future (Fig. 5). For cotton planted at a 2 m row spacing with partial irrigation, the increase in yield was 2·6 and 11·6% in 2030 and 2050, respectively, when compared to cotton

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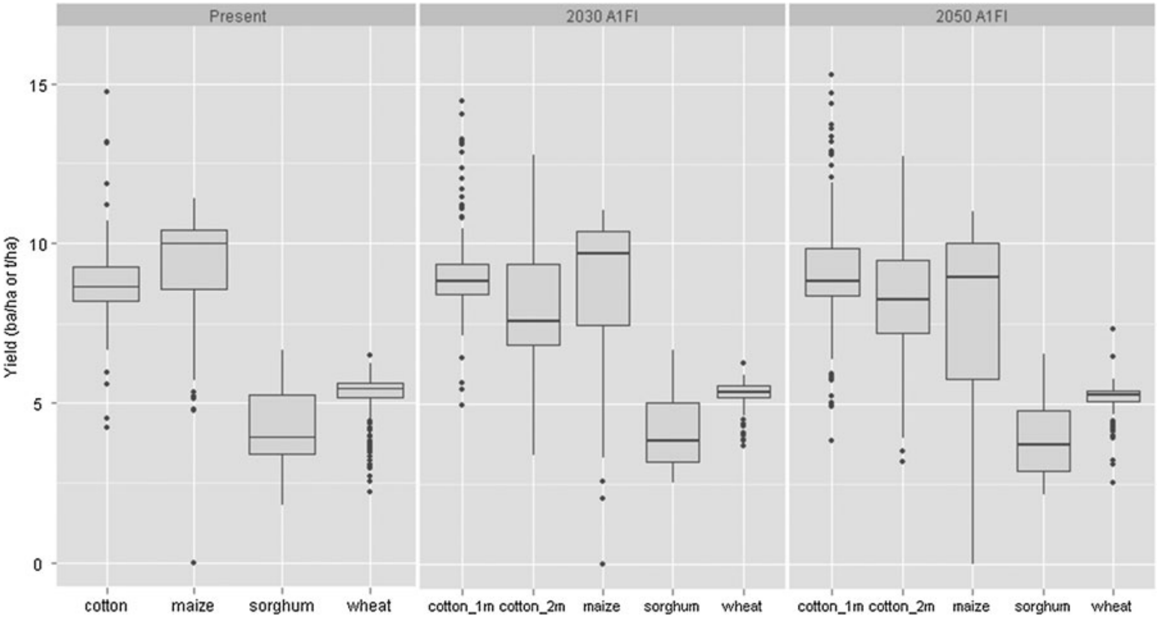

Fig. 6. Yields under adaptation strategy 1.

planted at 2 m under the present climate. This actually represents a 12·1 and 4·4% decrease when compared to cotton planted at 1 m row spacing with the present climate. The decrease in water availability leads to changes in area of the crops planted and hence overall production. This has an impact on gross margins, not only in terms of reduced income, but also greater year to year variation. The area of cotton planted at 1 m row spacing was reduced by 21·2 and 19·2% in 2030 and 2050. Allowing only partially irrigated cotton as the adaptation strategy (Strategy 1, Fig. 6), the overall area of cotton increased by 36 and 38% in 2030 and 2050, respectively. With Strategy 2 (Fig. 7), the area of solid planted cotton was reduced by 45% in 2030 and 2050, but the total area of cotton increased by 90% in 2030, falling back to 67% in 2050 (Table 6).

The impact of climate change and reduced water allocation can be partially offset by adaptation applied to cotton production. A more complete investigation could be undertaken whereby the whole farm enterprise is optimized, however, that is outside the scope of the present study and the primary focus was to understand how the relocation of cotton production causes impacts at a farm and regional scale.

Yields using the 2 m row spacing were increased by a similar margin to the solid planting, but there is also an increase in the year to year variation in cotton yields for both row spacings compared to continuous solid planting of cotton.

Under Strategy 2, the yields are similar in terms of the median, but the extreme values cover a greater range and hence the strategy whereby there is no account taken of available stored water is a riskier proposition (Fig. 7).

Irrigation

Total irrigation applied to cotton under present conditions was 257 million litres. Under climate change overall cotton irrigation water applied was greater under Strategy 2 (Table 7), which results in reduced production per million litres. However, this strategy has greater risk, as seen by comparing the yields for cotton with 2 m rows (Figs 6 and 7). In 2030 and 2050 the proportion of low yields, i.e. <5 bales/ha, increased under Strategy 2. If these were to occur in consecutive years, e.g. during a prolonged drought, then the losses incurred by the farm might be too much to bear.

Costs of irrigation were imposed in the model as variable costs and included the cost of water capture (from sumps to dams), irrigation (from dam to paddock), return of tail water (from paddock to dam) and bore allocation (from bore to dams). These costs were AUS$56.50/million litres except for the bore allocation, which incurred a cost of AUS$110.00/ million litres. In all cases the bore allocation was exhausted, however, there was 14% less water available in 2030 and 2050, which would reduce input costs but make less water available.

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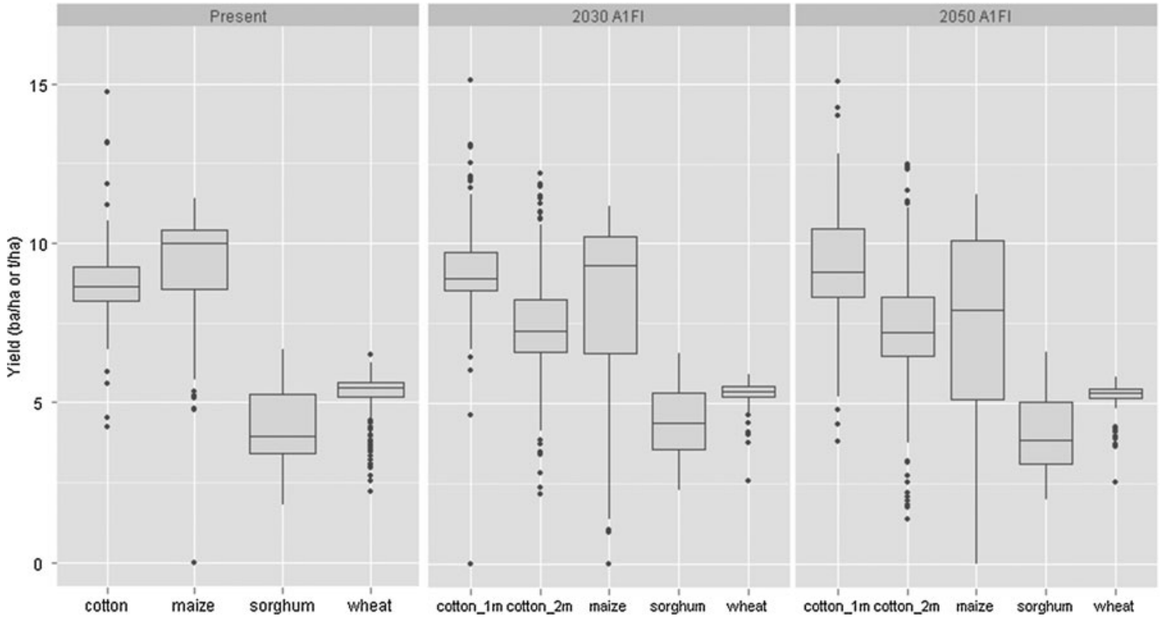

Fig. 7. Yields under adaptation strategy 2.

Table 6. *Area planted to cotton with and without adaptation on the Darling Downs*

	Area planted (ha)		
Type of planting	Present	2030	2050
Without adaptation			
Cotton (1 m)	73·0	58·0	47·0
Strategy 1			
Cotton (1 m)	73·0	57·5	59·0
Cotton (2 m)		42·0	42·0
Total cotton	73·0	99·5	101·0
Strategy 2			
Cotton (1 m)	73·0	40·0	40·0
Cotton (2 m)		99·5	84·0
Total cotton	73·0	139·5	124·0

Gross margins

Gross margins at the farm level were calculated as total gross margin (farm level), crop gross margin and crop gross margin/ha. Overall farm gross margin on the Darling Downs without adaptation was reduced by 27% in 2030 and by 43% in 2050 with losses being mainly due to the performance of irrigated crops, whereas sorghum showed a 22–23% increase in gross margin. There was an 8·8% increase in the total gross margin by 2030 when partial irrigation was introduced. However, by 2050 an overall 8·8% reduction was observed when compared to the present. Introducing dryland cotton to the rotation showed an increase of 49% in farm gross margin by 2030 and 12% by 2050.

Gross margins for cotton grown at 2 m were higher when grown with 1 m rows because the latter had a greater irrigation requirement and higher costs in terms of establishment (Table 8). However, if a 2 m system was used exclusively, the overall production was reduced. Farm-level gross margins would increase in 2030 and 2050 because the area of cotton planted was increased under both adaptation strategies (Table 7).

Results of regional economic impact analysis

Macroeconomic impacts: Scenario 1

Table 9 summarizes the projected changes in real economic output and real income for each region under each Scenario (see earlier for the definitions of real economic output and real income). When analysing the results, it is important to remember that the initial impact of each scenario related to the assumed changes in agricultural output in the Darling Downs and Burdekin regions. These changes then affected each region's total economic output with effects on the demand for labour and capital.

Capital was naturally mobile (albeit sluggishly) between all regions based on changes in rates of return, while labour was assumed to be fully mobile between Australian regions. Consequently, the

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Table 7. *Median irrigation applied to crops with and without an adaptation strategy on the Darling Downs*

Crop	Total ML applied						
	Without adaptation			Strategy 1		Strategy 2	
	Present	2030	2050	2030	2050	2030	2050
Cotton 1 m	257	210	170	182	181	103	92
Cotton 2 m	–	–	–	73	66	219	197
All cotton	257	210	170	255	247	322	288
Maize	53	69	57	55	57	52	54
Wheat	143	144	129	105	100	108	71
Total#	425	351	335	359	316	364	326
% sourced from bore	47	49	52	48	55	47	53

Table 8. *Median yield and gross margins for cotton grown on the Darling Downs using 1 m and two adaptation strategies using cotton grown at 2 m under the A1FI scenario and CSIRO MK 3·5 model*

Yield (Bales/ha)	Present	2030	2050
Cotton 1 m only	8·7	8·8	8·9
Strategy 1		7·6	8·2
Strategy 2		7·2	7·2
Gross margin (AUS$/ha)			
Cotton 1 m only	813	828	817
Strategy 1		1145	1094
Strategy 2		1174	1146
Farm gross margin (AUS$)			
Cotton 1 m only	253 701	186 431	144 688
Strategy 1		276 050	232 478
Strategy 2		329 154	273 321

supply of factors in the rest of Australia was also impacted by changes in the demand in the Darling Downs and Burdekin regions. Consequently, at a national level, the rest of Australia acted to reduce the magnitude of the aggregate impact experienced in the Darling Downs and Burdekin regions.

Real economic output: Under Scenario 1, the loss of water and consequent switching away from some intensively cropped cotton to less intensive cropping regimes was projected to reduce the real economic output of the Darling Downs region by:

- −AUS$9.4 million in 2029/30 (in 2010/11 terms)
- −AUS$25.5 million in 2049/50 (in 2010/11 terms)
- A cumulative total of −AUS$150 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

In the context of a region with *c.* 245 000 people, this is a noticeable change, with the loss in 2049/50 representing an average decrease in real economic output of *c.* AUS$85 per person projected to be living in the Darling Downs at this time.

Due to the assumption under Scenario 1 that there would be sufficient fallow land available to introduce a cotton growing industry into the Burdekin region, real economic output in the Burdekin increased (essentially, real economic output increased because of the increased productivity of existing factors (i.e. land) and because extra factors (labour and capital) would be drawn to the region). In particular, it is projected that the real economic output of the Burdekin region would increase by:

- AUS$54 million in 2029/30 (in 2010/11 terms)
- AUS$84 million in 2049/50 (in 2010/11 terms)
- A cumulative total of AUS$708 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

In the context of a region with *c.* 18 500 people, this would be a substantial change, with the increase in 2049/50 representing an increase in real economic output of around AUS$4500 per person projected to be living in the Burdekin at this time.

Under Scenario 1, the movement of labour was primarily towards the Burdekin region with some movement of labour away from the Darling Downs and the rest of Australia. More specifically, labour supply in the Burdekin region in 2030 and 2050 increased by 0·96 and 1·09%, respectively, as a result of wage-driven migration. It is projected that there will be small negative impacts on the rest of Australia under Scenario 1.

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Table 9. *Cumulative change in real economic output and real income under Scenario 1, relative to the reference case (in 2010/11 terms)*

	Scenario 1 – Burdekin cotton on fallow land					
	A. Real economic output*			B. Real income†		
	2029/30	2049/50	NPV (2010/11 to 2049/50)	2029/30	2049/50	NPV (2010/11 to 2049/50)
	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m
Darling Downs S.D.	−9·36	−25·53	−149·90	−8·10	−25·37	−135·81
Burdekin LGA	53·82	84·22	707·86	43·57	74·26	587·71
Rest of Australia	−6·92	−10·31	−92·41	−5·65	−5·92	−70·77
Total Australia	37·54	48·38	465·55	29·82	42·98	381·12

* The term 'real economic output' is used instead of GRP. The sum of the GRP of all three regions equals the change in Australian GDP.

† Real income for Australia is synonymous with RGNDI as used by the ABS. In this modelling real income is a measure of the change in economic welfare.

Notes: Totals may not add due to rounding. NPV, net present value (calculated using a 4% real discount rate). It should be noted that the NPV calculation only includes the impacts through to 2049/50 even though the impacts will be likely to continue producing beyond this artificial time horizon.

- At the national level, real economic output (or real GDP) is projected to increase by:
- AUS$37.5 million in 2029/30 (in 2010/11 terms)
- AUS$48.4 million in 2049/50 (in 2010/11 terms)
- A cumulative total of AUS$465.6 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

Real income: Under Scenario 1, the real income (in 2010–11 terms) is projected to change by:

- −AUS$8.1 million in 2029/30 and by −AUS$25.4 million in 2049/50 in the Darling Downs region
- +AUS$43.6 million in 2029/30 and by +AUS$74.3 million in 2049/50 in the Burdekin region
- −AUS$5.7 million in 2029/30 and by −AUS$5.9 million in 2049/50 in the rest of Australia
- A national total of +AUS$29.8 million in 2029/30 and +AUS$43.0 million in 2049/50

As with the projected changes in real economic output, in the context of the Burdekin and Darling Downs regions these are noticeable changes. In the Burdekin, the projected increase in real income in 2049/50 is equivalent to an average increase in real income of *c*. AUS$4000 per person living in the region at that time, compared with the fall in real income of the Darling Downs region, equivalent to a decrease of *c*. AUS$85 per person.

Macroeconomic impacts: Scenario 2

Table 10 summarizes the projected changes in real economic output and real income for each region under Scenario 2. The key difference between Scenarios 1 and 2 is that the hypothetical creation of a cotton industry in the Burdekin region comes at the expense of land dedicated to growing sugar cane. This scenario is designed to provide an indication of the potential competition for land that could occur if the Australian cotton industry is preferentially developed at the expense of other activities. A hectare of Burdekin land dedicated to sugar cane production is generally of higher value than a hectare dedicated to cotton.

Real economic output: As the assumptions regarding the Darling Downs region were the same under both Scenarios1 and 2, the projected impacts on the economy of the Darling Downs region were broadly the same. However, due to the higher value per hectare of sugar cane, the Burdekin region also experienced a fall in real economic output. In particular, under Scenario 2 it is projected that the real economic output of the Burdekin would change by:

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Table 10. *Cumulative change in real economic output and real income under Scenario 2, relative to the reference case (in 2010/11 terms)*

	Scenario 2 – Burdekin cotton displaces sugar					
	A. Real economic output*			B. Real income†		
	2029/30	2049/50	NPV (2010/11 to 2049/50)	2029/30	2049/50	NPV (2010/11 to 2049/50)
	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m	2010/11 AUS$m
Darling Downs S.D.	−9·38	−25·58	−150·22	−8·12	−25·42	−136·10
Burdekin LGA	−12·68	−15·20	−172·77	−50·78	−41·05	−574·94
Rest of Australia	6·04	19·31	100·10	−5·66	−5·94	−71·00
Total Australia	−16·02	−21·47	−222·89	−64·56	−72·41	−782·04

* The term 'real economic output' is used instead of GRP. The sum of the GRP of all three regions equals the change in Australian GDP.

† Real income for Australia is synonymous with RGNDI as used by the ABS. In this modelling real income is a measure of the change in economic welfare.

Notes: Totals may not add due to rounding. NPV, net present value (calculated using a 4% real discount rate). It should be noted that the NPV calculation only includes the impacts through to 2049/50 even though the impacts will be likely to continue producing beyond this artificial time horizon.

- −AUS$12.7 million in 2029/30 (in 2010/11 terms)
- −AUS$15.2 million in 2049/50 (in 2010/11 terms)
- a cumulative total of −AUS$172.8 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

In the context of the region, this is a noticeable change, with the decrease in 2049/50 representing a loss of real economic output of *c.* AUS$800 per person projected to be living in the Burdekin at this time.

Under Scenario 2, the rest of Australia is projected to benefit from a movement of labour from both the Darling Downs and Burdekin regions. More specifically, labour supply in the Burdekin region in 2030 and 2050 would decrease by −3·46 and −2·82%, respectively, as a result of wage-driven migration. Consequently it is projected that, under Scenario 2, the real economic output of the rest of Australia will increase by:

- AUS$6.0 million in 2029/30 and AUS$19.3 million in 2049/50 (in 2010/11 terms)
- a cumulative total of AUS$100 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

At the national level, the gains in the rest of Australia would negate a significant amount, but not all, of the losses in the Darling Downs and Burdekin regions. Under Scenario 2, national real economic output (or real GDP) is projected to change by:

- −AUS$16.0 million in 2029/30 (in 2010/11 terms)
- −AUS$21.5 million in 2049/50 (in 2010/11 terms)
- a cumulative total of −AUS$222.9 million in net present value terms over the period to 2049/50 (using a 4% real discount rate).

At a national level this loss (relative to the reference case) would be driven essentially by the lower value of output from the fixed area of land.

Real income: Under Scenario 2, the real income (in 2010/11 terms) is projected to change by:

- −AUS$8.1 million in 2029/30 and by −AUS$25.4 million in 2049/50 in the Darling Downs region
- −AUS$50.8 million in 2029/30 and by −AUS$41.1 million in 2049/50 in the Burdekin region
- −AUS$5.7 million in 2029/30 and by −AUS$5.9 million in 2049/50 in the rest of Australia
- A national total of −AUS$65 million in 2029/30 and −AUS$72.4 million in 2049/50.

As with the projected changes in real economic output, in the context of the Burdekin economy

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these are significant changes. In the Burdekin, the projected decrease in real income in 2049/50 is equivalent to an average loss in real income of approximately AUS$4000 per person living in the region at that time (relative to the reference case).

DISCUSSION

The present paper has demonstrated that integrating modelling and expert knowledge from the farm field to the regional scale can provide a more complete understanding of the biophysical and economic impact of relocation of agricultural production. The modelling can show how climate change, along with related and additional policy decisions, can flow through farm profitability to regional impacts. Further work is needed since the cotton model is unsuited to non-traditional cropping regions and it is recommended that resources should be directed to enhance the model so that it can cope with these situations. Valuable work has been done by Queensland DAFF and CSIRO in the Burdekin and Katherine regions and could be utilized to redevelop the model. It is likely that other cropping models would also fail to cope with other novel agricultural situations and given that understanding of the impact of climate change can only be assessed using models it is important that these shortcomings are addressed promptly.

For the current case, farm-level simulations showed that without adaptation overall gross margins would be decreased under a combination of climate change and reductions in water availability from underground storage. Some of the reduction in cotton yield expected as a result of climate change was offset by CO_2 fertilization as demonstrated by the crop model. The two adaptations explored demonstrate that Darling Downs farmers currently growing irrigated cotton could adapt production systems and continue to be relatively profitable. Darling Down cotton farmers are comparatively diversified already and so they will be relatively able to change the production systems. The long-term relative stability of the gross margins is indicative of the capacity of the system to cope with the changes but individual farm-level studies would need to be done on a case-by-case basis to investigate the farm profitability for particular farms. This potential for regional adaptation is one factor that could reduce the likelihood of current producers relocating. It should be noted, however, that one of the industry informants in the present study retained production on the Darling Downs while trying some additional production in the Burdekin region.

The current work shows there could be large negative effects on regional economies, if cotton simply replaced sugar cane. The increase in cotton production would not compensate for reduced production of the higher value sugar cane, which would be a cost to the economy over and above the direct cost of the environmental water. Utilizing sugar cane fallow land or new area development in Burdekin could be viable at the farm level, increase regional output and could possibly even result in increased national output. This latter effect is primarily due to the flexibility in the Darling Down cropping systems whereby adaptations would maintain a reasonable level of output despite reduced water availability. There are, however, a number of things that would need further examination before this could be considered a likely scenario.

Firstly, there are the problems that arise with scaling up from trials to paddock production, as noted above. Secondly, there are pest and disease impacts that may yet emerge. Thirdly, there is as yet no cotton-processing infrastructure in this area, which would add to the relative costs of production. Fourthly, there is the question of individual adaptation. Either new growers would have to learn and purchase additional equipment for sugar production, or sugar producers would need to do the same for cotton production. The expert informants in the present study suggested that sugar producers have developed lifestyle and supplementary enterprises, such as fishing, around the sugar season and an additional crop may not be appealing.

Fifthly, there is the issue of fitting cotton into the fallow period, which restricts the growers' capacity to choose the optimum growing period to avoid excessively wet conditions. This constraint could be addressed by developing new irrigation land, something long proposed for the Burdekin region, with cotton as the main crop. However, in terms of profitability and existing infrastructure, this might be more likely or at least predominantly used for sugar production. Then there is the cost of the infrastructure, which would result in additional costs to producers and/or the government. Alternatively, there could be an expansion of cotton within new schemes to the north-west of Burdekin on the Flinders and Gilbert Rivers, where drier conditions could favour cotton. Preliminary advice from the initial investigations for one site concluded 'that the high capital costs of in-stream dams and water delivery infrastructure …

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precluded commercial returns on combined investment in water assets and irrigated farming' (CSIRO 2013).

The conclusions of the CSIRO (2013) report and the present study suggest that the market incentives for the expansion of cotton production in the north of Queensland are limited, aside from the other risks and constraints listed above. Governments could return to an earlier nation-building approach and provide or partly provide the irrigation, transport and processing infrastructure but they would be against the trend of Australian political economy, where there has essentially been a move away from government intervention and production subsidies, especially since the early 1980s. Alternatively, there may be interest from international investors and the agreement for a Chinese company to develop another stage of the Ord River is noted (The Australian 2012). Hence, the development would shift from the market opportunity (for Australia) to the internal food security focus.

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