Modelling the impacts of climate change on cereal production in China

The project, *Impacts of Climate Change on Chinese Agriculture*, is a joint UK/China collaboration which sought to understand how climate change will affect rural China.

Phase I (2001-2004) examined the impact of climate change on crop yields. Phase II (2005-2008) built on this work to investigate the impacts of climate change on national cereal production and the cereal quantities available to each person in China to 2100. This pamphlet gives an overview of the main findings of Phase II relating to the impact of climate change on the yields and production of three staple crops (rice, maize, wheat) in China.
Crop production and yields under different climate scenarios

Food production in China is fundamental to the national economy. Chinese agriculture provides staple food supplies for most of the country’s population and significant amounts of the global production of rice, wheat and maize. Climate change is expected to have a significant impact on agriculture in China as crop yields and production are very sensitive to the weather (dry spells, heavy rain, etc.) and other environmental factors.

**Modelling Crop Growth and Climate Change**

In the first set of experiments we investigated the impacts of climate change on grain yields, additionally exploring the potential effects of CO₂ fertilisation and technological progress in agriculture. We used a crop modelling system, CERES (Crop Environment Resource Synthesis), to simulate the effects of environmental factors and crop management on the production and yield of rice, maize and wheat in China in the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100).

We looked particularly at changes in crop yield per unit area, total cereal production and the amount of cereal produced for each person in China (per capita production). Our work did not include the effects of pests, diseases and changes in management practice (e.g. the use of fertilisers and pesticides) as these processes are poorly understood.

We ran the CERES models for the three crops with climate change scenarios (changes in temperature, precipitation and solar radiation) from the regional climate model PRECIS to assess the impact of these scenarios on potential crop yields and national production. Because the level of future emissions is uncertain, we used two emission scenarios developed by the Inter-governmental Panel on Climate Change (IPCC) (for full definitions see Special Report on Emissions Scenarios, IPCC, 2000):

- **A2 scenario**: medium-high emissions from a continuously increasing global population
- **B2 scenario**: medium-low emissions and lower population growth

Based on the areas and distribution of crops sown across China in 2000, we calculated changes in yields due to the effects of climate change for:

- Rice, maize and wheat grown under irrigated conditions
- Maize and wheat grown under natural rainfall (i.e. rainfed)

Extensive testing confirmed that the crop models were capable of simulating crop yields across China. However, there are several important uncertainties in our modelling work:

- The results obtained with PRECIS show much higher changes in precipitation than most global climate change models
- The actual effects of higher carbon dioxide concentrations on crop yields are not yet fully understood
- No assumptions are made about the impact of crop prices on production or the measures that might be adopted in response to change as it occurs
- The effects of extreme weather events, which are likely to represent significant challenges to agricultural production in China, are not included.

**Climate Change Impacts on Potential National Cereal Production**

Climate change can affect overall crop production by altering both the yield per unit area and the area of production. To estimate future potential food production in China we made a number of assumptions:

- Changes in the production of irrigated rice, rainfed maize and rainfed wheat were used to represent total cereal production in China
- Yields due to improved agricultural technology will increase by 1% per year during 2000-2010, 0.7% during 2010-2030, and 0% after 2030. These rates are fairly conservative and compare with annual rates of ~3-4% since the late 1970s
- Management practices and the current area of production remain constant
- The total area of arable land does not increase and the proportion of each crop grown does not change
- Water availability does not limit production of the three crops (this is dealt with in a separate pamphlet)
- No specific adaptation strategies (policy or technological) are implemented.
THE EFFECTS OF CARBON DIOXIDE ($CO_2$) ON CROP YIELDS
Increasing levels of $CO_2$ in the atmosphere are likely to have a positive impact on crop yields, though there is uncertainty over the extent of this impact. The effects of $CO_2$ depend on crop type, soil and management factors; they may vary over time and there is interaction with many other environmental factors. This effect is known as the $CO_2$ fertilisation effect. Because different models tend to produce different conclusions on the magnitude of $CO_2$ effects, we considered crop yield changes with and without the direct effects of $CO_2$.

THE IMPACT OF CLIMATE CHANGE ON CROP YIELDS
Figure 1a shows the impacts of climate change on total production, with and without $CO_2$ fertilisation. Climate change alone is likely to lead to a decline in total production. When taking into account the maximum potential for $CO_2$ fertilisation, the effect is reversed and may lead to a modest increase. For individual crops the picture is more complex:

- **Irrigated rice**: without $CO_2$ effects, the yield decreases over time under both scenarios. With $CO_2$, yields increase until the 2050s and then decrease as higher temperatures offset $CO_2$ fertilisation effects.
- **Rainfed maize**: without $CO_2$ effects, the yields fall over time under both scenarios. With $CO_2$, the yields decrease, though changes are small until 2050.
- **Rainfed wheat**: without $CO_2$ effects, the yield decreases under both scenarios, with most change occurring by 2020s. With $CO_2$, yields show large increases from 2020s onwards (larger with A2 than B2), particularly between the 2050s and 2080s.

These national averages mask large regional differences. There are large variations in yield across China due to the combined influence of varying crop cultivars, soil factors, climate change, crop management factors (e.g. sowing date) and different sensitivities between crops. These combine to give an average change in yield that can mask potentially significant changes in particular locations.

Our results suggest that technological progress and the effects of $CO_2$ on plant growth could have a major impact on total production of rice, maize and wheat in China in future years (Figure 1b).

With improvements in agricultural technology, total production increases under both emission scenarios though the increase is less if the effects of $CO_2$ on plant growth are ignored. Without improvements in agricultural technology, total production increases only slightly even with the effects of $CO_2$ and, without them, falls after 2020 under A2 (medium–high emissions) and immediately under B2 (medium–low emissions).

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**Figure 1.** Changes in total national cereal production under A2 (medium–high emissions) and B2 (medium–low emissions) scenarios.
It is instructive to look at the impact of population growth on cereal production per capita as population is expected to rise. Looking at climate change alone, amounts decline steeply, falling below the threshold necessary to meet basic human dietary requirements (i.e. 300 kg/capita/year). Even with the full realisation of CO₂ fertilisation, per capita amounts fall below, or close to, the 300 kg threshold. With technological progress, similar falls are not seen until after 2080 (Figure 2b). The predicted falls are larger under the A2 (medium-high emissions) scenario due to its higher population growth.

**Figure 2.** Changes in per capita cereal production simulated to 2080 under two emission scenarios

**KEY FINDINGS**
- Detailed testing of the CERES crop models shows they produce realistic simulations of rice, maize and wheat yield patterns across China (and over time).
- Climate change alone reduces yields for all crops, but CO₂ fertilisation reduces the rate of decline and significantly increases yields of wheat. The effect of CO₂ fertilisation in a real farming situation is, however, uncertain.
- Technological progress could have a significant positive impact on yields.
- In nearly all scenarios, production per capita falls due to strong future growth in population size.
- There is an important need to improve our understanding of the effects of CO₂ fertilisation in real world situations, the effects of extreme events and pests and diseases, and to obtain better projections of future improvements in agricultural technology.

**FURTHER INFORMATION**
The full report, *National Level Study: The Impacts of Climate Change on Cereal Production in China*, together with all the other reports and six summary pamphlets from the project, are available from the project website [www.china-climate-adapt.org](http://www.china-climate-adapt.org).

**Project Implementers:**
- China: Chinese Academy of Agricultural Sciences
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