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Impacts of Climate Change on Chinese Agriculture – Phase II

Future Cereal Production in China: Modelling the interaction of climate change, water availability and socio-economic scenarios

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Project Background

The project *Impacts of Climate Change on Chinese Agriculture* (ICCCA) was funded by the UK Government's Department for Environment, Food and Rural Affairs (Defra – transferred to the Department of Energy and Climate Change, DECC, in October 2008) and Department for International Development (DFID), conducted in partnership with China's Ministry of Science and Technology (MOST).

Since 2001, the project has led the way in understanding how climate change can be expected to affect rural China.

The project was rolled out in two phases: Phase I (2001 to 2004) applied regional climate modelling to construct several possible future climate scenarios for China. These were subsequently fed into a suite of regional crop models adapted by the Institute of Environment and Sustainable Development in Agriculture (previously the Agrometeorology Institute) of the Chinese Academy of Agricultural Sciences (CAAS), in collaboration with UK climate-change researchers, to determine the potential impacts of climate change on crop yields in China up to 2100.

Building on Phase I, Phase II (2005 to 2008) refined and widened the national level analysis. CAAS also worked in collaboration with major regional implementers such as the Clean Development Mechanism Service Centre (Ningxia) and Meteorological Study Institute (Ningxia), and engaged a range of stakeholders to assess the impact of climate change on rural livelihoods. This led to the development of the first regional adaptation framework in China – for the northern province of Ningxia.

The key findings and approaches for the project are summarised in six pamphlets. These are:

- *Overall summary of results*
- *Understanding how China's climate may change in the future*
- *Modelling the impacts of climate change on cereal production in China*
- *Modelling the interaction of climate change - water availability and socio-economic scenarios on cereal production*
- *Rural livelihoods and vulnerability to climate hazards in Ningxia*
- *An adaptation framework and strategy for Ningxia*

The full technical reports from the project can be found at www.china-climate-adapt.org. These are:

- *National Level Study: The Impacts of Climate Change on Cereal Production in China*
- *Future Cereal Production in China: Modelling the Interaction of Climate Change, Water Availability and Socio-Economic Scenarios*
- *Climate and Livelihoods in Rural Ningxia*
- *Climate Change in Ningxia: Scenarios and Impacts. Technical Report.*
- *Adaptation Framework and Strategy:*
  - *Part 1 – A Framework for Adaptation*
  - *Part 2 – Application of the Adaptation Framework: A Case Study of Ningxia, Northwest China*
  - *Part 3 – An Adaptation Strategy for Agriculture in Ningxia, Northwest China*

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Project Team

The project team comprised the Institute of Environment and Sustainable Development in Agriculture of the Chinese Academy of Agricultural Sciences (CAAS), AEA Group, who managed the project and provided technical input, and Dr. Declan Conway of the University of East Anglia as Scientific Advisor. The project has benefited from the contribution of numerous partners and stakeholders in both China and the UK. Collaborative research links have been forged resulting in new insights into the scientific and policy challenges posed by climate change in China over the next century.

Acknowledgments

Key collaborators

China

- Chinese Ministry of Science and Technology
- National Development and Reform Commission
- China Meteorology Administration
- Chinese Ministry of Agriculture
- Chinese Academy of Social Sciences
- Ningxia Department of Science and Technology
- Ningxia Bureau of Meteorology
- Ningxia Agriculture and Livestock Department
- Office of Environmental Protection, Ningxia
- Office for Poverty Alleviation, Ningxia
- Clean Development Mechanism Centre, Ningxia

UK

- Cranfield University
- Environment Agency
- Met Office Hadley Centre
- The Tyndall Centre for Climate Change Research, University of East Anglia
- UK Climate Impacts Programme (UKCIP)
- University of Reading

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- Centre for Ecology and Hydrology, Natural Environment Research Council, UK
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- School of Earth, Environmental and Geographical Sciences, University of Edinburgh, UK
- Unit for Landscape Modelling, Cambridge University, UK

www.china-climate-adapt.org

Executive Summary

Food production in China is a fundamental component of China's economy and national policies on agriculture. Sustaining and increasing output to meet growing demand faces significant challenges including, climate change, changing patterns of food consumption, increasing population, agricultural land conversion, and competing demands for water. Recent warming in China is projected to accelerate by climate models, with associated changes in precipitation and frequency of extreme events.

How changes in cereal production and water availability due to climate change will interact with other socioeconomic pressures is poorly understood. By coupling crop and water simulation models and scenarios of climate and socioeconomic change, this report demonstrates that the absolute effects of climate change alone are modest and the interactive effects of other drivers tend to counter-balance, leading to small overall changes in total production by 2050.

Outcomes are highly dependent on socioeconomic development pathways and assumptions about the effects of CO_2 fertilisation, among other things. We find that water availability plays a significant limiting role on potential cereal production due to the combined effects of higher crop water requirements and increasing demand for non-agricultural use of water.

Without adaptation, per capita cereal production falls in all cases, by up to 40 per cent of current levels. By simulating adaptation responses out to 2050 we show that China is able to maintain per capita cereal production, given reasonably optimistic assumptions about policies on land and water management and agricultural technology.

This report is an output of the project *Impact of Climate Change on Chinese Agriculture* (ICCCA). It builds on ICCCA's *National Level Study: The Impacts of Climate Change on Cereal Production in China*, and addresses the following key questions:

1. **What are the likely impacts of climate change on China's cereal production?**
2. **How do climate impacts compare to socio-economic pressures over this century?**
3. **Where and how do significant interactions arise?**
4. **What are the effects of broad level adaptation policies on future impacts?**

This report sets out a framework to assess the direct effects of climate change on cereal crop yields in China on the basis of high-resolution regional climate scenarios and detailed crop models. It takes account of the indirect effects that changes in water availability have on irrigation water supply as well as the direct effects of CO_2 fertilization and of changes in arable land area and demand for water due to population increase and economic development as dictated by socio-economic scenarios downscaled from IPCC SRES.

Changes in crop yields and water availability are presented and, using areas of crops sown across China, converted into estimates of cereal production, expressed as a national total or a per capita basis. The effects of three adaptation strategies reflecting national level agricultural policy objectives are simulated to assess their effectiveness in offsetting climate change impacts on cereal production. They are: prioritizing water allocation for cereal production over other agricultural uses; successful implementation of controls on loss of agricultural land; and optimistic projection of improvements in agricultural technology in the future.

Results are presented for the 2020s and 2050s using two IPCC SRES emissions scenarios: A2 and B2. Each emissions scenario is underpinned by a particular storyline for the socio-economic evolution of the world, as follows:

- **IPCC SRES A2**: this emissions scenario (storyline) represents a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines (scenarios);
- **IPCC SRES B2**: this emissions scenario (storyline) represents a prosperous and fair world where a general orient towards sustainable development leads to relatively low emissions of greenhouse gases.

Taken together, the two scenarios A2 and B2 cover a wide range of socio-economic conditions that might prevail in the future.

The changes in climate variables projected by the Met Office Hadley Centre's regional climate model (PRECIS) for China overall under emissions scenarios SRES A2 and B2 are given in Table ES. 1 below.

Table ES. 1 Average change in surface air temperature, precipitation, and radiation under SRES A2 and B2 emissions scenarios for all China as projected by the regional climate model PRECIS; changes are relative to the average values for the baseline period (1961-1990). Corresponding CO_2 concentrations for each time period are also shown.

	A2 (Mid-high emission)				B2 (Mid-low emission)			
Periods	Temperature change (℃)	Rainfall change (%)	Radiation change (%)	CO_2 (ppm)	Temperature change (℃)	Rainfall change (%)	Radiation change (%)	CO_2 (ppm)
Baseline (1961-1990)	--	--	--	334	--	--	--	334
2020s (2011-2040)	+1.3	+5	+0.5	440	+1.5	+4	+0.5	429
2050s (2041-2070)	+2.6	+10	+0.7	599	+2.4	+6	+0.7	492
2080s (2071-2100)	+4.5	+17	+1.1	721	+3.4	+9	+0.9	561

The analysis in this report is carried out in a step-wise manner to highlight the relative effects of different drivers.

The main results without any adaptation are as follows:

- Climate change (based on average changes in temperature, precipitation and radiation) produces notable but modest impacts on total national cereal production in the 2020s. Scenario A2 results in modest positive impacts of +4.8% whilst B2 results in modest negative impacts of -4.1%; modest negative impacts prevail for both A2 and B2 in the 2050s (-2.7% A2, -7.4% B2).

- In all cases the positive effects of CO_2 fertilization on cereal production are quite large. These effects generally offset the negative impacts of climate change that result from its direct effects on yield and irrigation water requirements, and the indirect effects on water availability.

- Spatial patterns of change in total crop production by the 2050s show marked differences across China. The general pattern is for increases in the northeast and north and decreases in the central, eastern and southern provinces. Areas particularly sensitive to climate change include the following; the largest per cent changes occur in the northeast (±>30%), and areas of moderate decrease (central, eastern and southern provinces) and moderate increases (parts of the north and southeast).

- Climate change increases irrigation water requirements with scenario A2, and reduces them with B2. Changes are in the order of ~10% of the total irrigation water requirements in 2020 and 2050 and are due to differences in the spatial patterns of changes in temperature and precipitation.

- Although river flows tend to increase by ~10%, the combined effects of climate change on water availability and increases in water demand due to socio-economic development pathways lead to an overall decrease in water availability for agriculture if water allocation policies remain unchanged. These changes are as follows: under A2, -9% (2020s), -27% (2050s); under B2, -7% (2020s) and -20% (2050s).

- Water availability will act as a significant limit to national total production in the future, with or without CO_2 fertilization effects. Decreases in water available for agriculture lead to significant reductions in the area of irrigated rice and slight increases in the area of wheat and maize.

- Conversion of arable land due to economic development and population growth results in a significant decline in total production with A2 scenarios (not with B2).

- Overall, the combined effects of all drivers are fairly modest: slight increases in production occur for all cases, except the 2050s with A2 (+0.3% 2020s, -5.5% 2050s with A2, +3.6%, +2%, respectively, with B2).

- Factoring in future population growth leads to decreases in production per capita for all drivers combined in 2020 and 2050, for both A2 and B2.

The effects of three broad-level adaptation policies (in water allocation, arable land preservation and agricultural technology) on future impacts are addressed. We conclude that:

- Adaptation through water allocation policies produces modest benefits on total cereal production. However, allocating available water preferentially to maintain staple crop production could mean (and does in our results) that less water is available for other agricultural purposes (e.g. cash crops and livestock) purposes.

- An adaptation strategy based on water allocation policies and arable land conservation offsets the negative impacts on production (particularly for A2) and produces increases in total cereal production for both A2 and B2, in the 2020s and the 2050s.

- Adaptation based on optimistic and sustained improvements in agricultural technology results in significant increases in national total cereal production.

- In terms of cereal production per capita, only optimistic improvements in agricultural technology enable production to keep pace with population growth and the effects of other drivers, to maintain/improve existing levels of production.

In summary, the results demonstrate the importance of integrating climate change with socio-economic drivers of change as future development pathways will play a major role in determining which of the scenarios considered is most realistic.

In relation to climate change, the results demonstrate the critical importance of improving our understanding of the effects of CO_2 fertilization on crop growth.

Overall, we judge our results on climate change and water availability impacts on cereal production to be near the upper limits of response (i.e. optimistic) because the climate model used here gives much wetter conditions than a multi-model average, the CO_2 crop yield response function may not be sustained and may be counteracted by negative effects of surface ozone, and the impacts models are likely to underestimate the negative effects of extreme events on crop growth and water availability.

Water availability is a critical factor for agricultural production in China. Strong interlinkages between agriculture and water management and policy will be critical for effective adaptation in the future.

There is a need to develop more detailed adaptation policies based on a thorough understanding of context-specific decision-making and management practices across a range of scales, from national to local.

Table of contents

Acronyms

A2	One of the SRES emissions scenarios, A2 represents a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.
AEZ	Agro-Ecological Zone
ARC/INFO 8.0	A geographic information system produced by ESRI
AT	Agricultural Technology
B2	One of the SRES emissions scenarios, B2 represents a prosperous and fair world that as a result of a general orient towards sustainable development leads to relatively low emissions of greenhouse gases
BS	Baseline
C3	Relates to crop photosynthetic pathways: C3 crops (such as rice and wheat) show a greater CO_2 fertilization response
C4	Relates to crop photosynthetic pathways: C4 crops (such as maize) show a greater CO_2 fertilization response
CERES	A crop model: Crop Estimation through Resources and Environment Synthesis
DECC	UK Government Department of Energy and Climate Change
DEFRA	UK Government Department for Environment, Food and Rural Affairs
DFID	UK Government Department for International Development
DSSAT4.0.2	Decision support system for Agro-technology Transfer
ECCWA	Editors' Committee of Chinese Water Resources
ESRI	Environmental Systems Research Institute
FACE	Free Air CO_2 Enrichment
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GCM	General Circulation Model/ Global Climate Model
HadCM3H	Hadley Centre Atmosphere only Climate Model
ln	Mathematical function: natural logarithm
LP	Adaptation policy seeking conservation of arable land
MT	Megatonne = 10^6 tonnes
PRECIS	A Regional Climate Model developed at the Hadley Centre at the UK Met Office. "Providing REgional Climates for Impact Studies"
RMB	Renminbi – the Chinese currency. 1 US Dollar = 7 RMB (approx, May 2008)
SES	Socio-Economic Scenario
SRES	The Special Report on Emissions Scenarios is published by the Intergovernmental Panel on Climate Change. It contains four scenario families, including A2 and B2 used in this project.
UKCIP	UK Climate Impacts Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VIC Model	Variable Infiltration Capacity hydrological model
WD	Water demand

1 Introduction

Food production in China is a fundamental component of the national economy and a key driver of agricultural policy. Its global importance is measured by the fact that Chinese agriculture supports staple food supply for most of its population (~20% of global population) and, as of 2003, it yields 30, 15, and 17% of global production of rice, wheat and maize, respectively (Winters and Yusef, 2007).

The key questions addressed in this report are as follows:

- What are the likely impacts of climate change on China's cereal production?
- How do climate impacts compare to socio-economic pressures over this century?
- Where and how do significant interactions arise?
- What are the effects of broad level adaptation policies on future impacts?

Sustaining and increasing agricultural output to meet growing demand faces significant challenges including climate change, land degradation, maintaining the rate of yield gains using agricultural technology, changing patterns of food consumption (per capita increase / changes in dietary preference), population growth, conversion of land to non agricultural use, and competing demands for water currently used for irrigation. In the face of these challenges there is increasing concern about future food security, especially for poor people and poor countries (Gregory and Ingram, 2000; Parry et al., 2001; Rosegrant and Cline, 2003; Gregory et al., 2005).

ICCCA's *National Level Study: The Impacts of Climate change on Cereal Production in China* (Xiong et al., 2008) found that the absolute effects of changes in climate are large enough to compromise future cereal production in China but that the results are highly dependent on emissions and socio-economic scenarios. This report builds on the work done under the *National Level Study* and presents ICCCA's efforts to isolate the separate effects of climate change, population growth, technological progress, water availability and CO_2 fertilisation on cereal production in China out to 2050. The interplay among these drivers of change is analysed so as to provide a more contextualised assesment of climate change impacts. Finally, the effectiveness of different adaptation policy responses in relation to maintaining certain levels of national grain production is also examined.

This report begins with a review of earlier work on climate change and food production in China and an outline of the modelling and analytical framework. This is followed by a description of the scenarios and the impact models in Section 2. Section 3 presents results in a step by step manner, before the overall integrated results are introduced in Section 4. The effects of adaptation, including the contribution of improvements in agricultural technology, changes in agricultural land use policy and changes in water allocation policy are examined in Section 5. The final section, Section 6, concludes with a summary of the results, the main assumptions in the analysis and key areas for further research.

1.1 Crop production and climate change in China

Annual mean temperature in China has warmed during recent decades, especially since the 1980s (Tao et al., 2003a; Dai and Ding, 1994). The largest increases have occurred in the north, with smaller increases in the south. A significant increase (0.18℃/decade) in annual mean minimum temperature has been recorded for all of China, with the largest trend in winter (0.42℃/decade; Zhai et al., 1999). The warming trend is projected to accelerate by all General Circulation Models (GCMs), although at different rates. Future warming, plus changes in the amount and patterns of precipitation and other climatic variables, will impact on social, economic, and natural-resources sectors such as human health, agriculture, forests, water and coasts. Impacts of climate change on China's agriculture are a key concern due to the sector's importance to the national economy and security.

The potential impacts of climate change on China's crop production have been explored since the 1990s. For instance, Wang and Lin (1996) assessed the impacts of climate change (no consideration of changes in CO_2) on maize production in eastern China. They concluded that yields of both rainfed and irrigated maize decreased in most areas, due primarily to shorter maize growth time in the higher temperature environment. Tao et al. (2008) made a probabilistic assessment of changes in rice yield based on 20 different climate scenarios and found that rice yield would decrease with a probability of 90%. Higher temperatures increases of 1℃, 2℃, and 3℃, decreased yields by 6.1% to 18.6%, 13.5% to 31.9%, and 23.6% to 40.2%, respectively. Similar results have been reported by Jin et al. (1995), Yao et al. (2007) for rice, and by Jiang et al. (1998), and Ju et al. (2005) for wheat, although using different climate change scenarios and crop models. Lin et al. (2005) analyzed the impacts of increases in CO_2 concentration for IPCC SRES A2 and B2 emissions and climate change on rice, maize and wheat. They found that higher CO_2 concentrations compensate the negative effects of higher temperatures, resulting in average increases in yield of 13.2% for rice, 18.1% for maize, and 28.3% for wheat, and causing an overall increase in grain production by the 2080s in China.

The interactions between climate change, crop production, land use and water availability have been largely neglected until recently (Betts, 2005). The relentless pressure of increasing population and per capita consumption on land and water use are major factors in determining the characteristics of future scenarios of food security and are likely to be key factors in increasing the risk of famine in the future (Slingo et al., 2005). Recent studies have used a variety of models and climate scenarios to analyze the integrated impacts of climate change on food production. Several integrated assessments have incorporated water availability (e.g. Rosenberg et al., 2003; Rosenzweig et al., 2004) and others have considered different socio-economic development pathways (e.g. Parry et al., 2004; Fischer et al., 2005). Although most of the integrated assessments have been done in developing countries (e.g. Izaurralde et al., 2003; Holman et al., 2005a, 2005b), results for China have been referred to in global studies.

Parry et al. (2005) assessed global food production under different socio-economic scenarios, and found that China's national potential grain yield by the 2080s is within the range of 0% -- 2.5%, assuming no changes in crop cultivars, under three emissions scenarios (unmitigated, stabilization of CO_2 at 750ppmv, and 550ppmv). Changes of this magnitude are modest and indistinguishable from the effects of background climate variability.

Rosenzweig et al. (2004) suggested that the northeastern region of China, a mechanized and irrigated agricultural center, suffers from fairly serious scarcity of water for agricultural purposes now and over the next 20 years. Fischer et al. (2005) inferred that because of more favourable average precipitation regimes projected by GCMs, there will be strong shifts in use of currently arable land in China, from previous marginal to more suitable conditions, which would benefit China's national food production in future.

Some stand-alone impacts assessment on agriculture and water resources with climate change have also been undertaken in China (Jin et al., 1995; Lin et al., 1997; Thomas 2000; Tao et al., 2003b). The approaches have included empirical observations, expert analysis, and estimates of crop yield and water irrigation demand effects using crop models. Model-based estimates suggest that some production increases are possible due to warming and CO_2 fertilization, but expected moisture-deficit changes and the uncertainties of changes in the timing and frequency of hazardous conditions indicate that climate change poses serious threats to the stability and adaptability of China's food production system (Barry and Cai, 1996).

This paper presents an integrated modelling framework for the assessment of cereal production in China in the twenty-first century, under two future scenarios of population, economic growth and climate change.

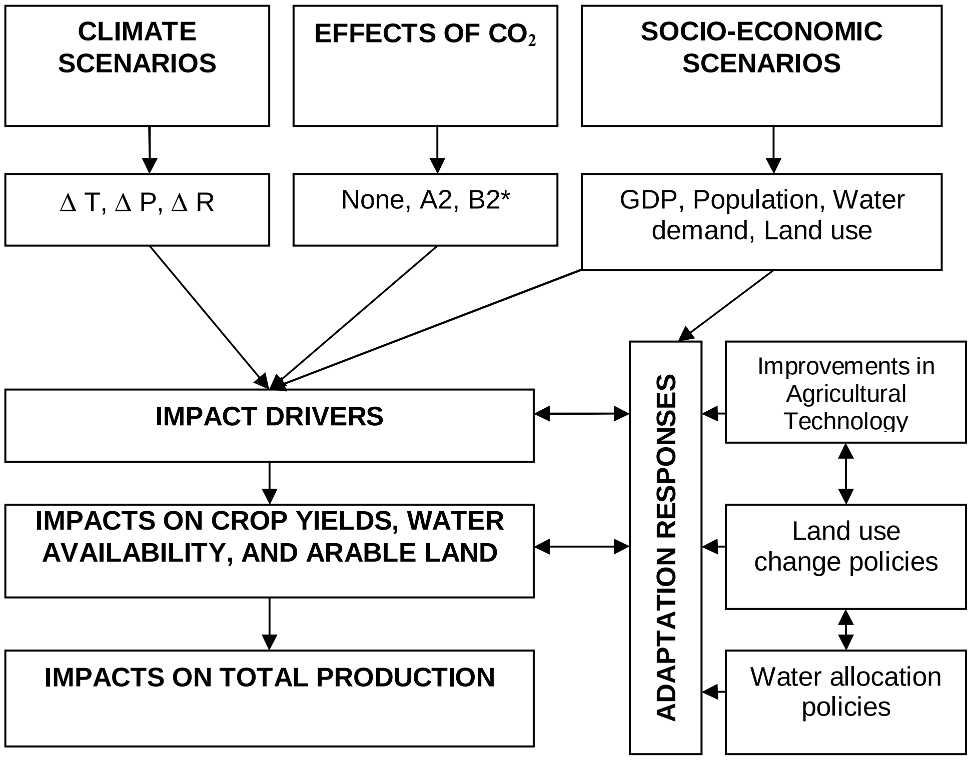
2 Description of the Drivers

2.1 Introduction to the analytical framework

Figure 2.1 shows the components of the analysis and their linkages. We use a step-wise approach to integrate the results, not a truly 'integrated' modelling system but stand alone in the sense that the SES are generated without ongoing modification of climate change and vice-versa: there is no attempt to 'co-evolve' the components of the future storyline (e.g. Lorenzoni et al., 2000). Expert judgement is used to ensure that as far as possible the climate scenarios, SES and adaptations are consistent with one another and underpinned by similar assumptions about the future guided by relevant storylines.

Climate impacts are simulated using process-based models with high-resolution climate scenarios (50km×50km). The overall process can be described in four stages: first, the CERES crop models and the VIC hydrological model are used to simulate the impacts of climate change on crop production and water availability respectively, under a SRES A2 and a SRES B2 scenario; second, socio-economic scenarios consistent with the two (IPCC) SRES scenarios as well as the Chinese mid- and long- term National Development Programme are constructed for China and used to link model results; third, national cereal production is calculated by adding rainfed and irrigated cereal production; and finally, the effects of three adaptation responses are assessed.

Figure 2.1 The main steps and interactions between different components in the analysis. ΔT=changes in temperature, ΔP=changes in precipitation and ΔR=changes in radiation. A2, B2 are the IPCC SRES emissions scenarios.



2.2 Climate change scenarios for China

Regional climate scenarios were generated following the methodology described in UKCIP (2002). The approach uses a nested climate model, with output from a coupled ocean-atmosphere global climate model (HadCM3H; ~ 300 km grid interval) to drive the high resolution (~ 50 km grid interval) atmospheric regional model PRECIS (Jones et al., 2004) for China. PRECIS takes the output of HadAM3H at its lateral boundaries, thereby inheriting the large-scale characteristics of the global climate model, but has finer spatial resolution (typically 50 km) and time resolution (i.e. daily weather data), better spatial detail (i.e. topography), and better simulation of extreme weather events. Details of the regional climate experiment can be obtained in Xu (2004); validation of PRECIS' performance in simulating China's climate is available in Xu et al. (2007) and Cao et al. (2007); see Zhang et al. (2006) for a description of the scenarios. Two emissions scenarios (A2 and B2) are available for use with PRECIS to obtain high-resolution changes in future climate variables (temperature, radiation, and precipitation). A2 represents medium-high emissions and B2 medium-low. Taken together, they encompass a wide range of future emissions pathways (Nakicenovic et al., 2000). Temperature and rainfall changes over China as projected by PRECIS are summarised in Table 2.1 for three future 30-year time slices. The corresponding CO_2 concentrations are also listed.

Table 2.1 Average change in surface air temperature, precipitation, and radiation under SRES A2 and B2 scenarios over China. Results from regional climate model PRECIS, changes are relative to the average values for the1961-1990 period (baseline). Corresponding CO_2 concentrations also shown.

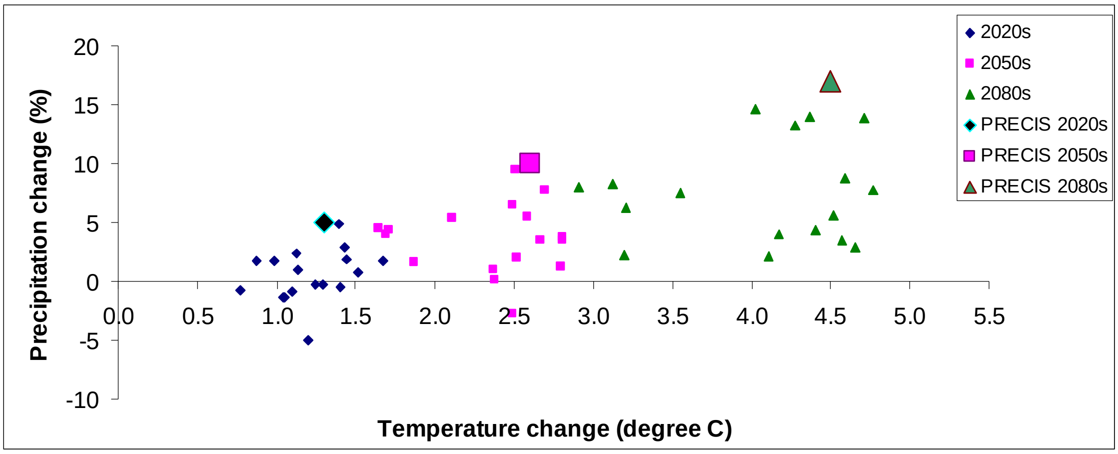
	A2 (Mid-high emission)				B2 (Mid-low emission)			
Periods	Temperature change (℃)	Rainfall change (%)	Radiation change (%)	CO_2 (ppm)	Temperature change (℃)	Rainfall change (%)	Radiation change (%)	CO_2 (ppm)
Baseline (1961-1990)	--	--	--	334	--	--	--	334
2020s (2011-2040)	+1.3	+5	+0.5	440	+1.5	+4	+0.5	429
2050s (2041-2070)	+2.6	+10	+0.7	599	+2.4	+6	+0.7	492
2080s (2071-2100)	+4.5	+17	+1.1	721	+3.4	+9	+0.9	561

As different climate models produce different responses to emissions of greenhouse gases, especially in what regards precipitation, it is important to assess how PRECIS results compare with those obtained with other climate models so as to reflect this source of uncertainty. This allows us to gauge the level of confidence in PREICS climate projections for China and to locate PRECIS scenarios within the range of results produced by other climate models. Results are presented from 17 climate models made available through the Program for Climate Model Diagnosis and Intercomparison (PCMDI) for the IPCC Fourth Assessment Report (AR4) (Meehl et al., 2007). Forty years of temperature and precipitation data were used from the 20th Century model runs (1961-2000), and 99 years of data were extracted from the SRES A2 and SRES B1 scenario runs from each of the climate models (2001-2099). Figure 2.2 shows the results for A2 emissions, with 30-year average changes in temperaure plotted against changes in precipitation for all models, including PRECIS, and three time slices. Climate scenarios obtained with PRECIS produce warming similar to the all-model average for China: for the 2020s, PRECIS predicts a 1.3℃ temper ature increase whilst the all-model average is 1.2℃; and for the 2050s, PRECIS's projection of 2.6 ℃ compares well with the all-model average of 2.4℃. Meanwhile, A2 climate scenarios obtained with PRECIS produce wetter conditions than the all-model average for China: PRECIS produces precipitation increases of 5% for the 2020s relative to the baseline whereas the average across all models is only +0.5%; for the 2050s, PRECIS yields precipitation increases of 10% whilst the all-model average is only 3.6%.

Results for B2 from PRECIS are not directly comparable with the all-model average results as the latter have been calculated for emissions scenario B1. However, a simple comparison of B2 and B1 results (not shown) shows warming is slightly slower with PRECIS, and precipitation increases slightly larger.

Figure 2.2 shows that PRECIS gives a reasonable mid-range projection of warming but a wetter precipitation projection. In summary, warming occurs in all seasons over the whole of China, with A2, B2 and B1. Warming is slowest in the southern and eastern sub-regions, and most rapid in the west. Climate models show consistent responses in mean annual precipitation change over China, with most models and emission scenarios projecting modest increases by the 2020s which continue to increase out to the 2050s and beyond.

Figure 2.2 Annual changes in temperature and rainfall averaged for the whole of China under A2, for the 2020s, 2050s, and 2080s with 17 GCMs from IPCC AR4 and PRECIS.



2.3 Socio-economic scenarios for China

It is important to explore how society and the economy will change over the coming decades, and how this will impact on climate change and adaptation. Socio Economic Scenarios (SES) generally span a range of alternative futures. They are projections of a potential future based on a clear storyline interpreted in quantified terms. The driving factors may be economic, social, institutional, managerial, and cultural (Nakicenovic et al., 2000). To be consistent with the high-resolution climate scenarios available from PRECIS, we used SRES A2 and B2; and to be consistent with Chinese National Planning we also generated a National Development scenario (not presented here, see ICCCA's *National Level Study: The Impacts of Climate Change on Cereal Production in China* (Xiong et al., 2008). The time frame chosen is for the period out to 2050. The methods are based broadly around methods used by the IPCC (Nakicenovic et al., 2000 and Gaffin et al., 2004). The IPCC SRES B2 storyline is consistent with China's plan of social and economic development over the medium to long term. The 'A2 family' represents the high end of the range of likely CO_2 concentrations, and is chosen here to show the impacts of a very high population projection. Ruosteenoja et al. (2003) summarise the SRES storylines from Nakicenovic et al. (2000) as follows:

A2 storyline and scenario family: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines.

B2 storyline and scenario family: a prosperous and fair world that as a result of a general orient towards sustainable development leads to relatively low emissions of greenhouse gases (Nakicenovic et al., 2000).

2.3.1 Population and GDP

Projections of population growth and economic growth (GDP) are fundamental components of SES and, from these, other indicators can be derived. Based on the GDP and population projections for SRES A2 and B2 provided by Gaffin et al. (2004), we changed the base year from 1990 to 2005 according to current statistical data (2006 China Statistical Year Book) and used these together with simple statistical rules to generate the required scenario indicators assuming a simple linear relationship between global and country scale[2]. National annual population and GDP growth rates were set equal to the larger regional rates. This is equivalent to keeping the fractional share of each nation's population or GDP constant relative to regional level (at the base year value), for the whole period.

[2] For GDP, the base year is 2005, but at comparable 2000 prices,

2.3.2 Water demand

Scenarios of future water demand are based on four sectors identified in the current China Statistical Year Book (2006): agricultural (AW), industrial (IW), domestic (DW), and environmental (EW). Different methods are used for each sector at provincial level. The results are aggregated in stages to yield total water demand by sector, and then total water demand for China. A combination of recent trends in water use, other research and expert judgement is used to calculate water demand in each sector, as follows.

For each climate scenario, the overall water consumption for China T is calculated as (1):

$$T = AW + IW + DW + EW = \sum_{i=1}^{31} t_i = \sum_{i=1}^{31} (aw_i + iw_i + dw_i + ew_i) \qquad (1)$$

Where t_i is the water consumption by province i ,$(i = 1,...,31)$ and aw_i, iw_i, dw_i, and ew_i are the amounts of water used in province i by agriculture, industry, domestic and ecosystem, respectively.

We compute irrigation (agricultural) water demand on the basis of the irrigation water use for arable land per hectare. Analysis of historical data from 1997 to 2005 for every province and results from other research are used to set a water use per hectare for every province for the years 2010, 2020, 2030, 2040, and 2050 (Zhen et al. 2004; Wang and Li. 2005; Wang and Ru. 2005; Li 2005; Li, 2006). In all provinces but Shanghai, irrigation water use is projected to decrease from the 2005 baseline to 2050 at different but constant annual rates. In Shanghai, meanwhile, the water quota increases slightly. These trends are based on the assumption that technological advancements in irrigation and irrigation water management and implementation of water sector reform and new policies will continue as at present, and we use the current rate of improvement in agricultural technology as the best estimate of future rates. Storylines in A2 and B2 have the same rate of technological development, so we assume the same rates of change in agricultural water use with both scenarios for all provinces.

For the industrial and domestic sectors, we make assumptions about per capita water use by province. Per capita water consumption is based on economic development and technological advances. Future rates of per capita water consumption are set by analysing current industrial structure and trends in water use. For the industrial sector, the per capita water use only decreases for Shanghai and Guangdong provinces; non-productive water consumption increases at different rates in all provinces. Water consumption for environmental needs includes water for urban environmental protection, and water supply for some rivers, lakes, and wetlands. Because local governments in China are slowly paying more attention to environmental protection, the proportion of demand from this sector is assumed to increase. For every province a different annual growth rate is set based on the actual rate from 2003 to 2006.[3]

2.3.3 Agricultural land use

A statistical method based on recent relationships between provincial scale GDP and change in arable land area is used. It is assumed that urbanization and industrial growth are the main drivers of decline in arable land area (Yang 2000; Li 1999).

Statistical analysis showed the best relationships were found between the natural logarithm of GDP (ln GDP) and the arable land area in certain regions: arable land area decreases as ln GDP increases. Such relationships were derived for 31 provinces in China, based on time series data from 1990 to 2005. Most of the regression relationships accounted for over 90% of variance in arable land area (adjusted $R^2 > 0.9$). Under A2, the future rate of change was assumed consistent with the trend observed between 1990 and 2005 of -3.2% per year. Under B2, the arable land area was held constant at 2005 levels because the B2 ‘storyline’ assumes more attention is paid to environmental considerations.

2.3.4 Socio-economic scenarios: main results

Table 2.2 lists the main results from the socio-economic scenarios. These are presented in more detail in Section 5 of ICCCA’s *National Level Study: The Impacts of Climate change on Cereal Production in*

[3] Data are only available from 2003

China (Xiong et al., 2008). Overall, a decrease in agricultural land use was projected, based on extrapolation of recent trends across China. The rates of change and area estimates are subject to large uncertainties due to problems with observed data and the important role of policy interventions. Changes range from large decreases with A2, primarily due to high contemporary rates, to no change at all with B2 – B2 assumes that government policy interventions succeed in slowing [halting?] the decline in agricultural land area.

Water demand was projected to increase from 563,300 x 10^6 m^3 in 2005 to 747,000 x 10^6 m^3 and to 691,400 x 10^6 m^3 in 2050 under A2 and B2 respectively. This is accompanied by a shift in the proportional use of water by sector primarily away from agriculture due to greater demand from other users (industrial, urban and environmental): the proportion of water used for agriculture is projected to decrease from 63.6% in 2005 to 37.5% (A2), 46.2% (B2) in 2050.

Table 2.2 China: population and GDP projections in the two SES, plus the general characteristics of the scenarios.

	2000	2005	A2		B2	
			2020	2050	2020	2050
GDP (106 RMB)*	9,920,000	15,600,000	30,100,000	83,700,000	48,100,000	145,000,000
Population (Billion)	1.27	1.31	1.53	1.94	1.44	1.51
GDP per capita ($)**	950	1,700	2,400	5,200	4,050	11,650
Water demand (106 m3)	549,700	563,300	616,100	747,000	619,400	691,000
Arable land (1000 Ha)	128,250	121,500	113,950	107,700	121,500	117,550
Characteristics			Rapid regional economic growth, materialist; low GDP growth rate; high population growth; rapid decrease of arable land; and rapid growth of water demand.		Local emphasis and environmental priority; moderate GDP growth rate and population growth; conservation of arable land; and steady growth of water demand.	

Notes: * at comparable prices in 2000; ** GDP per capita in USD in 2000 (100 USD = 828 RMB). Figures are rounded to the nearest thousand, except for per capita GDP, which is rounded to the nearest 50.

2.3.5 Adaptation scenarios for the agricultural sector

Future changes in agricultural production will not only depend on the magnitude of changes in climatic variables, but also on how well agriculture can adapt to these changes (Kaiser et al., 1993). Adaptation will play a key role in determining the economic and social costs of climate change (Tobey, 1992; Kahn, 2003). The IPCC AR4 (IPCC, 2007) reviews how adaptation can reduce the adverse impacts of climate change. A large number of studies have examined the consequences of agronomic adaptation, for example, modification of sowing dates (e.g. Matthews et al., 1997; Trnka et al., 2004; Mall et al., 2004), change of crop cultivars (e.g. Southworth et al., 2000; Ortiz et al., 2008), optimization of water and nitrogen management (e.g. Holden and Brereton, 2005), shifts in crops production areas (e.g. Iglesias and Minguez, 1997), and so on. Crop models can act as indispensable tools to assess the effectiveness of different adaptation strategies.

Differing trajectories of population growth and economic development will affect the level of future climate change as well as the responses of agriculture and water to changing climate conditions (Parry et al., 2005). Here we identify three broad policy level adaptation strategies; adaptation in water allocation policy (WD), in arable land policy (LP), and improvements in agricultural technology (AT) (Table 2.3). The goal of adaptation is assumed to be to maintain agricultural production in China. We analyse the effects of climate change with and without the adaptation policies to see whether, and to what extent, policies can offset the impacts of climate change.

A variety of potential adaptation actions and strategies exist. These three have been selected as illustrative of likely/realistic responses in three policy areas. Alternative perspectives would include other policy objectives for adaptation, e.g. ensuring sustainable production, or maintaining rural employment. The three areas identified for adaptation policies include many types of responses (e.g. across different scales, national or local programmes, regulations, laws, ‘hard’ or ‘soft’, new technologies). It is unrealistic for this scale of analysis to quantify the details of adaptation strategies.

We therefore use three broad level policies to encapsulate the detail implicitly. For example, within the water sector, adaptation may turn on irrigation technology/efficiency, water demand management and large scale infrastructures such as the South to North water transfer scheme and China's extensive reservoir construction programme. These developments and the future socio-economic decision making context in adaptation have major implications for water availability for agricultural purposes.

Table 2.3 The three adaptation policy responses and their assumptions.

Adaptation policy	No adaptation	Adaptation policy assumptions
WD - Prioritising water for agriculture	Without adaptation, we assume that all sectors have equal access to water according to the size of their demands relative to projected total demand. If demand exceeds supply all sectors experience water shortage.	Future national food supply is prioritised and, in line with current water allocation practices in arid and semi-arid northwest China, agriculture is given the highest priority for water use after domestic demand has been satisfied.
LP – Conservation of arable land	The current decline in cultivated land is assumed to continue in the future based on the rates of change observed in 1990 – 2005.	Implementation of policies to limit loss of arable land is successful. For A2, the current annual rate of change is halved. For B2, the arable land area is held constant at 2005 levels.
AT - Continued improvement in agricultural technology	No assumption is made about increases in crop yields due to improvements in agricultural technology.	Considerable potential exists to continue making increases in crop yields. We assume a scenario in which the same annual rates of change in yield (only if positive) due to technology improvement between 1980 – 2000 apply from 2011 to 2050.*

*Since the 1980s China's government has heavily supported research in agricultural technology, including the development of new crop varieties with better harvest indices, and insect and pathogen resistant crops. Efforts have also been made to preserve genetic diversity. The original county level census yield data from 1980 to 2000 was used and compared to simulated yield data with constant management practices, cultivars and observed weather. Contribution ratios of technology progress were calculated based on the comparison of these two datasets, with 3-year rolling average. From 1980 to 2000, the average annual contribution ratios of agricultural technology to increases in crop yield were 1.13%, 3.10% and 1.21% for maize, rice, and wheat, respectively.
Note that we use different assumptions about future progress in agricultural technology to those used in the companion report on national impacts of climate change produced by ICCCA*, National Level Study: The Impacts of Climate change on Cereal Production in China* (Xiong et al., 2008).

3 Modelling Impacts

3.1 The crop models

3.1.1 CERES: rice, maize and wheat

Three CERES crop simulation models (Ritchie et al., 1989) modified to run on a regional basis across the whole of China are used for the analysis. We assume that three main food crops are of primary interest: rice, maize and wheat. CERES models are process-based, management-oriented models that simulate the growth and development of cereal crops. The crop models used in this study are included in the modelling system DSSAT4.0.2 (Jones et al., 2003). They can simulate the effects of the main environmental factors, such as weather, soil type, and major soil characteristics, together with the effects of crop management on crop growth, development, and yield (Ritchie et al., 1998). The three crop models have been shown to give comparable performance to other crop model results for China and for other parts of the world, which provides good confidence in the results of the simulation of crop impacts. The results presented here are based on the improved calibration and validation of the crop models for China and are updated and slightly different to earlier impacts studies using similar approaches (Lin et al., 2005; Xiong et al., 2007a).

3.1.2 Modelling of crop yield and irrigation demand

Regional crop simulation is performed at the same resolution as the regional climate model PRECIS grid (50 km $\times$ 50 km). The detailed methodology is described in Xiong et al. (2007a; 2007b). There are 2622 grid cells classified as arable land in China based on a land use map of China (Liu et al., 2002). A soil file was obtained by overlaying the regional model grid coverage with the digital Soil Map of China at a scale of 1:1000 000, based on the classification of the Food and Agriculture Organisation (FAO and UNESCO, 1988). A spatial data processing method described in detail by Knox et al. (2000) was used to transfer soil properties of agricultural soil from mapping units into the 50 km $\times$ 50 km grid cell unit, and to aggregate the soil properties into median values for topsoil (0-30 cm) and subsoil (30-100 cm) from the original values distributed across each profile layer, so that averaged soil properties were generated for each 50 km $\times$ 50 km polygon. Representative cultivars and their present sowing date are assigned to each grid based on Agro-Ecological Zone (AEZ) and seasons, according to the calibration process of Xiong et al. (2008). Nutrients are assumed to be unlimited in all seasons. Areas of rice, wheat, maize for the 1990s in each grid cell were downscaled from maps of the distribution of cropland in China (Frolking et al., 2002; Qiu et al., 2003) using a resampling method in ARC/INFO 8.0 (Dejan et al., 2003). Because most of the rice in China is grown in irrigated conditions, the models run for flooded paddy rice only, and for both irrigated and rainfed wheat and maize, at 50km × 50km grid scale.

Daily PRECIS output of maximum and minimum temperatures, precipitation, and solar radiation are used to drive the crop simulation models for all grid cells for a baseline period (1961-1990) and from 2011 to 2100 under A2 and B2 for the short term (2020s: 2011-2040), mid-term (2050s: 2041-2070), and long term (2080s: 2071-2100). The results for two future time slices (2020s and 2050s) are retrieved for afterward analysis. Daily data for the 2020s and 2050s are generated using a pattern scaling technique (UKCIP, 2002).

On the assumption that the necessary water is available, for irrigated crops the simulations apply irrigation in the amount demanded periodically throughout the growing season. Irrigation is triggered by moisture deficits in the soil root zone, that is, when soil water content is less than half of that corresponding to saturation. Irrigation efficiency is set at 0.5. This approach allows us to determine the optimum amount of water for each crop in each grid under each of the climate change scenarios. The total amount of irrigation water for each grid and crop is the simulated irrigation amount multiplied by the total irrigated area.

3.1.3 The direct effects of CO_2 fertilization

Recent reviews (e.g. IPCC 2007) have concluded that there is no clear evidence to support the hypothesis of model overestimation of the direct effects of CO_2 on fertilization (Long et al., 2005; 2006). Recent crop impact simulations are still within the range of effects observed in FACE experiments (Kimball et al., 2002). Therefore we present results with equal emphasis of crop yield changes with and without the direct effects of CO_2. The relationship as used in CERES models is based on results from FACE experiments by Kimball et al. (2002); a 850 ppm CO_2 concentration would cause roughly a 40% increase in photosynthesis for wheat and rice, and a 15% for maize. Additionally, the higher CO_2 would tend to decrease the evapotranspiration rates of crops and improve their water use efficiency. This influence is of particular relevance in rainfed conditions as it alleviates water stress during growth.

3.2 The hydrological model

ICCCA used the Variable Infiltration Capacity (VIC) hydrologic model to simulate runoff, water yield (surface flow + groundwater flow + lateral flow – loss from evapotranspiration), and other hydrologic parameters for the whole of China. VIC, and in particular version VIC-3L, is a distributed, physically based hydrologic model that balances surface energy and water over a grid cell, typically run at a resolution of between a fraction of a degree and several degrees latitude by longitude (Liang et al. 1994; 1996). VIC has been successfully applied in many settings, on scales ranging from global to that of a single river basin (e.g. Abdulla et al. 1996; Maurer et al. 2001; Nijssen et al. 1997; 2001), to assess the impacts of climate change (Christensen et al. 2004; Payne et al. 2004; Wood et al. 2004; Vicuna et al. 2007). For this study, we ran the model at 50km × 50km grid resolution over China. Three main data inputs are required by VIC: vegetation, soil and weather data. We used a procedure similar to that of Su and Xie (2003) and Xie et al. (2004) to generate the inputs at 50km × 50km.

Previous studies have validated VIC's simulations of runoff for the whole of China (e.g. Su and Xie 2003) and streamflow simulation in some catchments (e.g. Su and Xie, 2003). These studies have demonstrated VIC's satisfactory simulation and potential for use in climate change impacts. In order to improve the robustness of the model application and reduce the difference between the simulated and the observed streamflow values, six parameters of the VIC model (the infiltration parameter, the thicknesses of first and second soil layers, and three Arno model parameters) were calibrated for 60 catchments accounting for 39% of China's territory prior to any simulations being carried out. For the remaining catchments, for which no calibration could be carried out, the parameters corresponding to neighbouring areas were used instead.

Three model runs were carried out to simulate the runoff distribution over China; baseline climate (1961-1990), A2 (2011-2100) and B2 (2011-2100). Daily runoff (in mm, including ground runoff and underground runoff) was calculated from each grid cell. Annual total river flow series were calculated for ten main river basins in China as

$$S_j = \sum_{k=1}^{n} (R_k \times A_k) \qquad (2)$$

Where S_j is the total water yield for river basin j, R_k is the annual water yield for grid k, n is the number of grid which contained by that basin, and A_k is the area of that grid falling in j basin.

3.3 Calculating water availability for agriculture from VIC simulation and socio-economic scenarios

The total amount of water available for agriculture (AWP_i) in province i was calculated as in equation (3) below:

$$AWP_i = \left(\sum_{j=1}^{n} (S_j \times Ra_j \times P_{ij}) \right) \times \left({aw_i}/{t_i} \right) \qquad (3)$$

Where S_j, aw_i, and t_i are, respectively and as before, total water yield of basin j, projected agricultural and total water consumption of province i; Ra_j is the water exploitation ratio in basin j, -- and indicates of how much water can be withdrawn from the basin, something that depends on precipitation anomaly, water accessibility, capacity for water storage, and technology in place. For each basin, the exploitation ratio is assumed to remain constant in the future at the average exploitation ratio observed between 1994 and 2005. P_{ij} is the proportion of water in province i that comes from basin j and again it assumes the values of the corresponding historical averages between 1994 and 2005. Equation (3) implies that, for any province, the projected total available water comes from basins the province lies in, based on simulated and historical observed data. The water available for agriculture is the total available water (for all purposes) multiplied by the projected proportion allocated to agricultural use.

We assume that there is a good conveyance system and a distribution method for irrigation water, and that irrigation water is geographically distributed across grids in each province, based on their present proportion of irrigated crops acreage to provincial irrigated acreage (data for 2000 were used). Here, the irrigated acreage is the potential maximum value calculated based on present (until 2000) capacity for accessing water, which includes areas of flooded paddy rice and other irrigated crops. For any given grid k in province i, irrigation water (AWG_k) is computed as (4)

$$AWG_k = AWP_i \times \left(IA_k / IA_i \right) \quad (4)$$

Where IA_k is the irrigation area in grid k, and IA_i is total irrigation area in province i.

3.4 Using the balance between water availability and demand to limit irrigation at the grid cell scale

Because most of the rice planted in China is paddy rice, and irrigation is the determinant for rice growth, we assume that rice is given highest priority for water withdrawal, with the objective of irrigating as much of the present area of rice as available water (AWG_k) permits. The remaining water is assumed to be used by maize and wheat, with their withdrawal allocations depending on their present acreages. We calculated the total irrigation demand of crops (DWG_k_rice, DWG_k_wheat, DWG_k_maize) for any grid k as [irrigation amount × irrigated acreage in 2000], and compared this with water supply (AWG_k). In grid k, if $AWG_k \le DWG_k\_rice$, rice acreage $(IR_k) = AWG_k / DWG_k\_rice$, and irrigated wheat acreage $(IW_k) = 0$ and irrigated maize acreage $(IM_k) = 0$; if, on the other hand, $AWG_k > DWG_k\_rice$, then rice acreage equals the value in 2000, and (IW_k), (IM_k) are calculated as in (5) and (6), respectively.

$$IW_k = \frac{(AWG_k - DWG_k\_rice) \times (WA_k / (WA_k + MA_k))}{DWG_k\_wheat} \quad (5)$$

$$IM_k = \frac{(AWG_k - DWG_k\_rice) \times (MA_k / (WA_k + MA_k))}{DWG_k\_maize} \quad (6)$$

where WA_k and MA_k are, respectively, the wheat and maize acreage in grid k in 2000. The remaining agricultural land in specific grid cells is assumed to be dryland.

3.5 Using the area of arable land to determine national cereal production

Land use change in China is related closely to global environmental change and national food security (Tong et al., 2003). Land use change is affected strongly by socioeconomic factors such as land use policies, human migration, urbanization, agricultural product prices and world trade. Land use policy is to some extent the most important factor affecting land use pattern in China. Since 1980s, the arable land area has decreased steadily in China due to factors such as urbanization, desertification, and grain-to-green policy. In order to estimate the national total cereal production, the land use change scenarios were extracted from the socio-economic scenarios and used at grid scale. The crop land (AL) in future period t and scenario v at each grid k was calculated according to equation (7) below:

$$AL_{t,v} = AL_0 \times \left(TAL_{t,i,v} / TAL_{0,i,v} \right) \quad (7)$$

where AL_0 is the arable land in 2000 in the grid, $TAL_{t,i,v}$ is the projected total arable land of *i*th province where such grid lies in, and TAL_i is the total arable land of the *i*th province in 2000.

The changes in arable land were incorporated to calculate the agricultural land in the future, with the crop-planting pattern and crop mix kept constant as it was in 2000. Therefore, the total production was obtained by multiplying the acreages of irrigated (dryland) crops by irrigated (dryland) yield per unit of land area.

3.6 Selecting combinations of driving forces

In order to determine the contributions of different driving forces to the overall impacts on crop production and per capita availability, a series of runs were performed with different combinations of scenarios and drivers. The overall list is presented in Table 3.1.

Table 3.1 Combinations of drivers for simulations of future total cereal production and per capita cereal production.

Drivers	BS	2020s		2050s	
Climate Change	--	A2	B2	A2	B2
CO_2 fertilization effects	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Water Availability	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No
Arable land loss	Yes/No	Yes/No	Yes/No	Yes/No	Yes/No

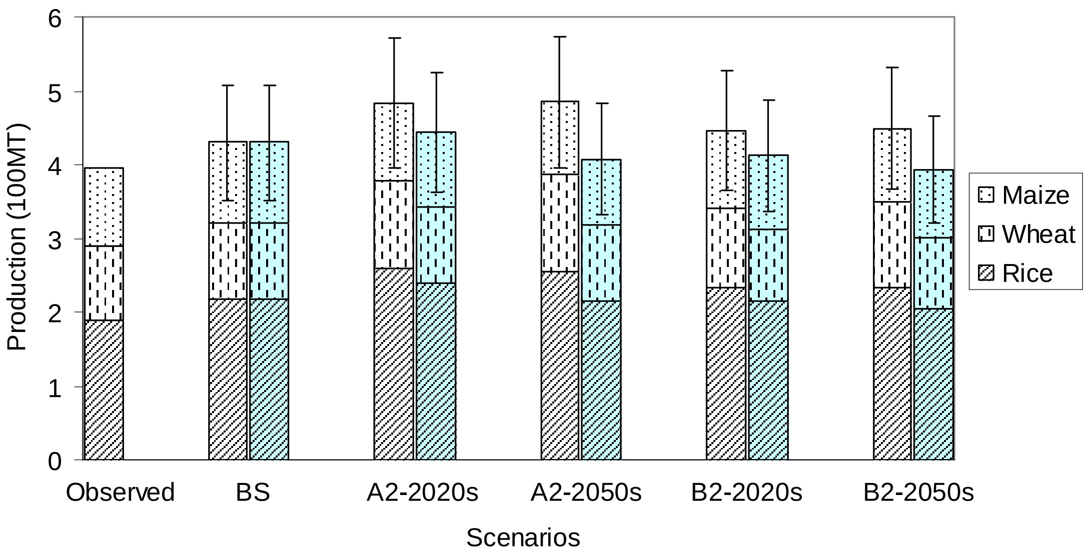
4 Impacts with No Adaptation

4.1 Impacts of climate change on crop production

In 2000, the total cereal production in China was 395.7 million metric tones (MT), with 189.8, 99.6 and 106.2 MT for rice, wheat, and maize, respectively (FAOSTAT). The corresponding planting acreages for the three crops were 30.3, 26.7, and 23.1 million ha. The crop simulations use the technology levels (e.g. crop varieties, management) and planting areas observed in 2000 to calculate future potential production. The projected cereal production for the baseline period (1961-2000) is 429.8 MT (rice: 216.6 MT; wheat: 104.6; and maize: 108.6 MT). Figure 4.1 shows future potential cereal production for each time period with climate change and with/without CO_2 fertilization.

Our results are consistent with other results: climate change negatively affects cereal production in China for most periods and scenarios except A2 in the 2020s. Specifically, for A2, cereal production increases in the 2020s and decreases in the 2050s; for B2 decreases occur for both the 2020s and 2050s. The production of rice and wheat increases a little in the 2020s with A2 but decreases in all other cases. Maize production, by contrast, decreases in all scenarios. Although the differences in future climate (Table 2.1) and characteristics of daily weather projected by PRECIS with A2 and B2 are fairly small in both 2020s and 2050s, B2 leads to a less favorable climate for crop growth (more days with precipitation and low radiation). However, the effect of CO_2 fertilization is to offset the reductions in yield caused by climate change in all cases. The effects of CO_2 fertilization are largest for wheat and smallest for maize.

Figure 4.1 Changes in total cereal production for China with present (2000) cultivation areas and maximum irrigation area. Observed production (from FAO, baseline period 1961-1990, A2 and B2 emissions, for both the 2020s and 2050s. White (green) background with (without) the effects of CO_2 fertilization.



4.2 Regional impacts of climate change on crop production

Figure 4.2 shows that the spatial patterns of change in total crop production by the 2050s without the effects of CO_2 fertilisation are similar between A2 and B2 (although slightly larger with A2) but there are marked differences across China. The general pattern shows increases in the northeast and north and decreases in the central, eastern and southern provinces. The patterns are, however, quite complex, and exceptions to the above include a large area of significant decreases in the central part of north-east China and areas of increasing production along the lower Yangtze valley and southeast provinces (especially with A2). The marked spatial differences in production highlight areas particularly sensitive to climate change; the largest per cent changes occur in the northeast (30% or more), and areas of moderate decrease (central, eastern and southern provinces) and moderate increases (parts of the north and southeast). Figure 4.3 shows the change in production including the effects of CO_2 fertilisation. The spatial patterns are similar to those in Figure 4.2 but lower in magnitude, except for Hainan in the south, which shows marked negative changes in yield with B2.

Table 4.1 and Table 4.3 list the changes in maize (absolute changes) and rice (per cent changes), respectively by province including the effects of CO_2 fertilisation. Impacts on rice are more negative in southern provinces and increase into the future.

Figure 4.2 Percentage change in total production of cereal in China due to climate change with A2 (left panel) and B2 (right panel) for the 2050s. Without CO_2 fertilization effect.

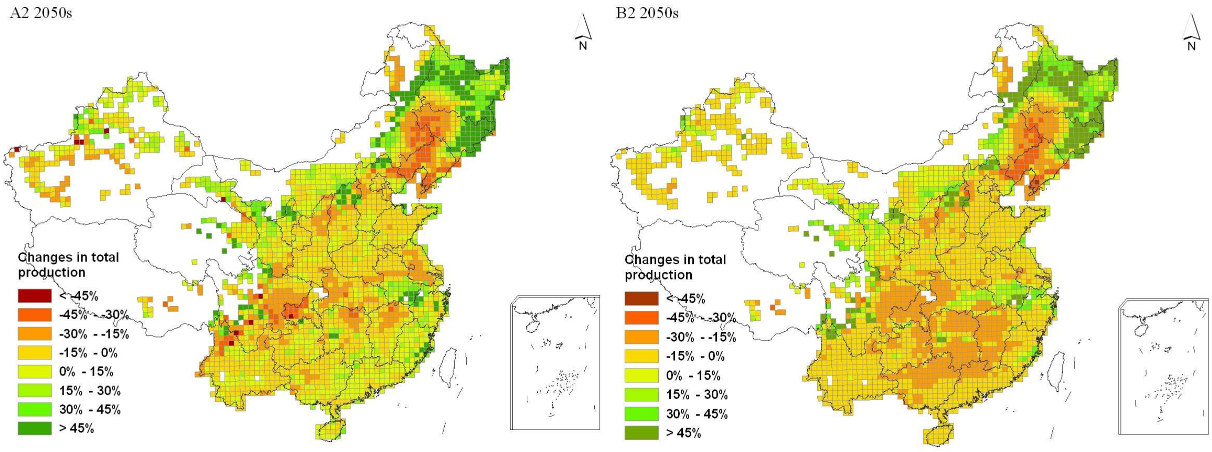
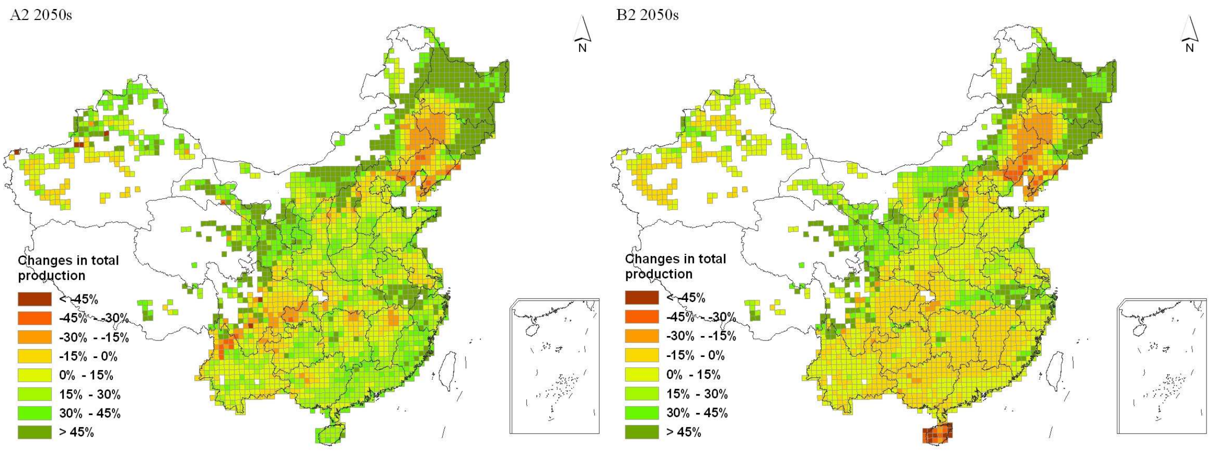


Figure 4.3 Percentage change in total production of cereal in China due to climate change with A2 (left panel) and B2 (right panel) for the 2050s. With CO_2 fertilization effect.



There is a big contrast in the change in production in northeastern China: increases in the northernmost parts of the area, and large decreases in central and southern parts of of the area. This contrast can possibly be attributed to the present crop patterns and production levels and different changes in yield for diffferent crops. The central and southern areas of northeastern China are the traditional main agricultural areas with fertile soil, favourable weather and cultivars with long growing periods and mainly cultivated with maize. A significant increase in temperature could shorten the growing period, making the crop mature more rapidly, decreasing the yield, even with the CO_2 effects (particularly for the C4 crop, maize). The northern tip of northeastern China is usully considered agriculturally marginal area because of low yield and unstable production. Rice dominantes this area and cold events are one of the main climatic disasters leading to low rice yields. Decrease in frequency is likely to result in a increase in yield. Furthermore, as a C3 crop, rice shows more positive sensitivity to CO_2 concentrations, so that rice production increases more in the simulation with CO_2

effects. These interactions therefore lead to quite marked differences in production changes in northeastern China.

Table 4.1 Change in maize production (million tonnes) for selected provinces in 2080

Province (code, alias)	Actual Production in 2000 (million tonnes)	2080 A2 scenario		2080 B2 scenario	
		Rainfed	Irrigated	Rainfed	Irrigated
Shandong (37, SD)	15.83	0.25	-0.21	0.02	-0.2
Liaoning (22, LN)	10.44	-0.03	-0.22	0.11	-0.14
Henan (41, HN)	9.68	0.12	-0.22	0.03	-0.18
Heilongjiang (23, HLJ)	8.41	0.17	-0.1	0.14	-0.1
Sichuan (51, SC)	6.12	-0.07	-0.15	0.06	-0.07
Neimeng (15, NM)	5.9	0.15	-0.09	0.27	-0.05
Jilin (21, JL)	5.61	-0.08	-0.25	-0.01	-0.18
Yunnan (53, YN)	4.37	0.14	-0.02	0.18	-0.02
Guizhou (52, GZ)	3.72	0.05	-0.13	0.16	-0.09
Shanxi (14, SX)	3.63	0.54	0.22	0.42	0.24
Anhui (34, AH)	2.47	0.04	-0.21	0.05	-0.19
Jiangsu (32, JS)	2.35	0.05	-0.13	0.12	-0.12
Chongqing (50, CQ)	2.22	0.22	-0.23	0.15	-0.12
Gansu (62, GS)	2.2	0.26	0.07	0.31	0.12
Hubei (42, HB)	1.99	0.06	-0.15	0.04	-0.08
Guangxi (45, GX)	1.81	-0.08	-0.16	0.13	-0.03
Hunan (43, HN)	1.34	0.01	-0.22	0	-0.08
Ningxia (64, NX)	0.83	0.01	-0.07	-0.03	-0.04
Fujian (35, FJ)	0.11	0.35	-0.1	0.32	-0.15
Jiangxi (36, JX)	0.08	0.1	-0.21	0.2	-0.12

Table 4.2 Change in rice production, all China and selected provinces

Region	Province[4]	Baseline Production (10^6 ton)	Change in production under A2 (%)			Change in production under B2 (%)		
			2020s	2050s	2080s	2020s	2050s	2080s
North-eastern	Heilongjiang(HLJ)	4	58	98	95	93	94	92
	Jilin(JL)	4	31	48	46	35	40	42
	Liaoning(LN)	4	39	49	47	29	35	37
Central	Jiangsu(JS)	13	8	3	-13	7	8	6
	Jiangxi(JX)	24	14	7	-13	-0.7	-2	-5
	Zhejiang(ZJ)	13	27	30	22	13	18	21
	Shanghai(SH)	4	13	11	2	13	18	20
	Anhui(AH)	21	26	21	0.5	12	19	20
	Hubei(HB)	14	14	6	-16	13	13	8
	Hunan(HUN)	23	17	10	-14	1	0.6	-2
	Sichuan(SC)	19	0.4	-4	-18	3	2	0.2
	Chongqing (CQ)	1	-4	-21	-38	-6	-10	-16
Southern	Guangdong(GD)	25	23	23	16	1	1	0.9
	Guangxi(GX)	30	23	20	9	0.1	-2	-3
	Hainan(HAN)	3	21	24	21	2	-41	-40
Others	Fujian(FJ)	8	32	35	30	4	8	9
	Henan(HN)	2	4	-7	-27	0.1	-4	-11
	Shandong(SD)	1	10	-6	-39	18.1	13	6
	Yunnan(YN)	6	16	21	22	4.4	6	8
Total		226	19	17	3	7	7	6

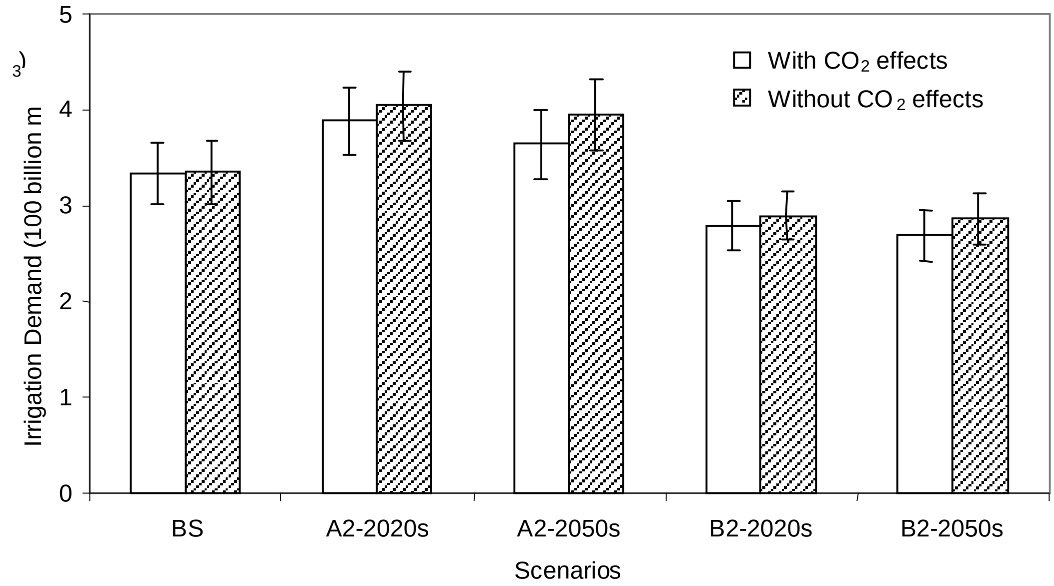
4.3 Impacts of climate change on irrigation water demand

Future potential irrigation demand is presented in Figure 4.4. The total irrigation demand is calculated as crop water requirements simulated by CERES with an assumption of irrigation efficiency of 0.5 for rice, and 0.8 for both wheat and maize, using the maximum irrigated area for each crop in 2000. The

[4] Only the provinces whose production is greater than 1 million tons are listed.

potential total irrigation demand increases under A2 and decreases under B2 , whether CO_2 fertilization is factored in or not. The differences are due to differences in the daily timing and frequency of precipitation between the A2 and the B2 scenarios. CO_2 fertilization also affects crop water requirements by increasing water use efficiency and this leads to a 4% - 14% offset (decrease) in total water demand (greater with A2 than B2).

Figure 4.4 Total potential irrigation demand due to climate change for the baseline period, and under A2 and B2 emissions scenarios, for the 2020s and 2050s. Estimates are based on cultivation areas and maximum irrigated areas in 2000.

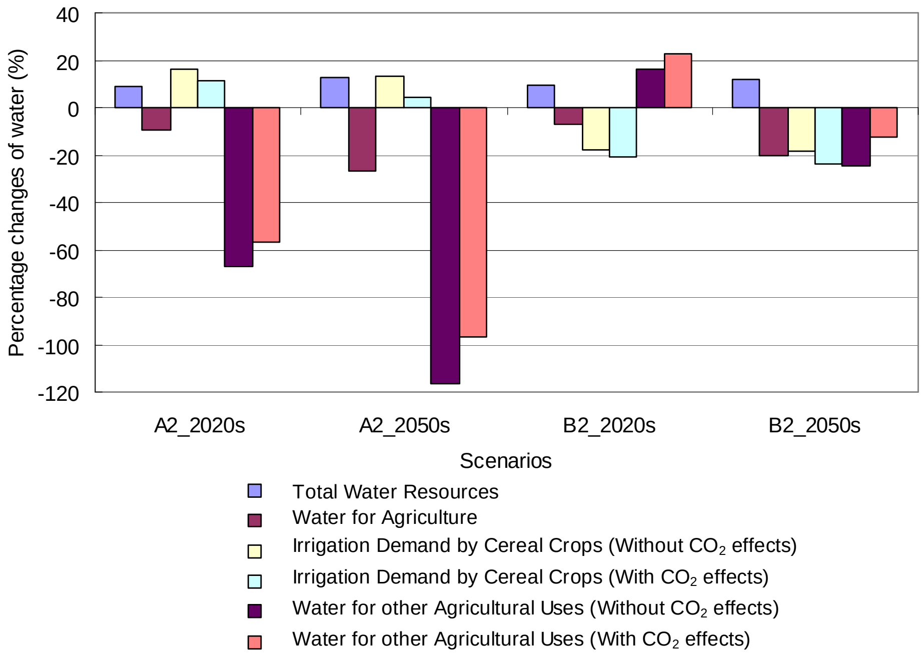


4.4 The interaction of climate change and socio-economic scenarios on water availability for agriculture

During the baseline period (1961 – 1990), the estimated mean annual total water withdrawal for overall use was 666 billion m^3, and water for agriculture was 485 billion m^3 (based on 1997-2005 data in ECCWA 2006). This is greater than the estimated potential irrigation demand from cereal crops, 372 billion m^3, suggesting that the remaining water (around 113 billion m^3) was used for other agricultural uses, such as other irrigated crops (e.g. cash crops) and livestock.

Figure 4.5 shows the percentage change (relative to the baseline period) in total water resources, water available for agriculture once increases in demand from other sectors are allowed for, potential total irrigation water requirements for cereals taking into account changes due to climate change, and the potential supply for other agricultural purposes. Results from simulations with the VIC hydrological model show an overall increase in water resources in the future as increases in precipitation offset losses to evaporation (which are roughly 10% in all cases). However, due to increases in demand in sectors other than agriculture, as captured by the socio-economic scenarios (SES) (e.g. in the domestic, environmental and industrial sectors), the water available for agriculture decreases dramatically: under A2, it decreases by 9% (2020s) and 27% (2050s); under B2, by 7% (2020s) and 20% (2050s). Figure 4.5 shows that when demand from other sectors and for irrigation by cereal crops is satisfied, there are significant decreases in water availability for other agricultural purposes under A2, and modest decreases by 2050 under B2. Given that irrigation water requirements also increase with A2, but decrease with B2, this will increase the risk of water imbalance in some regions and during dry years.

Figure 4.5 Percentage changes in total water resources, water for agriculture, potential total irrigation requirements by cereal crops, and the potential supply for other agricultural uses (relative to the baseline period).



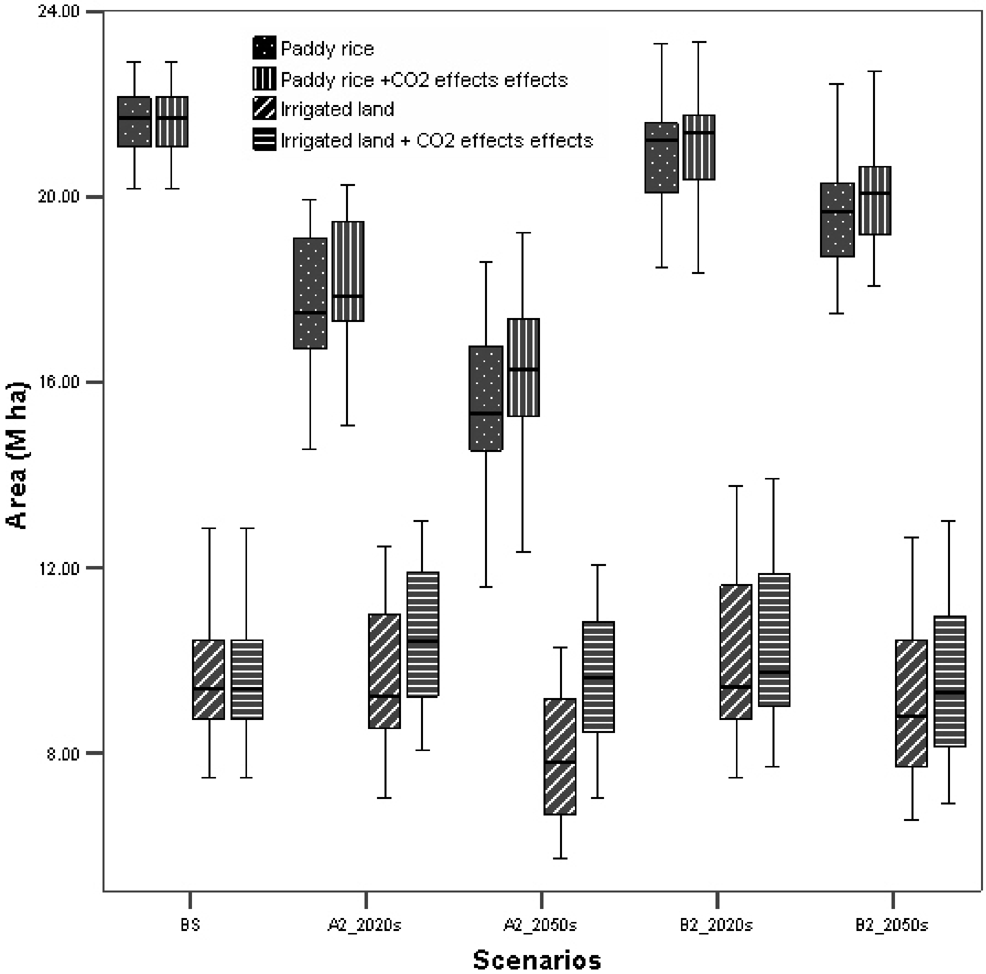
Differing trajectories of population growth and economic development will affect the level of future climate change as well as the responses of agriculture and water to changing climate conditions (Parry et al., 2005). A2 and B2 result in very different impacts on crop production and water demand for cereal crops: A2 yields increase, B2 decrease. In terms of total water resources, the differences are fairly small, but in terms of water available for agriculture, they are very large. For B2, availability is sufficient in the 2020s; not so for A2. In fact, water availability by the 2050s under A2 is insufficient to satisfy demand for cereal crop irrigation as well as any water use for other agricultural purposes: a deficit of 250 billion m^3 emerges as compared with the demand for irrigation from cereal production.

The significant difference in water availability and demand between A2 and B2 results from their different effects on yield and water use, and highlights the importance of assumptions about future development pathways and about the detailed characteristics of climate scenarios. The large reductions in water available for other agricultural purposes whilst other needs remain satisfied imply significant impacts on the production of cash crops (e.g. fruit and vegetables) and livestock. Importantly, their production is to some extent more dependent on irrigation water than subsistence crops such as wheat or maize, yet cash crops and livestock are the main sources of income for many Chinese farmers, particularly in areas serving urban markets.

4.5 Impacts of climate change and water availability on the area of irrigation

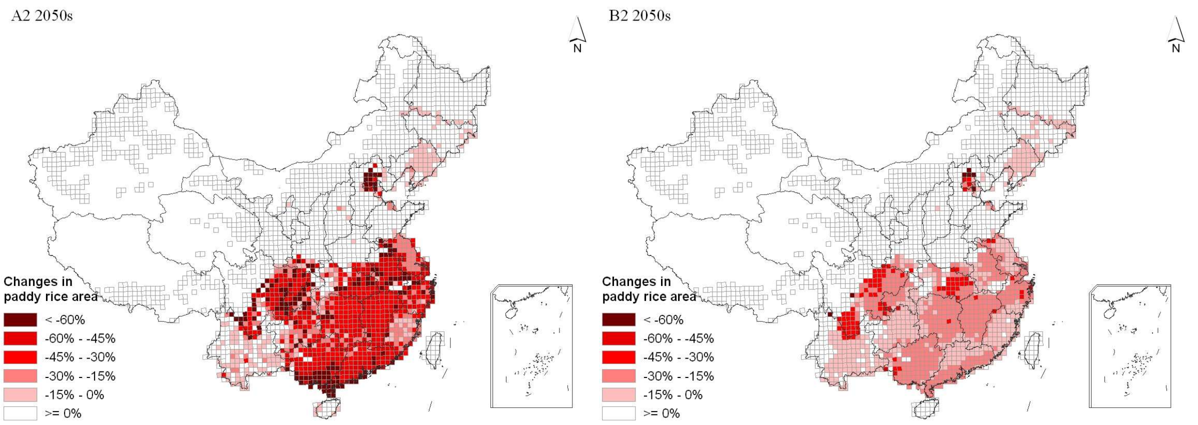
Figure 4.6 shows changes in irrigated land area due to climate change once irrigation is limited according to water availability. For paddy rice the baseline area is 21.7M ha. This is projected to decrease significantly with A2: ignoring the effects of CO_2 fertilization, the paddy rice area decreases to 17.5M ha (2020s) and 15.3M ha (2050s); with the effects of CO_2 fertilization taken into account, this area becomes 17.8M ha (2020s) and 16.3M ha (2050). Meanwhile, the decreases with B2 are less dramatic: without the effects of CO_2 fertilization, paddy rice area is estimated at 21.2M ha and 19.7M ha for 2020s and 2050s, respectively; with the effects of CO_2 fertilization, it is 21.4M ha (2020s) and 20.1M ha (2050s). Most paddy rice in China is located in southern, southeastern, and northeastern areas where, except for northeastern China, the actual area of paddy cultivated has declined during 1980-2000 (Tong et al., 2003). The projections assume that rice is fully irrigated and only flooded paddy rice is planted in China. Decreasing water availability exacerbates the ongoing decline in paddy rice area in the future, particularly under A2. The change in area of paddy rice is not even across regions because of the uneven distribution of water supply and demand between regions. The decline is most significant with A2 in the southern part of China (Figure 4.7).

Figure 4.6 Change in the total irrigated land area (including paddy rice area and other irrigated land wheat/maize) due to changes in future water availability (resulting from both climate change and socio-economic change).



We assume that full irrigation is applied in areas of irrigated wheat/maize. This differs from the usual practice of deficit irrigation for these crops. At 9.4 M ha, the simulated area in the baseline is therefore smaller than the observed area: the effective irrigation area in 2000 for wheat and maize is estimated at around 13M ha based on Wu et al. (2006) and county level census data. Median irrigation area generally varies little: for A2, it is 9.2M ha for the 2020s, and 7.8M ha for the 2050s; for B2, 9.4M ha and 8.8M ha, respectively. Slight increases in irrigation area result if CO_2 fertilization effects are included: for A2, the irrigation area becomes 10.4M ha for the 2020s and 9.6M ha for the 2050s; for B2, it is 9.8M ha and 9.3M ha, respectively. Because most of the wheat and maize irrigated areas are located in the northern part of China where water scarcity is currently an issue, the increased water use efficiency caused by higher CO_2 concentration could potentially reduce irrigation demand and allow an increase in irrigation area.

Figure 4.7 Percentage change in spatial patterns of irrigated paddy rice area due to changes in future water availability (resulting from climate and socio-economic change according to A2).



4.6 Impacts of climate change and water availability on total potential crop production

The simulated mean cereal production under baseline conditions with CO_2 effects taken into account was 396.7 MT, which matches well with the observed production in 2000 of 395.7 MT. The joint effects of changes in water availability (due to climate change and SES) and changes in irrigated areas result in a decrease in production under both A2 and B2, in both time periods, when CO_2 fertilization effects are not contemplated (Table 4.3). Small increases in production as compared with the baseline occur when CO_2 fertilization effects are included. Including limited water availability as a contributing factor reduces future production by as much as 9 - 16%, depending on the climate change scenario and time period considered.

Table 4.3 Percentage changes in total cereal production under A2 and B2 including the effects of changes in water availability and changes in irrigated area, with and without the effects of CO_2 fertilization.

Changes from baseline (%)	A2		B2	
	2020	2050	2020	2050
CC, no CO_2	+12.0	+2.6	+4.0	-1.0
CC, with CO_2	+22.1	+22.2	+12.6	+13.2
CC and water, no CO_2	-4.7	-13.6	-6.2	-12.7
CC and water, with CO_2	+6.7	+7.2	+3.7	+2.7

4.7 Integrated results of national cereal production

China is undergoing rapid changes in economic structure and development, lifestyle, demand on land and water resources, and pressures on the environment (Rosenzweig et al., 1999), which will drive significant changes and fluctuations in future food supply and demand. Recognising the complexity of these interactions, this section shows the integrated effects of agricultural land use change, water availability, CO_2 fertilization, and climate change. Total and per capita cereal production in China is presented for each scenario. The changes in arable land are calculated based on the socio-economic projections for each province and extrapolated to grid scale according to equation (7). Figure 4.8 shows the geographic distribution of accumulated changes in arable land for 2050s under A2 and B2.

Figure 4.8 Accumulated changes in arable land due to socio-economic development, for 2050s, with A2 and B2.

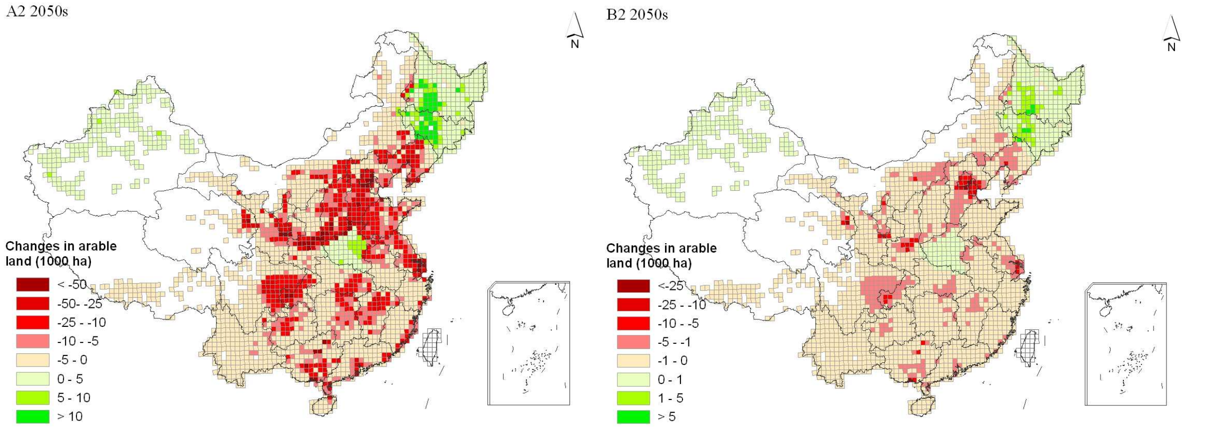


Figure 4.9 Change in total cereal production under different combinations of drivers (CC: Climate Change; CO_2: CO_2 fertilization effects; WA: Water Availability; LA: Agricultural land change; All: Climate Change, CO_2 fertilization effects, Water Availability, and Agricultural Land Change).

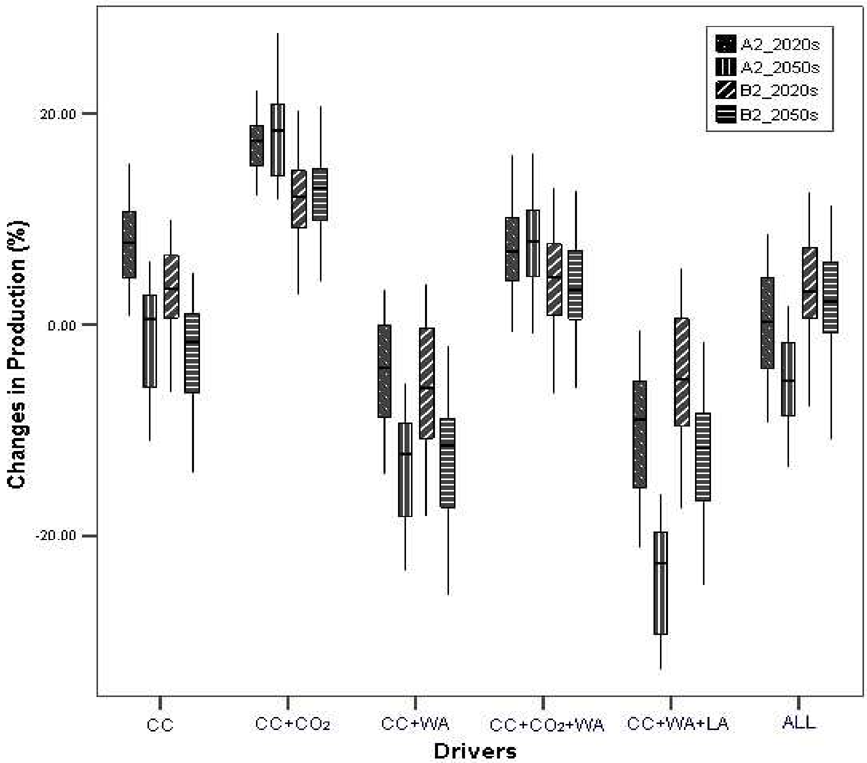


Figure 4.9 shows the percentage change of total cereal production in China under different combinations of drivers. The simulated average cereal production with baseline conditions (398.4MT, includes the CO_2 fertilization and water availability) was used as the reference with respect to which future changes in production are computed. Climate change alone results in changes in production of -3% to +7%, depending on climate change scenario and time period. With A2 and B2 production increases in the 2020s and decreases in the 2050s. Including CO_2 effects leads to increases in production ranging from 8% to 18% (due to stimulated photosynthesis and improved water use efficiency). A2 produces a larger increase in production than B2 because of its higher CO_2 concentrations.

Climate change with CO_2 fertilization and water availability increases production (4% - 7%) in all cases, but water availability acts as a significant limitation to total production. The final cluster of bars in Figure 4.9 shows the integrated effects of all drivers (i.e. similar to the previous example but including land use change and constraints in irrigation area). Slight increases in production occur for most cases, except 2050s for A2 (A2: +0.3% for 2020s, -5.5% for 2050s; B2: +3.6% for 2020s, +2% for 2050s). Decreases in arable land area caused by economic development and population growth result in a significant decline in total production with A2 scenarios due to rapid population growth and high rate of land conversion.

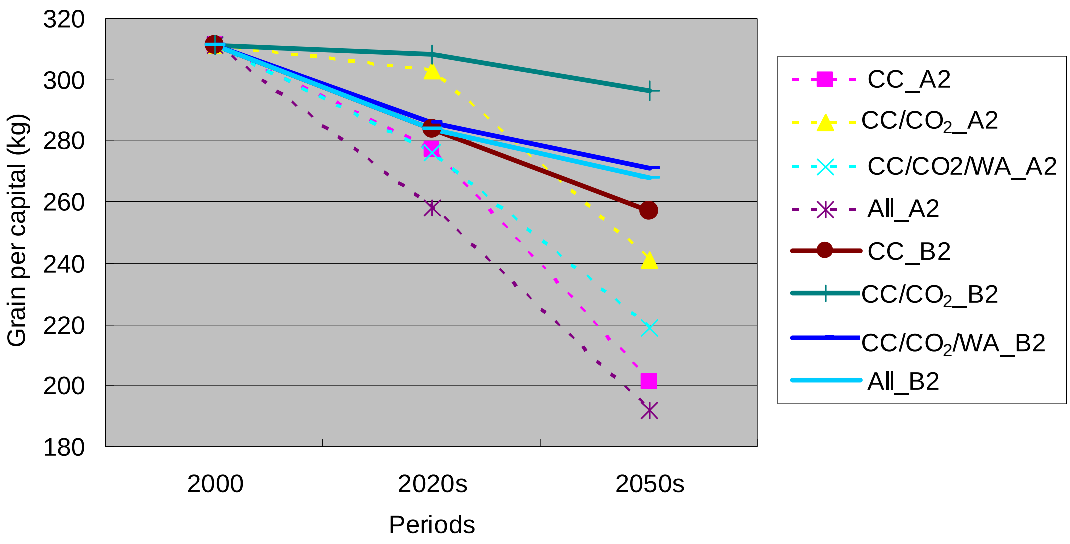
Per capita production or supply of food can be used as an indicator of food security (e.g. Xiong et al., 2007a). Here, we use per capita cereal production to provide a perspective on changes in production in relation to national priorities for self sufficiency in staple food production. International trade and other crops (e.g. barley) are not included in the analysis. Figure 4.10 shows the results after converting total production to per capita amounts (only results with CO_2 fertilization effects are included). In all cases, per capita production is projected to decline, particularly with A2 and in the 2050s. The beneficial effects of high CO_2 with A2 climate scenario are offset by the higher rates of population growth associated with A2 and other stressors such as reduced water for agriculture and reduced arable land area, which combine to cause huge reductions in per capita production. In contrast, B2 produces much smaller changes in per capita cereal production due to the modest population growth it presumes.

To summarize, per capita cereal production decreases in the future, due to the combined effects of climate change, population increase, water scarcity, and loss of arable land. The interaction of multiple drivers narrows the range of change in the future due to the offsetting effects of different factors on crop production (e.g. positive effects of CO_2, negative effects of reduced water availability). Future development pathways will critically determine which of these scenarios is most realistic.

Our results identify the key determinants which are, in decreasing order of importance:

- The rate of future population growth
- The role of CO_2 fertilization
- Socioeconomic and biophysical determinants of water availability
- Land use change and climate change (pattern and magnitude of temperature and precipitation change).

Figure 4.10 Changes in cereal production per capita under different combinations of drivers.

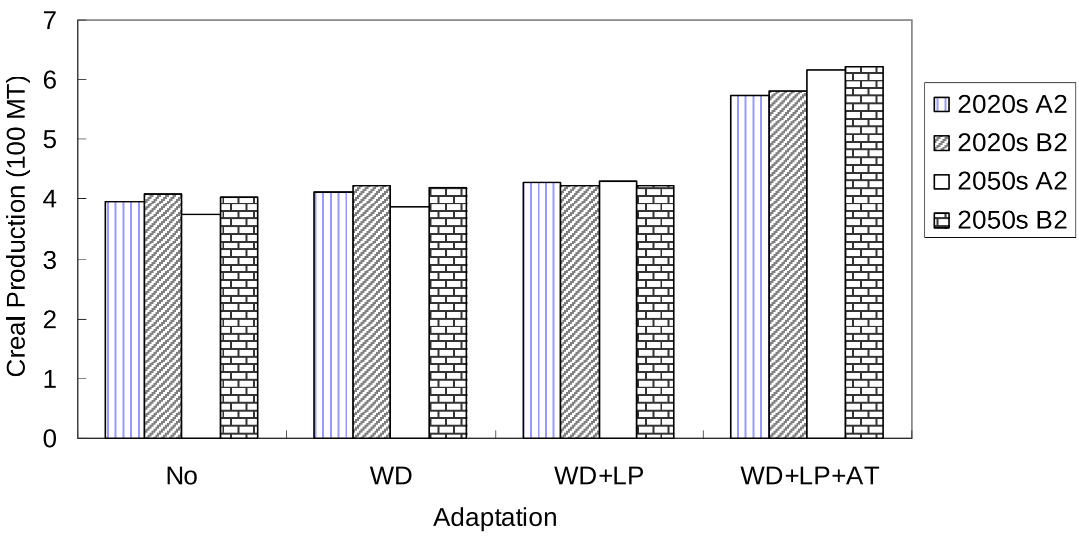


Not included here are major uncertainties relating to: differences in precipitation patterns between GCMs (our results are optimistic, most GCMs show much lower changes in precipitation) and uncertainty about the effects of increased CO_2 concentrations on crop yields. We have given no consideration to possible effects that crop prices may have on production nor to incremental responses/anticipatory actions in response to changes as they occur: the scenarios considered do not include any feedbacks.

5 The Effects of Adaptation Policies

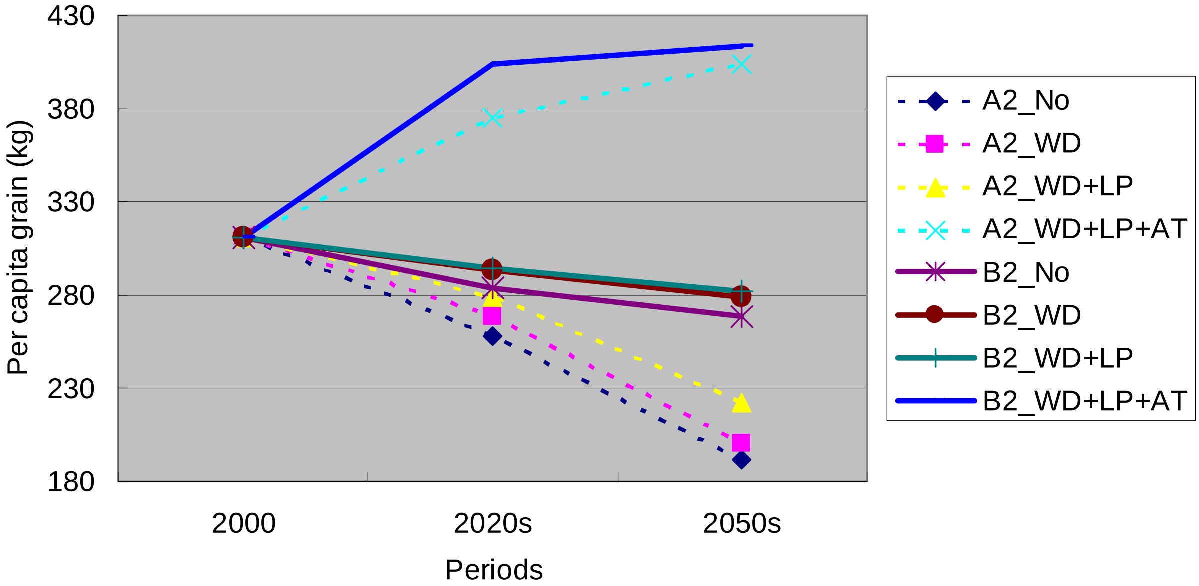
Figure 5.1 and Figure 5.2 show projected total and per capita cereal production respectively, for all drivers, with and without adaptation. Differences are calculated between current production (taking account of water availability limitations and CO_2 fertilization effects) and future production. Prioritizing water for agriculture (adaptation WD) produces fairly small increases in production, 3.8% (A2) and 3.2% (B2) for the 2020s, and 4.0% (A2) and 4.0% (B2) for the 2050s. Overall, water availability is projected to be sufficient to irrigate the area which is currently irrigated for cereal crop production, however, the existing water imbalance between regions would remain. Combining water and land use adaptation policies (WD and LP) results in an increase in production of between 4% and 15%, with A2 attracting larger increases). The LP policy on its own produces substantial increases, particularly with A2 in the 2050s. Protection of arable land could counteract the negative effects of climate change and reduced water availability. Improvements in agricultural technology (AT) produce the largest benefits in production. The accumulated improvements in yield, 37% and 50% for the 2020s, and 2050s, respectively, both A2 and B2, which increase production by 44.9% and 42.1% respectively with A2 and B2 2020s, and corresponding values of 65.1% and 54.6% for the 2050s.

Figure 5.1 National potential cereal production with and without adaptation (WD: prioritising water for agriculture; LP: arable land conservation; AT: sustained improvements in agricultural technology).



For all adaptation strategies, the effects on total production were larger with A2 than with B2, indicating the more beneficial results entailed by this less environmentally oriented development pathway. In terms of per capita cereal supply, the benefits of adaptation are greater with B2 than A2 in all cases (Figure 5.1 and Figure 5.2). Adaptation in agricultural technology, AT, clearly has the largest impact and leads to increases in per capita production even out to the 2050s. In all the other cases, per capita production decreases and the WD and LP policies results in fairly modest improvements.

Figure 5.2 The effect of adaptation strategies on cereal production per capita.



6 Conclusions

The effects and interactions of multiple drivers of change (climate, CO_2 fertilization, water availability, and land use change) have been considered in relation to their impacts on staple cereal production in the 2020s and 2050s. Two IPCC SRES emission scenarios and SES storylines provided the quantitative inputs and qualitative context for the future drivers of change. The main conclusions are as follows.

- Scenarios of future climate change project continued warming in all seasons over the whole of China, and consistent but modest increases in mean annual precipitation. The regional climate model PRECIS produced warming similar to a multi-model average for China but precipitation wetter than a multi-model average for China.

Results without adaptation:

- Climate change alone produces small to moderate negative effects on China's potential cereal production, with the most serious impacts with B2 in the 2050s.
- If the effects of CO_2 fertilization are included, climate change produces increases in cereal production with both A2 and B2 climate scenarios. The increases are larger with A2.
- Climate change combined with reduced water availability due to demand from sectors other than the agricultural sector produces a significant decrease in the area of rice that can be irrigated with A2, and a moderate decrease with B2.
- Water availability will act as a significant limit to national total production in the future, with or without CO_2 fertilization effects. The declining water availability for agriculture decreases the irrigation area in all cases, particularly under A2, for irrigated paddy rice area.
- Including land use change leads to negative impacts on total cereal production with A2 (decreases up to -10%) and positive impacts with B2 (increases up to +10%)
- Due to population growth, cereal production per capita decreases for all drivers combined in 2020 and 2050 with both A2 and B2.
- Outcomes are highly dependent on socioeconomic development pathways and the effects of CO_2 fertilization; and their underlying assumptions.

Results with adaptation:

The effects of three broad-level adaptation policies (in water, land and agricultural technology) were addressed. Changes in the future were calculated relative to current cereal production (including water availability and CO_2 effects).

- Adaptation through water allocation policies (WD) produced modest benefits on total cereal production. However, allocating available water preferentially to maintain staple crop production could mean (and does in our results) that less water is available for other agricultural purposes (e.g. cash crops and livestock) purposes. Much greater potential for adaptation in water use exists through e.g. efficiency gains and technology improvements, and so we judge this policy to be fairly conservative in relation to what is feasible.
- A combination of adaptation in water (WD) and arable land conservation policies (LP) offsets the negative impacts on production (particularly with A2) and produces increases in total cereal production in 2020 and 2050, for both A2 and B2.
- Adaptation based on optimistic and sustained improvements in agricultural technology (AT) results in significant increases in national total cereal production.

- In terms of cereal production per capita, only improvements in agricultural technology enable production to keep pace with population growth and to offset the negative effects of other drivers to maintain/improve existing levels of production.

The results demonstrate the importance of integrating climate change with socio-economic drivers of change. Future development pathways will play the major role in determining which of these scenarios is most accurate.

Our results identify the key determinants of change in agricultural production which are, in decreasing order of importance:

- the rate of future population growth
- the role of CO_2 fertilization
- socioeconomic and biophysical determinants of water availability
- land use change and climate change (emissions scenarios).

The absolute effects of climate change presented here are similar to those in the IPCC AR4 model average (Meehl et al., 2007) and are large enough to compromise future cereal production in China. Meanwhile, different drivers tend to counter-balance one another, leading overall to small changes that are highly dependent on socio-economic scenarios. Not included here are major uncertainties relating to: differences in precipitation patterns between GCMs (ICCCA results rely on PRECIS projections and the latter are optimistic in that they show much higher changes in precipitation than most GCMs) and the real-world effects of increased CO_2 concentrations on crop yields. We have made no assumptions about the impact of crop prices on production nor about the incremental responses/anticipatory actions that may be adopted in response to change as it occurs (i.e. ICCCA scenarios include no feedbacks). Recent evidence suggests that surface ozone could have negative effects on crop growth, particularly for C3 crops (rice, wheat). The Royal Society (2005) reports estimates of yield loss rising to potentially ~30% in 2050 and China already experiences locally high surface ozone levels which are predicted to rise significantly. Finally, ICCCA results do not include the effects of extreme events and adaptation of agronomic practices.

Overall, we judge our results on climate change and water availability impacts on cereal production to be near the upper limits of response (i.e. optimistic) because the climate model used here (PRECIS) gives much wetter conditions than a multi-model average, the CO_2 crop yield response function may not be sustained and may be counteracted by negative effects of surface ozone, and the impacts models are likely to underestimate the negative effects of extreme events on crop growth and water availability.

In relation to climate change, ICCCA results demonstrate the critical importance of improving the understanding of the effects of CO_2 fertilization in real world situations. For agricultural production in China, water availability is a critical factor, and linkages between agriculture and water (management) policy will be critical for effective adaptation. There is a clear need to improve projections of future water availability. This will require improved surface and groundwater modelling and simulation of soil moisture dynamics and evapotranspiration. ICCCA identified broad-level policies but there is a need to develop more detailed and grounded policies based on a thorough understanding of highly context specific decision-making and management practices.

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