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CLIMATE CHANGE AND AGRICULTURE RESEARCH PAPER

Future distribution of cotton and wheat in Australia under potential climate change

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SUMMARY

The present study applies refined and improved scenarios for climate change to quantify the effects of potential alterations in climatic factors on localities for wheat and cotton production, which are two crops important to Australia's economy. The future distributions of *Gossypium* (cotton) and *Triticum aestivum* L. (wheat) were modelled using CLIMEX software with the A2 emission scenario generated by CSIRO-Mk3·0 and MIROC-H global climate models. The results were correlated to identify areas suitable for these economically important crops for the years 2030, 2050, 2070 and 2100 in Australia. The analysis shows that the areas where wheat and cotton can be grown in Australia will diminish from 2030 to 2050 and 2070 through to 2100. While cotton can be grown over extensive areas of the country until 2070, the area grown to wheat will decrease significantly over the period.

INTRODUCTION

The production of crop and livestock, hydrologic balances, input supplies and other agricultural system components are expected to be influenced by climate change (Adams *et al*. 1998). The potential impact of climate change on different species has been researched worldwide. The majority of studies link dynamic models with the general circulation model (GCM) for downscaled outputs. From these models, it is predicted, for example, that climate change will reduce agricultural profit by US$2.4 billion, close to 0·50 of the current annual profit, in California (Deschênes & Greenstone 2007). Similar trends have been projected for climate change in Colorado and Oklahoma (Deschênes & Greenstone 2007). In North Africa, it is projected that date production will become totally unviable by 2100 in countries such as Sudan, Algeria, Niger, Mauritania and Mali (Pearson *et al*. 2006). Projections show that by 2055 three quarters of countries in Africa and Central and South America will be less suitable for maize cultivation than they are currently (Elith & Leathwick 2009). In contrast, Song *et al*. (2004) found that climate change has produced a positive impact on cotton (*Gossypium*) growth and yield in the Xingjiang Autonomous region over the last 50 years. Nonetheless, a related study has demonstrated that if global warming predictions are reliable, the high temperatures and humid environment will cause food and fibre production to become limited to vegetative structures (Reddy *et al*. 1997). A similar study by Ortiz *et al*. (2008) suggested that wheat, a crop providing 0·21 of global food and using a total of 200 million hectares of global farmland will be affected significantly by changes in climatic factors. Morton (2007) predicted that the major impacts of global climate change will be most severe for populations comprising 'subsistence' or 'smallholder' farmers who will have limited capacity to adapt to the changes, constrained by socioeconomic and demographic trends and institutional effects.

The Stern Review on the Economics of Climate Change (Stern 2006) identified Australia as one of the country's most vulnerable to climate change because of its high dependence on primary

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production, extensive arid and semi-arid areas, high annual rainfall variability and existing pressures on water supply. According to a technical report on climate change in Australia by the Commonwealth Scientific and Industrial Research Organisation and Intergovernmental Panel on Climate Change (IPCC 2007), average temperatures in Australia have increased by 0·9 °C since 1950. The report estimated increases in the range of 1·2–2·2 °C by 2050 under conditions of low and high emissions, respectively. There are several consequences, including increasing occurrence of drought and significant reductions in important water sources such as the Murray and Darling rivers and Melbourne's water supply. The impact is predicted to be higher inland than in coastal areas.

Two crops most likely to be affected by climate change are wheat and cotton. Australia produces on average 24 million tonnes (t) of wheat a year, of which 0·75–0·80 is exported (Australian Bureau of Agricultural and Resource Economics (ABARE) 2011). In 2010/2011, total output of wheat amounted to 28 million t (ABARE 2011). Data for 2010/2011 indicates that production occurs mostly in New South Wales (NSW) (11 million t), followed by South Australia (6 million t), Western Australia (WA) (5 million t) and Victoria (4·5 million t).

Cotton is also one of Australia's largest rural export earners, generating more than $2 billion in annual export income (Cotton Australia 2014). In 2011/2012, the industry recorded its highest output of 5·3 million bales worth almost $3 billion. Currently, there are 1500 cotton farms, with about half in NSW and the other half in Queensland. However, most of Australia's cotton is produced in NSW, in the area extending from the MacIntyre River in the south through the Gwydir, Namoi and Macquarie Valleys, and along the Barwon and Darling Rivers. The rest of the production occurs in Southern and Central Queensland from Emerald in Central Queensland southwards through the Darling Downs, especially along the Condamine River (Cotton Australia 2014).

There has been growing awareness of the value of plant and animal species distribution models (SDMs) over the past two decades. Some commonly used SDMs are Maximum Entropy modelling (MaxEnt), BIOCLIM and CLIMEX. Each species modelling technique has its own advantages and disadvantages. For example, Townsend Peterson *et al.* (2007) documented that the effects of input data gaps and bias in the MaxEnt software necessitates careful interpretation of model results. A major criticism of BIOCLIM is that the inclusion of all 35 variables leads to 'over-fitting', which may result in misrepresentation of the distribution of the projected species (Beaumont *et al.* 2005). It is suggested that refining the CLIMEX output by including non-climatic parameters, such as suitability of soil physicochemical properties, soil taxonomy, slope and land use, are essential to achieving more realistic results than those based purely on climate (Shabani *et al.* 2014*a*). However, CLIMEX has been identified to be among the most reliable and comprehensive inferential modelling programs (Kriticos & Randall 2001). The program produces a niche model that may be described as process-oriented and ecophysiological. It is capable of combining inferential and deductive models to describe responses of a species to climatic factor variability in order to project potential geographical distribution (Webber *et al.* 2011).

The present study aimed to refine projections for those localities that may be potentially suitable for the economic cultivation of cotton (*Gossypium*) and wheat (*Triticum aestivum* L.) based on changes in climate expected in Australia for the years 2030, 2050, 2070 and 2100, using CLIMEX, and the A2 emissions scenario together with two global climate models (GCMs): the CSIRO-Mk3·0 (CSI) model and the MIROC-H (MR) model.

MATERIALS AND METHODS

The A2 SRES scenario was chosen for the present study because it includes relevant demographic, financial and technological factors that relate to greenhouse gas (GHG) emissions drawn from independent and self-reliant nations (IPCC 2007). The predictions of the A2 scenario depict a relatively moderate increase in GHG, clustered around the mid-point of extreme low and high projections. The projections were then refined to enhance accuracy and reduce the uncertainties in assessing the impact of climate change on future climatic projections derived by GCMs (Masutomi *et al.* 2009; Shabani *et al.* 2014*b*, *c*) by ascertaining common areas in the projections from different GCMs. Thus, the outputs were overlaid for each of these important species to establish the projected localities and associated suitability found from both models (CSI and MR). To this end, the CLIMEX program version 3.0.2 (available from http://www.hearne.software/Software/CLIMEX/Editions) was utilized to simulate responses of both species to changes in major climatic factors. The

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ArcGIS program was utilized to extract CLIMEX outputs for projecting suitable future localities.

CLIMEX software

CLIMEX incorporates the assumption that the chief determinant of the distribution of plants and poikilothermal animals is climate and therefore models climatic conditions for different scenarios for various species (Kriticos *et al*. 2007). It has been utilized with success in the matching of climates and to predict potential weed distribution, through its use of a thermo-hydrological Growth Index (GI) and the climatic stressors that apply to the particular climatic condition (Sutherst & Floyd 1999). The Ecoclimatic Index (EI) (values between 0 and 100) denotes an overall assessment of a given locality's potential for supporting the permanent population of a species. It is calculated by subtracting from the GI the climatic stress variables Hot (HS), Cold (CS), Dry (DS) and Wet (WS) (Sutherst & Floyd 1999). Where the stress indices exceed in total the GI (i.e. $EI = 0$), it is projected that the species will not be able to persist at that specific locality (Shabani & Kumar 2013). In other words, CLIMEX incorporates an Annual Growth Index (GI_A) that denotes the potential favourable season for growth of the species. The cold, hot, wet and dry stress indices and their interactions illustrate the impact of unfavourable seasons on reduction of the species' population (Sutherst *et al*. 2007). The EI is formulated from a combination of the growth and stress indices and shows the favourability of the location or year for permanent occupation by the target species: it denotes the overall measure of the location or year's favourability for permanent occupation of the target species. The EI, which is based on weekly calculations of growth and stress indices, forms an average yearly index of the level of climatic suitability, rated from 0 to 100, where an $EI > 0$ denotes the potential level for establishment of the species. Climatic parameters of overall maximum and minimum monthly temperature (T_{max} and T_{min}), the overall monthly precipitation (P_{total}) and the relative humidity at 09:00 h ($RH_{09:00}$) and 15:00 h ($RH_{15:00}$) were drawn from the meteorological database (Shabani & Kumar 2014).

Current distribution of *Gossypium* and *Triticum aestivum* L.

Data on *Gossypium* and *T. aestivum* L. distributions were collected from the Global Biodiversity Information Facility (2015) and other related literature in CAB Abstracts databases (CAB Direct 2015).

A total of 19 302 records for *Gossypium* and 394 838 for *T. aestivum* L. were obtained from the literature and databases. Of these, 1224 *Gossypium* and 1940 *of T. aestivum* L. records had no geographic coordinates and were discarded, leaving a total of 18 078 for *Gossypium* and 392 898 for *T. aestivum* L. (Figs 1 and 2).

Climate data and future projections using global climate models and climate change projection scenarios

The two GCMs selected were CSIRO-Mk3·0 (CSI) and MR, in conjunction with the A2 Special Report on Emissions Scenarios (SRES) for modelling potential distribution under future climates of *Gossypium* and *T. aestivum* L. An initial 23 GCMs were assessed to develop a dataset that included the following four variables: monthly daily averages of maximum and minimum temperature, precipitation levels, average sea level pressure and specific level of humidity (Kriticos *et al*. 2012). These variables are vital for calculating CLIMEX input data, in addition to the 35 Bioclim variables which together enabled the first requirement to be met. As a second requirement, an output capable of relatively small horizontal grid spacing was sought. Lastly, in terms of assessing GCMs, the software chosen performed best in relation to other GCMs for modelling basic aspects of the observed climate on a regional scale (Hennessy *et al*. 2007; Kriticos *et al*. 2012).

The IPCC established the so-called SRES scenarios, consisting of a set of forty emissions scenarios for future global emissions of greenhouse gases and sulphate aerosols (Nakicenovic & Swart 2000). Each scenario depicts a 'tale' created from a set of logical assumptions associated with demographic, economic and technological factors, considered to impact future emissions. The SRES scenarios are based on a sub-set of six illustrative marker scenarios which range from the B1 scenario of diminishing GHG emission levels to the A1FI scenario in which the usage of fossil fuels continues at an intensive level. The perpetual inability to achieve international agreement in policy binding a global reduction in GHG emissions suggests that conservative emissions scenarios are no longer valid. For example, Rahmstorf *et al.* (2007) have shown that GCM projections have generally underestimated more recent trends in global temperature and

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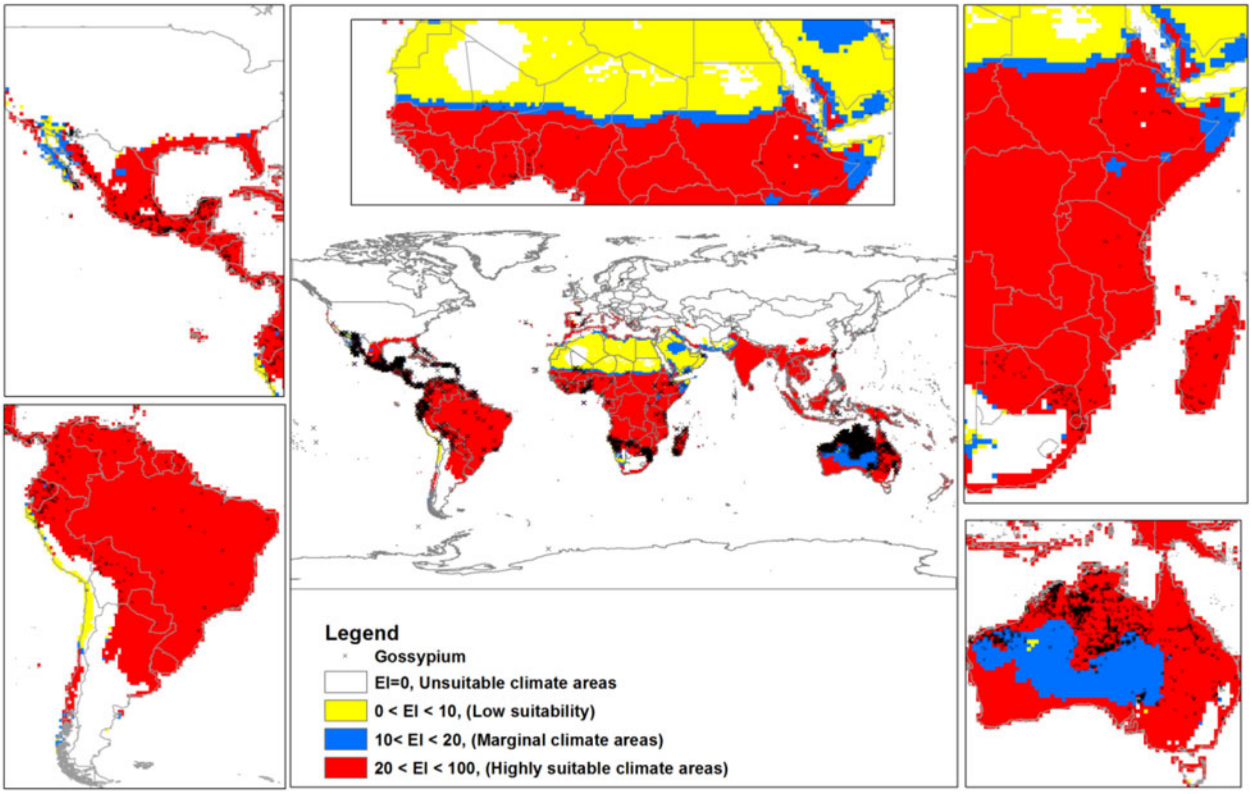

Fig. 1. Global distribution of *Gossypium* (cotton) cultivation and validation of the model.

sea level changes. Manning *et al.* (2010) have also demonstrated that since 2000, carbon dioxide emissions of fossil fuels equate with the most extreme SRES scenarios. Hence, only 'A' family SRES emissions scenarios in the CliMond dataset were included in the models used for the present study (Kriticos *et al.* 2012).

Model framing

Matching CLIMEX parameters to the distribution of already established species essentially amounts to the construction of a hypothesis from the definitive factors that have been proven to limit its distribution (Sutherst *et al.* 2007). Responses of many species to temperature and moisture are as yet largely unrecorded or not yet researched. In such cases, CLIMEX values are derived from the CLIMEX template that best matches the observed distribution. The parameter values used in CLIMEX for *Gossypium* and *T. aestivum* L. in the present study, have been derived directly from intensive dedicated studies on these two species. CLIMEX inferential model validation may only be achieved where data on the distribution of the species have been derived from more than one geographic locality. A set of parameter values may be considered validated where values developed from distribution data in one area successfully predict distribution in another (Kriticos & Randall 2001; Sutherst *et al.* 2007).

Cold stress

The CLIMEX parameters indicating cold stress variables of a species are the temperature threshold of cold stress (TTCS) and the associated weekly rate of cold stress (THCS). The temperature below which the accumulation of cold stress begins is established by TTCS and the rate of accumulation by THCS. *Gossypium* may establish in locations as low as 11 °C (Hearn 1994). Therefore, frost intolerance was incorporated by the aggregation of stress where the mean monthly minimum temperature was <11 °C, with the accumulation rate of frost stress (THCS) set at −0·1 per week. For *T. aestivum* L., the TTCS and associated THCS were set at −10 °C and −0·001 per week as this provided the best fit to the observed distribution of this species in North America, Canada and Asia.

Heat stress

Since *Gossypium* is able to persist up to 39 °C, this was the parameter value selected for heat stress

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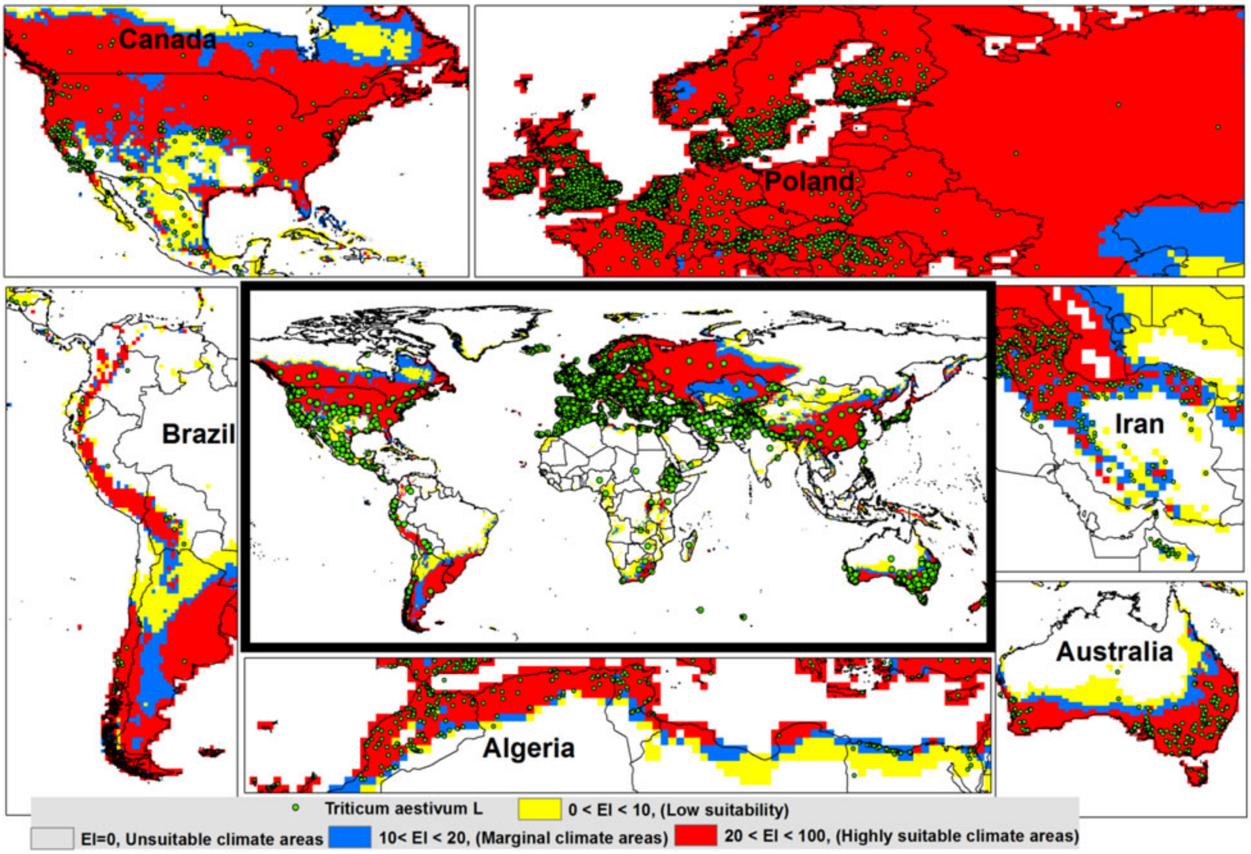

Fig. 2. Global distribution of *Triticum aestivum* L. (wheat) cultivation and validation of the model.

(TTHS) (Wall *et al.* 1994; Cothren 1999; Rogers *et al.* 2007). The accumulation rate of heat stress (THHS) was set at 0·001 per week, the rate that has enabled persistence of *Gossypium* in Southern Mexico, Colombia and Ecuador. Conversely, the TTHS parameter for *T. aestivum* L. of 39 °C was derived from documented research which demonstrates the species persistence when environmental conditions reach this temperature (Beddow *et al.* 2013) and also provides the best fit to the observed distribution of this species in North America, Canada, Australia and European countries. This temperature is just above the known maximum temperature for development of the species, and the rate of stress accumulation is in accordance with the known distribution in the Southwest USA. The THHS parameter for *T. aestivum* L. of 0·005 per week was chosen in accordance with its persistence in Europe.

Wet stress

Values for the parameter of moisture response in *Gossypium* were sourced from the literature on the physiology and growth of cotton (Feddes *et al.* 1978; Hearn 1994; Wall *et al.* 1994). For *Gossypium*, the threshold value for wet stress (SMWS) was established as 3, with the associated accumulation rate (HWS) as 0·001. For *T. aestivum* L. SMWS and HWS parameter values selected were 3 and 0, respectively. These values fit the known distributions in Iran, Tunisia, Northern Algeria, Germany, Spain and France.

Growth index

The CLIMEX growth index is obtained by the product of the temperature and moisture indices. The temperature index components are: DV0, the lower temperature limit; DV1, lower optimal temperature; DV2, upper optimal temperature; and DV3, the high temperature limit. *Gossypium* cultivation is possible in areas with temperature ranges between 22 and 36 °C (Reddy *et al.* 1997; Cothren 1999). Data on climatic conditions suitable for *Gossypium* cultivation match data derived from actual conditions in Madagascar, Ghana, Venezuela and Colombia. Based on the literature, the lower and upper limits

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(DV0 and DV3) were established at 10 and 36 °C, with optimum lower and upper values (DV1 and DV2) at 22 and 32 °C. For *T. aestivum* L. the lower and upper limits (DV0 and DV3) were established at 4 and 32 °C, with optimum lower and upper values (DV1 and DV2) at 14 and 25 °C (Reynolds *et al.* 2001; Beddow *et al.* 2013).

The CLIMEX index of soil moisture comprises the following parameters: SM0 denotes lowest permissible; SM1 the lower optimum; SM1 the upper optimum and SM2 the upper permissible level. In the present study, *Gossypium* SM0 was established as 0·001, matching observed distributions in South America, with SM1 and SM2 at 0·3 and 1·9, to improve the cultivation in Madagascar and Mexico. The upper threshold (SM3) was set at 3, matching the observed distribution on a number of continents.

Combining outputs of both global climate models for *Gossypium* and *Triticum aestivum* L.

The overlaying of CSI and MR outputs facilitated the identification of common areas of projection likely to become highly conducive to *Gossypium* and *T. aestivum* L. for the designated years for future scenarios. All locations satisfying the condition $EI > 20$ for *Gossypium* and *T. aestivum* L., common in the two outputs, were categorized as potentially of high suitability for cultivation, while all locations satisfying the condition $10 < EI < 20$ for each species common in the two outputs were categorized as areas of potential marginal suitability. Likewise, the condition $0 < EI < 10$ identified areas of potential low suitability. This EI classification is based on research by Shabani *et al.* (2014*d*). As already stated, the main aim in combining GCM outputs is to identify common localities projected, which enhances certainty regarding areas likely to become conducive to cultivation in the future.

RESULTS

Model validation and projections under current climate

The fitting parameters for both species in the present study used the indigenous range and worldwide agricultural crop distribution, although distribution data of the two species from Peru, Bolivia, Yemen, Ethiopia and Nigeria were set aside for model validation. In terms of validation of areas, 0·83 and 0·89 of the *Gossypium* and *T. aestivum* L. records matching the acceptable parameters of the suitable GCM confirm that values selected for the CLIMEX parameters were optimum (see Canada, USA, Bolivia, Yemen, Ethiopia and Nigeria in Figs 1 and 2).

Historical climate at global scale

Comparisons of the suitable GCM with the world distribution for *Gossypium* (Fig. 1) and for *T. aestivum* L. (Fig. 2) show consistency of the EI of the models with current world distributions. Climatic conditions conducive to *Gossypium* cultivation are projected for areas of the southern USA, Southern, Eastern and Western Mexico, Paraguay, Colombia, Venezuela, Ghana, Kenya, Swaziland, Northern Namibia and Madagascar. Suitable conditions are also projected for *T. aestivum* L. over large areas of the Central, Northern, Eastern and Western USA, Central Mexico, Central Ecuador, Northern Algeria, Spain, Portugal, France, Italy, Germany, Northern Tunisia, Iran, Ecuador and Nepal. The fact that nearly 0·95 of *Gossypium* and 0·93 of *T. aestivum* L. records matched the parameters of the suitable GCM (red and blue areas) proves that values selected were optimum (Figs 1 and 2).

Agreement between CSIRO-Mk3·0 and MIROC-H global climate models on areas becoming suitable for *Gossypium* cultivation in Australia for the designated years of future scenarios

The overlaying of results of the two GCMs indicated widespread agreement in projected areas suitable for *Gossypium* growth for 2030, 2050 and 2070 (Fig. 3). Almost the whole of NSW, Queensland, large northern areas in the Northern Territory, large southern areas in WA and areas between 10–20°S and 120–130°E, southern South Australia and Central and Western Victoria are shown by both models to become highly conducive to the cultivation of cotton by 2030, continuing through to 2050 (Fig. 3). However by 2070, this position will become limited to 145–155°E in NSW and Queensland and by 2100 to 148–155°E for the same regions (Fig. 3). Northern regions in WA and the Northern Territory display a similar downward trend by 2100. A comparison of the areas of unsuitability ($EI = 0$ or $0 < EI < 10$) derived from both GCMs for 2030 indicates that nearly 0·65 of Australia will be unsuitable for the cultivation of cotton by 2100 (Fig. 3). However, the two models agreed that northern regions of WA and

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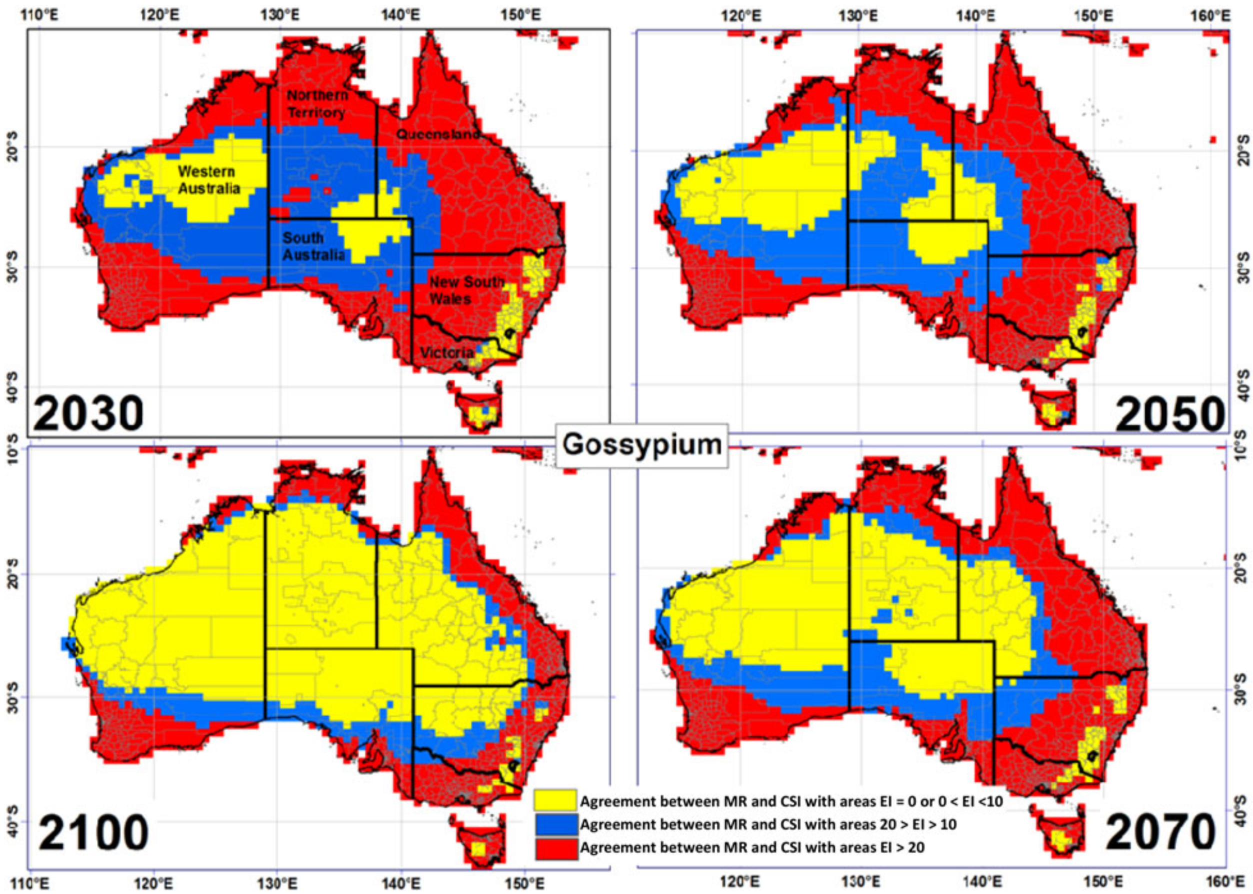

Fig. 3. Common climate projections (EI) for *Gossypium* using CLIMEX under the CSI and MR GCMs running the A2 scenario for the designated years for future scenarios.

Victoria will retain a climate suitable for cultivation up to 2100 (Fig. 3).

Agreement between CSIRO-Mk3·0 and MIROC-H global climate models of areas becoming suitable for *Triticum aestivum* L. cultivation in Australia for the designated years of future scenarios

Combining CSI and MR GCMs projections for *T. aestivum* L. for 2030 shows that wider areas of western Queensland, most of the Northern Territory and the northern and western regions of WA will become highly unsuitable for cultivation. This deteriorating trend is predicted to continue to 2050 and 2070 through to 2100 (Fig. 4). By 2100 the whole of the Northern Territory, Northern, Western and Central WA, most of Northern and Western Queensland and the northern regions of South Australia will no longer be suitable for growing *T. aestivum* L. Climatically, Northwestern NSW will experience a reduction in suitable areas of cultivation when the current cultivation areas are compared with those for 2030. This declining trend will extend through to 2050 and 2070 to 2100 (Fig. 4).

DISCUSSION

The importance of wheat and cotton to Australia's rural regions and the government's goal of encouraging residents in the highly populated major cities and coastal areas to migrate to the rural regions means understanding the impact of climate change on production of the two crops is critical to the future of the Australian economy. Therefore, the present study sought to assess the climate change impact on localities suitable for wheat and cotton cultivation in Australia over the periods 2030, 2050, 2070 and 2100.

The refined projections illustrated in Figs 3 and 4 provide greater certainty with regard to areas projected to become highly suitable to the cultivation of cotton and wheat than achieved by the majority of earlier studies that used a single high or low end

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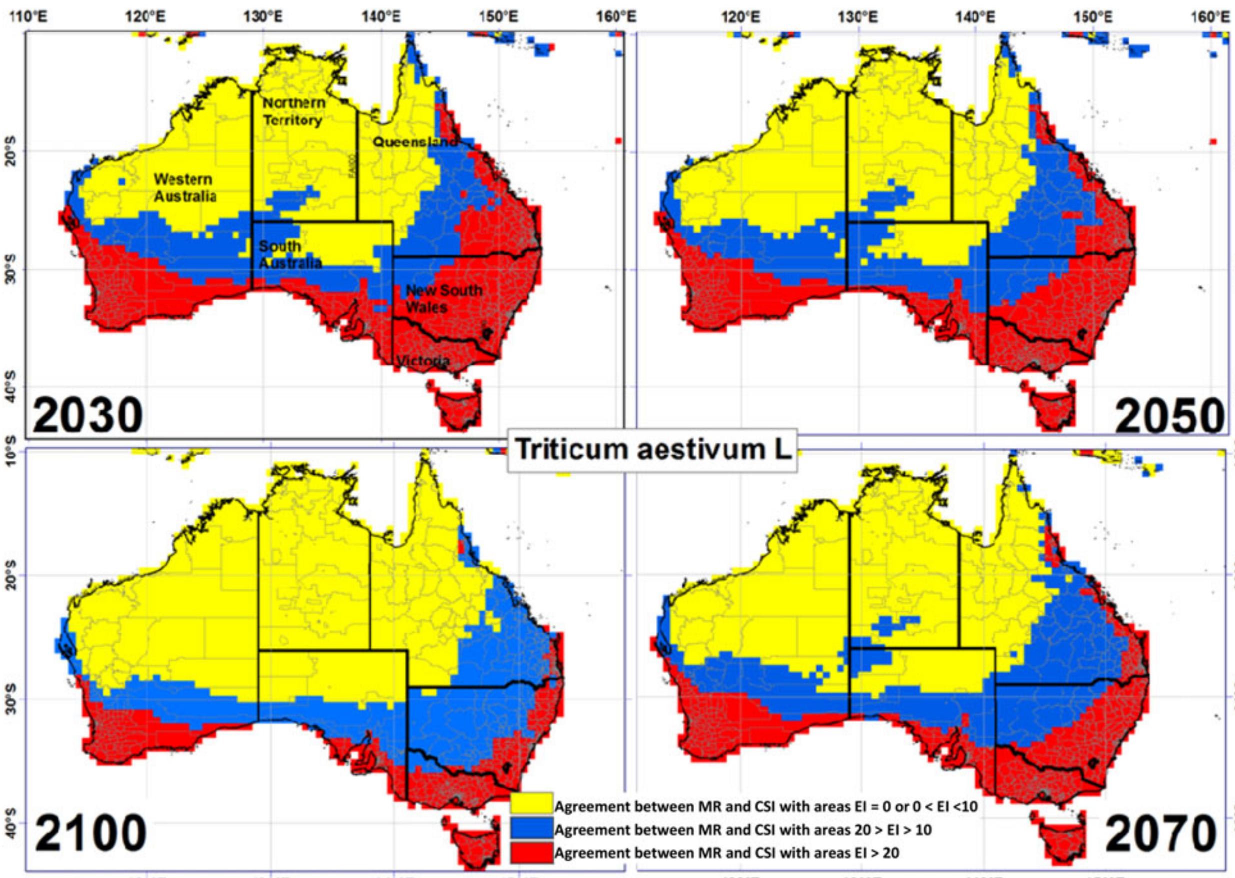

Fig. 4. Common climate projections (EI) for *Triticum aestivum* L. using CLIMEX under the CSI and MR GCMs running the A2 scenario for the designated years for future scenarios.

scenario or single GCM (Brklacich & Stewart 1995; Mearns 1995; Luo *et al.* 2003). This is due to the overlaying of results from the two GCMs for each period of time. Results derived from a single GCM, while generally precise, are limited to projections valid only for that specific scenario and thereafter are purely speculative in terms of representing alternative future scenarios. While the outcomes in these single GCM studies have some application, they generate no information in terms of probable eventualities. Moreover, they provide no indications of how their results will match broader uncertainty ranges, or define these uncertainty ranges.

The current combined CSI and MR results shows that the western and northern areas of Queensland, most of the Northern Territory, central, northern and western areas of WA, the northern half of South Australia and the northwestern regions of NSW will gradually lose their suitability for the cultivation of *T. aestivum* L. from 2030 through 2050 and 2070 to 2100. Projected scenarios for 2030–2100 show that only a few southern regions of Australia, especially Victoria, will continue to be highly suitable for producing *T. aestivum* L. These findings are consistent with those reported by Howden & Jones (2001).

In contrast to the findings for *T. aestivum* L., the simulations indicate that almost all of NSW and Victoria, large parts of Queensland, the northern areas of the Northern Territory, large southern areas of WA and southern South Australia will become highly conducive to the cultivation of *Gossypium* (cotton) by 2030 and will continue through to 2050. However by 2070, this position will become limited to the eastern areas of NSW and Queensland, most of Victoria and the southeastern parts of WA. This deterioration in suitable areas will continue through to 2100. The projections indicate that drought stress will impact negatively on both *Gossypium* and *T. aestivum* L. production in Australia with regional differences in the effects of the stresses (temperature and drought).

From the current findings, the area currently planted to cotton can be extended from Queensland and NSW to other states and various species trialled to ascertain those that will provide the best yields under the climatic conditions available in these states. At the same time, production of wheat can be extended by trialling various farming strategies that can reduce and even improve yield loss at a cost that will enable farmers to continue to earn better returns on their output. It is reported that strategies such as reducing planting densities, increasing fallow, increasing residue retention or choosing shorter season varieties provide smaller offsets in yield loss than strategies that increase residue retention to conserve moisture under mix cropping and grazing systems. Therefore, a mix of cropping and grazing systems is recommended for reducing the rate of yield loss. In addition, income from crops more suited to the changed climatic conditions will offset losses from wheat. Farmers in the yellow areas in Fig. 4 can replace wheat production with cotton in the areas conducive to cotton while those in the blue and red areas for both crops can rotate the two crops to maximize yields from each. At the same time other crops suited to the changing climate conditions with high returns can be cultivated.

Furthermore, based on the projection of the present study, attention should be given to developing secondary and tertiary industries, especially manufacturing and tourism, for diversification and mitigation against the problems that will emerge from a diminishing primary food production sector. This is important as the majority of Australia's rural regions are dependent on agriculture and their economic conditions fluctuate with climate change, access to water and global demand for their produce. Without any interventions, the deteriorating climatic conditions will cause populations to migrate from rural to coastal areas and major cities, adding to the pressure on resources such as water, infrastructure and housing and increasing the unemployment rate.

Significant factors that contributed to the success of the present study were: (1) availability of and accessibility to all variables necessary for accurate CLIMEX modelling, including temperature, humidity and precipitation; (2) well documented historical data on the distribution of *Gossypium* and *T. aestivum* L.; and (3) the qualities of the two GCMs chosen in regard (a) small horizontal grid spacing design and (b) their strong representation of observed local climatic factors.

There were, however, limitations that must be noted. CLIMEX results are climate response based, the impact of non-climatic parameters such as biotic interactions and inter-species competition were not taken into account Shabani *et al.* (2012). Thus, the following should be considered when interpreting the results:

(i) The modelling is purely climate-based and does not take into account non-climatic factors such as use of land, type of soil, biotic interaction, competition and diseases.
(ii) Current broad-scale climatic data was employed, and thus results present purely broad-scale shifts.
(iii) Results are subject to the uncertainties surrounding future GHG emission levels.
(iv) Similar modelling should be carried out for crop models using nitrogen, soil properties and irrigation.
(v) In the present study, carbon dioxide enrichment and the potential genetic progress were not taken into account.

CONCLUSION

In conclusion, the distribution maps presented in the study provide information useful for the long-term planning of the cultivation of *Gossypium* and *T. aestivum* L. in the areas projected to become suitable, with strategic shifts in production away from areas projected to become unsuitable. The two species can be replaced with more suitable crops and broad diversification of the economic base undertaken to enhance economic activity and maintain the populations in rural Australia.

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