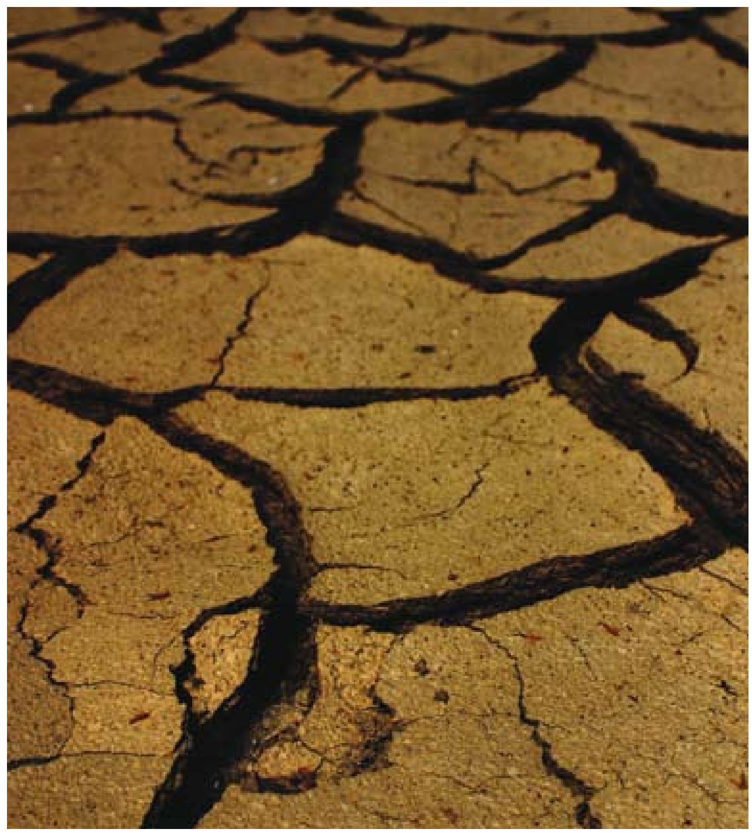
Climate Change and China's Agricultural Sector:

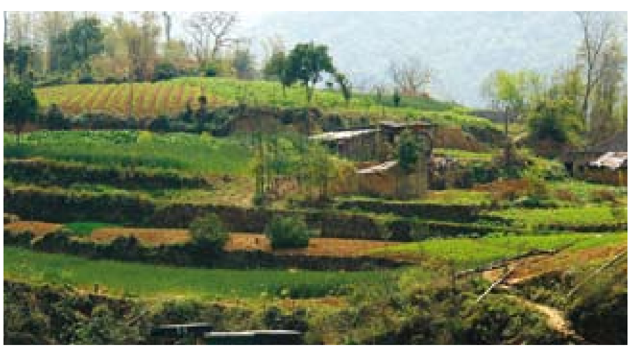
An Overview of Impacts, Adaptation and Mitigation

Issue Brief No. 5



J. Wang, J. Huang and S. Rozelle

May 2010



ICTSD-IPC Platform on Climate Change, Agriculture and Trade

ICTSD

International Centre for Trade and Sustainable Development

International Food & Agricultural Trade Policy Council

Climate Change and China's Agricultural Sector: *An Overview of Impacts, Adaptation and Mitigation*

By Jinxia Wang, Jikun Huang and Scott Rozelle

Jinxia Wang is Senior Researcher and Jikun Huang is Director at the Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resource Research, Chinese Academy of Sciences. Scott Rozelle is Senior Fellow, Food Security and Environment Program, Feeman Spogli Institute, Stanford University.

Issue Brief No. 5

ICTSD

International Centre for Trade and Sustainable Development

International Food & Agricultural Trade Policy Council

Published by

International Centre for Trade and Sustainable Development (ICTSD)
International Envrionment House 2
7 Chemin de Balexert, 1219 Geneva, Switzerland
Tel: +41 22 917 8492 Fax: +41 22 917 8093
E-mail: ictsd@ictsd.ch
Visit ICTSD's website at: www.ictsd.org

And

International Food & Agricultural Trade Policy Council (IPC)
1616 P St., NW, Suite 100, Washington, DC 20036, USA
Tel +1 202 328 5056 Fax +1 202 328 5133
Visit IPC's website at www.agritrade.org

Charlotte Hebebrand, President/CEO of IPC, and Marie Chamay Peyramayou, Manager of the ICTSD Global Platform on Climate Change, Trade Policies and Sustainable Energy, are the persons responsible for this initiative.

Acknowledgments:

The authors would like to thank Christine St. Pierre, Charlotte Hebebrand, Christophe Bellmann, Marie Chamay Peyramayou and Samantha Derksen for comments on earlier versions of the paper.

This paper was produced under The ICTSD Global Platform on Climate Change, Trade Policies and Sustainable Energy—an initiative supported by DANIDA (Denmark); Ministry of Foreign Affairs of Finland; the Department for International Development (U.K.); the Ministry for Foreign Affairs of Sweden; the Ministry of Foreign Affairs of Norway; Oxfam Novib; and ICTSD's institutional partners and project supporters such as the Commonwealth Secretariat, the Netherlands Directorate-General of Development Cooperation (DGIS), the Swedish International Development Cooperation Agency (SIDA); and the Inter American Development Bank (IADB).

IPC wishes to thank the Bill & Melinda Gates Foundation, the William and Flora Hewlett Foundation and all of its structural funders for their generous support.

ICTSD and IPC welcome feedback and comments on this document. These can be forwarded to Marie Chamay Peyramayou, mchamay@ictsd.ch and/or Christine St Pierre, stpierre@agritrade.org.

Citation: Wang, J., Huang, J., and Rozelle, S. *Climate Change and China's Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation,* ICTSD–IPC Platform on Climate Change, Agriculture and Trade, Issue Brief No.5, International Centre for Trade and Sustainable Development, Geneva, Switzerland and International Food & Agricultural Trade Policy Council, Washington DC, USA.

ISSN 2075-5856

CONTENTS

FOREWORD

When both "climate change" and "China" are topics in the same discussion, the focus is typically on energy and manufacturing. While it receives considerably less attention, the agriculture sector is not an insignificant source of emissions. Agriculture accounts for more than 15 percent of China's total greenhouse gas emissions, nearly 90 percent of nitrous oxide emissions, and 60 percent of methane emissions. Excessive fertilizer use is not only fueling a major portion of the nitrous oxide emissions but also is raising alarm about water pollution from agriculture. At the same time, however, there is opportunity for China's agriculture sector to play a role in mitigating against climate change through carbon sequestration and adopting production methods that reduce emissions. In addition, the potential impact of climate change on agricultural production and prices in China could have tremendous implications for both domestic and international markets, due to the sheer size of China's domestic demand for agricultural products.

This paper by Jinxia Wang, Jikun Huang and Scott Rozelle is the first Issue Brief produced by the IPC-ICTSD Platform on Climate Change, Agriculture and Trade to be entirely devoted to one particular country. Given the myriad challenges facing China—developing the economy, eliminating poverty, mitigating the emissions of greenhouse gases and adapting to climate change, and ensuring long-term food security—it is deserving of such specific consideration.

Ricardo Meléndez-Ortiz
Chief Executive, ICTSD

Charlotte Hebebrand
President/CEO, IPC

EXECUTIVE SUMMARY

Although China and the United States are the two largest emitters of greenhouse gases, China's emissions on a per capita basis are significantly lower than those of the U.S.: in 2005, per capita emissions in China were 5.5 metric tons—much less than the U.S. (23.5 metric tons per capita), and also lower than the world average of 7.03 metric tons. China's total GHG emissions were 7,234.3 million tons of CO_2 equivalent (tCO_2e) in 2005, 15.4 percent of which came from the agricultural sector. By comparison, total U.S. emissions were 6,931.4 million tCO_2e, 6.4 percent of which were from agriculture. Within China's agriculture sector, 54.5 percent of emissions come from nitrous oxide, and 45.5 percent come from methane, which is the opposite of the composition of global GHG emissions from agriculture.

Economic studies show that climate change will affect not only agricultural production, but also agricultural prices, trade and food self-sufficiency. The research presented here indicates that producer responses to these climate-induced shocks will lessen the impacts of climate change on agricultural production compared to the effects predicted by many natural scientists. This study projects the impacts of climate change on China's agricultural sector under the A2 scenario developed by the Intergovernmental Panel on Climate Change (IPCC), which assumes a heterogeneous world with continuous population growth and regionally-oriented economic growth. Depending on the assumptions used related to CO_2 fertilization, in 2030 the projected impacts of climate change on grain production range from -4 percent to +6 percent, and the effects on crop prices range from -12 percent to +18 percent. The change in relative prices in domestic and international markets will in turn impact trade flows of all commodities. The magnitude of the impact on grain trade in China will equal about 2 to 3 percent of domestic consumption. According to our analysis, trade can and should be used to help China mitigate the impacts of climate change; however, the overall impact on China's grain self-sufficiency is moderate because the changes in trade account for only a small share of China's total demand.

The effect of climate change on rural incomes in China is complicated. The analysis shows that the average impact of higher temperatures on crop net revenue is negative, but this can be partially offset by income gains resulting from an expected increase in precipitation. Moreover, the effects of climate change on farmers will vary depending on the production methods used. Rain-fed farmers will be more vulnerable to temperature increases than irrigated farmers, and the impact of climate change on crop net revenue varies by season and by region.

In recent years, China has made tangible progress on the implementation of adaptation strategies in the agricultural sector. Efforts have been made to increase public investment in climate change research, and special funding has been allocated to adaptation issues. An experiment with insurance policies and increased public investment in research are just two examples of climate adaptation measures. Beyond government initiatives, farmers have implemented their own adaptation strategies, such as changing cropping patterns, increasing investment in irrigation infrastructure, using water saving technologies and planting new crop varieties to increase resistance to climatic shocks.

China faces several challenges, however, as it seeks to reduce emissions and adapt to climate change. Fertilizers are a major component of nitrous oxide emissions, and recent studies indicate that overuse of fertilizer has become a significant contributor to water pollution. Application rates in China are well above world averages for many crops; fields are so saturated with fertilizer that nutrients are lost because crops cannot absorb any more. Changing fertilizer application practices will be no easy task. Many farmers also work outside of agriculture to supplement their income and opt for current methods because they are less time intensive.

In addition, the expansion of irrigated cropland has contributed to the depletion of China's water table and rivers, particularly in areas of northern China. Water scarcity is increasing and will constrain climate change mitigation strategies for some farmers. One of the main policy/research issues—as well as challenges for farm households—will be to determine how to increase water use efficiency.

Despite the sizeable amount of greenhouse gases emitted by and the environmental impact of China's agriculture sector, it also offers important and efficient mitigation opportunities. To combat low fertilizer use efficiency in China, the government in recent years has begun promoting technology aimed at calibrating fertilizer dosages according to the characteristics of soil. In addition, conservation tillage (CT) has been considered as a potential way to create carbon sinks. Over the last decade, China's government has promoted the adoption of CT and established demonstration pilot projects in more than 10 provinces. Finally, extending intermittent irrigation and adopting new seed varieties for paddy fields are also strategies that have been supported and promoted as part of the effort to reduce GHG emissions.

1. INTRODUCTION

The scientific community widely agrees that climate change is already a reality. Over the past century, surface temperatures have risen, and associated impacts on physical and biological systems are increasingly being observed (PRC, 2007). Climate change will bring about gradual shifts such as sea level rise, movement of climatic zones due to increased temperatures, and changes in precipitation patterns. Climate change is also likely to increase the frequency and magnitude of extreme weather events such as droughts, floods and storms. While there is uncertainty in the projections with regard to the exact magnitude, rate and regional patterns of climate change, its consequences will change the fates of generations to come.

While climate influences virtually all aspects of life, the impact on agricultural production is likely to be particularly important. Despite the fact that the relative magnitude of these impacts is still under debate, there is general consensus that China's agriculture sector will be affected significantly. Moreover, since China is a large, important producing and trading nation, the impact of climate change on China will likely also affect the rest of the world via international trade. For example, the IPCC concluded that the expected effects of temperature increases and precipitation decreases—under the worst case scenario—could lead to a drop in China's rain-fed yields of rice, wheat and maize of between 20 and 36 percent over the next 20 to 80 years (IPCC, 2007; Xiong et al., 2008). In contrast, cotton yields in China might increase (IPCC, 2007). However, these figures may overestimate changes in yield, as they do not account for the adoption of new technologies or changes in policy in response to climate change.

In addition, the nature of the climate impact will be affected by the agriculture sector's own growth since its emissions also contribute to climate change. As agreed by many scientists, climate change is mainly driven by the emission of greenhouse gases, such as carbon dioxide, methane and nitrous oxide (IPCC, 2007). Among all sources of emissions, agriculture is one of the most important contributors. According to the World Resources Institute's Climate Analysis Indicators Tool (CAIT), the emission of greenhouse gases from agricultural sources constituted 15.4 percent of China's total emissions in 2005, behind only electricity & heat and manufacturing & construction.[1] Nitrous oxide emissions from agricultural sources (mainly from the application of nitrogen fertilizer) accounted for 88.6 percent of China's total nitrous oxide emissions. Methane emissions from agricultural activities (mainly from ruminant animals and the cultivation of paddy rice) amounted to 59.4 percent of total methane emissions. These emissions are important; when comparing the consequences of different emissions, the temperature-increasing potential from nitrous oxide (methane) is 296 times (23 times) that of carbon dioxide.

The emission of greenhouse gases from agricultural sources constituted 15.4 percent of China's total emissions in 2005, behind only electricity & heat and manufacturing & construction.

While agriculture is one of the most important sources of emissions of greenhouse gases, the sector is increasingly being recognized for its potential to be part of the solution. This recognition of the positive role that agriculture can play is timely. Within China, the combination of climate change and rapid economic growth will force the nation to look for new ways to both deal with the unfolding changes in weather patterns and find effective mitigation policies/measures. In this vein, China is currently undergoing some fundamental changes to its climate change strategy. It is beginning to formulate a set of plans to deal with adaptation and mitigation issues by aiming at improved public access to information, stronger enforcement of laws, and higher accountability for emitters.

1 The most recent figures official emissions figures in China are from the *People's Republic of China Initial National Communication on Climate Change,* published in 1994. Recently, China has started to prepare the *Second National Communication on Climate Change of the People's Republic of China,* which will update emissions data for agricultural sector soon. The availability of GHG emission data for China is discussed further in Section 6.

However, in order to improve its adaptive capabilities and realize its mitigation targets, China must first examine several key questions. How is climate change expected to impact production and trade in China's agricultural sector? Within agriculture, where are the primary sources of emissions? What are some of the ways the sector can adapt and what efforts are already underway? What are potential mitigation measures and policies that could be promoted in the agricultural sector in China?

China is currently undergoing some fundamental changes to its climate change strategy. It is beginning to formulate a set of plans to deal with adaptation and mitigation issues by aiming at improved public access to information, stronger enforcement of laws, and higher accountability for emitters.

The overall goal of this paper is to review and document the likely impacts of climate change on China's agricultural production, efforts that China might be able to make in reducing greenhouses gas emissions from agriculture, and analyze how these efforts would in turn impact agricultural productivity and trade. In order to realize this goal, we have the following specific objectives. First, we will synthesize the likely impacts of climate change on agricultural production (crop yield and cropping systems), farmer income and agricultural trade (imports and exports) in China. Second, we will review adaptive responses to climate change that could potentially be made by the government and by farmers. Third, we will review some potential mitigation measures and policies that could be promoted in the agricultural sector.

The remainder of this paper is organized as follows. Section 2 briefly reviews the observed scientific evidence on climate change in China. Section 3 synthesizes the impacts of climate change on crop yields and cropping systems according to scientific estimates; the discussion in this section is based primarily on various biophysical modeling efforts. Section 4 reports the impacts of climate change on agricultural production, trade and farmer income. These results are based on research carried out by authors using economic models. Section 5 examines the adaptive responses to climate change made by China's government and its producers to climate change. Section 6 examines some alternative mitigation policies and measures that may be promoted in China's agricultural sector. The final section provides some overall conclusions.

2. CLIMATE CHANGE: OBSERVED EVIDENCE

Increasing evidence shows that shifts in China's climate have already occurred and indicates that changes will continue in the coming years. The average surface air temperature across China increased 0.5-0.8˚C during the 20th century. The upper end of this range is higher than the global average during the same period (PRC, 2007a). Moreover, there is evidence that this process is accelerating; most of the temperature increase took place over the past 50 years. There is also a regional dimension, which shows that the warming trend was more significant in areas north of the Yangtze River. The seasonal distribution of the temperature changes shows that the most significant temperature increases occurred in winter; warmer than average winters were observed 20 consecutive years nationwide between 1986 and 2005 (Ren, 2007).

There are also signs that rainfall patterns are changing. Although in the past 100 years there have been no statistically significant shifts in the trend of annual precipitation across China, there are considerable variations among regions. Most notably, areas of northern China saw severe decreases in rainfall; beginning in the 1950s, rainfall decreased between 20 to 40 mm/decade on average. At the same time, however, precipitation significantly increased in southern and southwestern China. Since the 1950s, rainfall levels have risen 20 to 60 mm/decade on average in these areas (PRC, 2007; Ren, 2007). In contrast, national average rainfall across all of China decreased 2.9 mm/decade from the 1950s to the 1970s before increasing slightly over the period from 1999 to 2000 (PRC, 2007).

While the evidence is less conclusive, the frequency and intensity of extreme climate/weather events throughout China appear to have increased during the past 50 years. Droughts in northern and northeastern China have become more severe, and flooding in the middle and lower reaches of the Yangtze River and southeastern China has intensified (PRC, 2007). Although the average annual precipitation in most years since 1990 has been higher than normal, the pattern has been dipolar—heavier rains in the South and more severe droughts in the North—which seems to correspond to the more frequent weather-related disasters (Ren, 2007).

Some uncertainty still exists regarding specific weather changes over the next 50 to 100 years, but there is general agreement that the climate will continue to warm in China and will do so at an accelerated pace. Projections by scientists in China show that the nation's overall annual mean air temperature will increase 1.3-2.1˚C by 2020 and 2.3-3.3˚C by 2050 compared with 2000 levels (PRC, 2007a). The magnitude of the warming is projected to be greatest in the South and the West and somewhat diminished in the North. It is estimated that by 2030, the annual temperature will likely increase 1.9-2.3˚C in northwestern China and 1.6-2.0˚C in southwestern China. The Qinghai-Tibetan plateau is expected to warm 2.2-2.6˚C by 2030.

The frequency and intensity of extreme climate/weather events throughout China appear to have increased during the past 50 years. Droughts in northern and northeastern China have become more severe, and flooding in the middle and lower reaches of the Yangtze River and southeastern China has intensified.

Precipitation in China is also expected to change, and scientists predict an overall increase of rainfall nationwide in the coming years (Ren, 2007). Specifically, rainfall across China is expected to increase 2 to 3 percent by 2020 and 5 to 7 percent by 2050. With rainfall, as with temperature, there are regional disparities and concerns about more frequent extreme weather events. The most significant impact is predicted to be in China's southeastern coastal regions. There are reports predicting that these changes in precipitation and dramatic weather events could have serious impacts on the socio-economic development of the nation and on the welfare of China's population. It is probable that the arid area in western China will become larger, and the risk of desertification would subsequently increase (Ren, 2007; Zhang and Wang, 2007).

3. IMPACTS OF CLIMATE CHANGE ON CROP YIELD AND CROPPING SYSTEMS: VIEWS FROM NATURAL SCIENTISTS

China's agricultural GDP has grown at an average of 5 percent annually over the last three decades, and while this figure is less than the 10 percent annual growth in total GDP, it is nonetheless respectable. Within the agricultural sector, significant structural changes have taken place. Commodities' share of the total value of agricultural output fell from 82 percent in 1970 to less than 50 percent after 2006 (NSBC, 2009). In the meantime, the more labor-intensive and less land-intensive horticulture, livestock and fishery sub-sectors have expanded rapidly.

While agricultural production was growing rapidly, agricultural trade grew even faster. Agricultural trade (both imports and exports) nearly tripled from 1980 to 1995 (Huang and Yang, 2005). During this time, exports rose more quickly than imports. Since the early 1980s, China has been a net food exporter. In general, net exports of land-intensive bulk commodities such as grains, oilseeds and sugar crops have fallen (or imports have risen). At the same time, exports of high-value, more labor-intensive goods such as horticultural and animal (including aquaculture) products have risen. Grain exports, which comprised nearly one third of food exports in the mid-1980s, fell to less than 10 percent of those levels during the next decade. Since the late 1990s, horticultural, animal and aquatic products have accounted for about 70 to 80 percent of food exports. For the first time in several years, China's total food imports were recently slightly larger than its exports.

> ***In general, net exports of land-intensive bulk commodities such as grains, oilseeds and sugar crops have fallen. Since the late 1990s, horticultural, animal and aquatic products have accounted for about 70 to 80 percent of food exports.***

Although grain exports have been decreasing in their relative share of total Chinese food exports, China remains self-sufficient in rice, wheat and maize. As Annex Table 1 indicates, China was a net exporter of rice and maize in 2006 (101 percent self sufficiency in rice means production was one percent higher than demand), and wheat production was able to fully meet domestic demand.

China has diverse agricultural production conditions across regions, which affects the spatial distribution of crop production and intensity of land use for different crops. In the northeast and northwest areas of the country, only one crop a year is normally planted. However in regions along the middle and lower reaches of the Yangtze River and South China, planting three crops a year is possible. Farmers use various cropping systems based on local weather and resource conditions: double-cropping rice systems (rice-rice, rice-wheat, rice-others) are common in tropical and subtropical areas, in some tropical areas (e.g., in Hainan province), three-cropping rice systems are utilized by a few farmers but are not common, and farmers in the North China Plain commonly use cropping rotations (e.g. maize-wheat and cotton-wheat).

> ***Nearly 45 percent of China's farmland is irrigated, and because of the common practice of multi-cropping on this land, 54 percent of all sown area is irrigated.***

Irrigation is one of the major factors contributing to high productivity of farmland. Nearly 45 percent of China's farmland is irrigated, and because of the common practice of multi-cropping on this land, 54 percent of all sown area is irrigated. The share of irrigated land varies significantly across regions due to diverse environmental conditions, ranging from more than 70 percent in the East to only about 20 per cent in the Northeast. Water shortages, particularly in the North China Plain and the northwest part of the country, have become more acute over the last two decades. With intensified farm and non-farm uses of water, the water table has declined rapidly in northern China, and many rivers stop flowing during the dry season (Wang et al, 2009b).

Due to differences in climate and physical features, the particular crops under cultivation can vary widely across regions in China. Rice is the primary grain crop produced and is grown in southern and central China. Other major crops in this region include oilseeds, vegetables and sugarcane. North and northeastern China are the main production areas for wheat, maize, soybeans and cotton. Sweet potatoes are widely grown in southern China, while white potatoes are more common in the North. Fruits and vegetables are grown in all regions; the specific types of produce cultivated are chosen in accordance with the growing conditions of the region.

3.1 Climate Change and Crop Yields

Studies by natural scientists indicate that the impacts of climate change on crop yields are expected to be significant. Careful examination of the literature also suggests that there are differences among the many studies. Major findings of the existing studies are summarized below.

The impacts of climate change on crop yields, albeit ambiguous, are significant and will become more amplified over time. Specifically, Xiong et al. (2008) shows that the magnitudes of the yield impacts in 2050 on China's three major food/feed crops (rice, wheat and maize) ranged from -22.8 percent in the case of irrigated maize to +25.1 percent for the case of irrigated wheat (see Table 1).

Estimates of the impacts of climate change on crop yields vary widely depending on assumptions about the CO_2 fertilization effect. In some studies, accounting for the benefits of CO_2 fertilization reduces the negative impacts of climate change on crop yields or even results in a projected increase in yields (Table 1). For example, under the A2 scenario, without the CO_2 fertilization effect, yields of all crops analyzed are projected to decrease. However, when a considerable CO_2 fertilization effect is factored in, yields actually increase in all cases except that of irrigated maize.

Overall, rain-fed crops are projected to be much more severely affected by climate change than irrigated crops. Higher incidences of drought and rising temperatures will increase water demand per unit of cropland area and negatively affect crop yields.

The impacts of climate change on crop yields also differ widely among crops. Wheat yields generally benefit most under the scenarios that account for CO_2 fertilization, while rain-fed maize and rice yields are the most adversely affected under scenarios that do not account for any CO_2 fertilization effect. More generally, these results indicate that wheat may be the most resilient to the adverse effects of climate change. Overall, rain-fed crops are projected to be much more severely affected by climate change than irrigated crops (Table 1).

The literature summarily suggests that there will be large regional differences in the impact of climate change (Lin et al., 2006). For example, in China's northeast region, increasing temperatures will benefit agricultural production, but in the North China Plain, higher incidences of drought and rising temperatures will increase water demand per unit of cropland area. Such dynamics are expected to make water shortages more serious in this region and negatively affect crop yields. In China's northwest region, projected precipitation increases will not be enough to offset the chronic water shortages that limit agricultural production. At the same time, flooding in southeastern China is projected to become more serious, and average yields are expected to decrease. In other parts of the South, rising sea levels may affect agricultural production by reducing crop area.

3.2 Climate Change Impacts on Cropping Systems

The scientific literature also predicts that China's cropping systems will experience moderate changes as a result of climate change. In this section, we highlight two interesting sets of changes.

First, studies estimate that both planting and harvesting dates of crops will change. For example, warmer temperatures will allow earlier planting dates for crops in the areas north of the Yangze River Basin (particularly in the middle latitudes and high plateau regions). In addition, the harvesting dates can be pushed later in the year, extending the entire growing season (Lin et al., 1997). As a result, producers in some regions may be able to shift from single to multi-cropping systems.

Second, there is evidence that the cultivated area under both single and triple-cropping (e.g., rice-rice-rice in Hainan of South China) systems could be increased. Based on the results of predictions using several alternative GCM models, temperatures in 2050 would increase 1.4°C while precipitation would decrease 4.2 percent (Deng et al., 2006).[2] Under this set of assumptions, scientists estimate that the planting areas of single cropping systems will be able to expand 23.1 percent. At the same time, models project that the sown areas of three-cropping system will also increase in southern China (Wang, 2000). The potential for cropland expansion is primarily due to the warmer temperatures, which will allow production in regions that were formerly too cold. It is interesting to note that the share of cultivated area that will be double-cropped is predicted to change only slightly: from 24.2 percent to 24.9 percent. This, however, does not mean that the double-cropped area is static. According to the estimates of one research team, double cropping regimes will be migrating towards the middle regions of the country, where originally only single cropping was an option.

Potential for cropland expansion is primarily due to the warmer temperatures, which will allow production in regions that were formerly too cold.

3.3 Climate Change Impacts on Livestock

China's grasslands have experienced a warming trend in recent decades, particularly in Inner Mongolia during the winter months. As a result, spring droughts in the grassland areas are becoming more serious. The productivity of the grasslands (in terms of its biomass production) has trended downward since 1993 (Li et al., 2002). In the future, continued changes in temperature and precipitation will further decrease the output of pasture regions (as measured by the production of livestock—e.g., the production weight of cattle) (Shao, 1995). For example, the production of beef is forecast to decrease 9.8 percent by 2030.

2 There exists much uncertainty on projecting future temperatures and precipitation. This is due to different assumptions and model structures. Therefore, the climate projection applied by Deng et al. (2007) is different from others that we cited in Section 2. Even the numbers are not exactly same. The warming trend in the future, however, is confirmed by all models.

4. IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION, PRICES, TRADE, FOOD SECURITY AND FARM INCOME: VIEWS FROM ECONOMISTS

In this section, we supplement the discussion in the previous section, which was based on scientific research, with a review of the economic literature. This section will examine the effects of climate change on production, prices and trade of agricultural commodities, as well as on farmer income in China.

Mirroring scientific research, economic studies demonstrate that climate change will impact agricultural production in varying degrees based on the crops analyzed and assumptions regarding CO_2 fertilization (Wang et al., 2009a). The findings presented in this section importantly advance the work on climate change impact assessments in two ways. First, Wang et al. (2009a) also find that climate change indirectly affects crop production as farmers react to changes in market signals. Second, the economic research accounts for the ways in which changes in trade flows and prices (which are direct consequences of climate change effects in other countries) will impact China's agricultural sector.

Four scenarios were analyzed by Wang et al. (2009a). They are as follows: 1) the A2 scenario with the assumption that there is neither a CO_2 fertilization effect nor an impact of climate change on the rest of world (S1); 2) the A2 scenario with the assumption that there is no CO_2 fertilization effect, but that there is an impact of climate change on the rest of world that can affect China (S2); 3) the A2 scenario with the assumption that there is a CO_2 fertilization effect, but there is not an impact on China from climate change in the rest of world (S3); and 4) the A2 scenario with the assumption that there is both a CO_2 fertilization effect and an impact on China from the effects of climate change on the rest of world (S4). In the remainder of this section, we summarize the findings of S1 to S4, which are analyzed and explained in detail in Wang et al. (2009a). Appendix Table 1 shows the levels of agricultural production, trade, prices and rates of self-sufficiency in China in 2006 and 2030 under the reference scenario.[3]

4.1 Impacts of Climate Change on Agricultural Production

Results show that without the CO_2 fertilization effect, grain production will fall over the projection period (Table 2). Compared to the 2030 reference scenario, both the yield and sown area of rice will fall due to shocks from climate change. For rice specifically, the decrease is largely due to a decline in water availability for irrigation. Farmers will be able to increase inputs (e.g., adopting new seed varieties, increasing labor, machine, chemical and other production inputs) to offset some of the negative effects, but overall, production will still decrease.

Results show that without the CO_2 fertilization effect, grain production will fall over the projection period.

A comparison of results under the S1 and S2 scenarios in Table 2 shows that accounting for the impacts of climate change on the rest of the world (S2) will lessen production declines in China, as higher international prices resulting from decreased supply will stimulate expanded grain production in China, ceteris paribus. Production increases are primarily due to a slight expansion of grain area through crop area substitution and increased use of inputs with the exception of water. In the simulation, Wang et. al., (2009a) already considered the impacts of climate change on availability of water.

When the CO_2 fertilization effect is considered (S3 and S4), the impacts of climate change on grain production are drastically different. Production of wheat and maize is projected to increase, and the decrease in rice production is far less severe than under S1 and S2. Once again, consideration of the negative effects of climate change in the rest of the world (S4) results in higher production levels than when only accounting for the effects of climate change in China (S3).

3 Under the reference scenario, demand for wheat and rice is projected to decrease as incomes and diet improve and population growth approaches zero. As a result, prices are also expected to fall, leading to a decrease in production. Conversely, maize production is projected to increase as growing demand for meat increases the demand for livestock feed.

4.2 Impacts of Climate Change on Crop Prices

Without the CO_2 fertilization effect, decreases in agricultural production both in China and in the rest of the world will result in higher grain prices. Prices are higher under S2, the scenario that considers the global effects of climate change, with rice prices seeing the sharpest increase (17.6 percent). Taken with the production impacts estimated in Table 2, these results indicate that failure to account for the impacts of climate change in the rest of the world would result in underestimating the effect of climate change on prices and overestimating the effect on production in China.

> ***Trade is an important tool that can mitigate the adverse impacts of climate change on domestic production and help China balance demand and supply gaps resulting from climate change.***

It should be noted that grain prices in China in 2030 would be much higher than those presented in Table 2 if there were no increase in grain imports (or no decline in exports).[4] This implies that trade is an important tool that can mitigate the adverse impacts of climate change on domestic production and help China balance demand and supply gaps resulting from climate change.

When we account for CO_2 fertilization effects, climate change is projected to have a negative impact on grain prices. Wheat prices would see the largest decrease because wheat production is projected to benefit most from CO_2 fertilization; the increase in supply will place downward pressure on prices. These results further highlight the critical importance of the potential impacts of CO_2 fertilization on future crop yields.

4.3 Impacts of Climate Change on Trade

The changes in trade flows shown in Table 3 reflect the shift in comparative advantage of crop production caused by climate change in China and the rest of world. As discussed above, under the scenarios that do not account for CO_2 fertilization, domestic production in China is projected to decrease and commodity prices are forecasted to increase. Following on these results, the analysis indicates that Chinese exports will decrease while imports increase in order to stabilize the domestic market. Once again, the changes are less dramatic when climate change effects in the rest of the world are considered (S2), compared with only examining the effects of climate change in China (S1). Of the three crops analyzed, maize imports are projected to increase most, as they will be needed to close the gap between rapidly growing demand and the forecasted decrease in domestic production under these two scenarios.

> ***Changes in trade flows reflect the shift in comparative advantage of crop production caused by climate change in China and the rest of world.***

In contrast, China's trade balance will improve under the scenarios that consider a CO_2 fertilization effect (S3 and S4). Exports of all three commodities will increase and imports will decline compared to the 2030 reference scenario. These results are in line with the increase in domestic production and decrease in prices discussed in the sections above. Of particular note here, the impact of climate change on China's imports and exports depends on the relative magnitude of the CO_2 fertilization effect in China compared to the rest of the world (analyzed under S4). In the case of rice, the positive impact of CO_2 fertilization on rice yield in China is projected to be less than that in the rest of world, so the price in China will rise compared with the international rice price. Therefore, China's rice exports will decrease and imports will increase relative to S3. The situation is reversed for wheat and maize: China's yields will increase more than those in the rest of world, causing wheat and maize exports to increase and imports to decrease compared to S3.

4.4 Impacts of Climate Change on Grain Self-sufficiency

While the impacts of climate change on China's trade in agricultural commodities vary considerably

4 Results in Table 2 take into account changes in trade flows when projecting price; the impacts of climate change on trade are presented in Table 3 in the next sub-section.

across the scenarios analyzed, the overall impact on China's grain self-sufficiency is moderate because the changes in trade will account for only a small share of China's total demand. Under the reference scenario in 2030, grain self-sufficiency is projected to be 104 percent for rice (that is, production will be four percent higher than demand—and China will be a net exporter), 101 percent for wheat, and 92 percent for maize. Under alternative scenarios (Scenarios 1-4), we project that China's self-sufficiency in rice, wheat and maize will change by (at most) a few percentage points (Table 3). The negative impact on self-sufficiency is more severe under S1 than S2, and climate change is projected to actually improve grain self-sufficiency when we consider the impacts of CO_2 fertilization on crop yields (with the exception of rice under S4). Taking the reference scenario and the results presented in Table 3 together, China would remain self-sufficient in rice, could dip slightly below self-sufficiency in wheat under S1 but would remain self-sufficient under the other three scenarios, and would remain below 100 percent self-sufficiency in maize under all scenarios.

While the impacts of climate change on China's trade in agricultural commodities vary considerably across the scenarios analyzed, the overall impact on China's grain self-sufficiency is moderate because the changes in trade will account for only a small share of China's total demand.

4.5 Impacts of Climate Change on Farmer Income

Researchers have long pointed out that rural people are particularly vulnerable to climate change, especially in the case of extreme weather events such as droughts and hailstorms (Tor, 1995). In the dry regions of western China such as Ningxia Province, a reduction in rainfall and an increase in the incidence of drought in recent years have been shown to affect local farming activities and farmer income (Ju et al., 2008). In the following discussion, we summarize the major results from our recent studies on the impacts of climate change on farmer income based on both simulation models and econometric research (Ricardian model).

Findings based on Simulation Modeling

Using the analytical framework and models that were discussed in the previous section on price and trade issues, the same group of authors analyzed the impacts of climate change on farmer income in the 3H region (Huang-Huai-Hai Plain). The 3H region is located in northern China and covers all or part of Beijing, Tianjin, Hebei, Shandong, Henan, Jiangsu and Anhui Provinces. The total area is 350 km², and it is one of most important agricultural production regions in China. In 2007, the sown area of wheat in the 3H region was 47 percent of China's total wheat area. Maize and rice production in the 3H region comprised 27 percent and 16 percent respectively of China's total production of each of these crops (NSBC, 2007). Irrigation has played an important role in promoting the growth of agricultural production in this region.

The second study, henceforth called Wang et al., 2009b, examines the impact of climate change on farmer income through its effect on both production and prices. Recall that results for S1 and S2 presented in Table 2 indicated that production of rice, wheat and maize would decrease while prices would increase. As a result of combining both the production and price effects, Wang et al. (2009b) projects that the overall effect on farmer income will be positive because the increase in price will be more than the decrease in production. Farmers benefit more under S2 compared to S1 because the positive price effect is greater and the negative production effect is lesser.

In contrast, the increase in production due to CO_2 fertilization does not lead to corresponding increases in farmer income. Although grain production will rise with the positive contribution of CO_2 to grain yields, the decrease in market price will be more significant.

Findings based on the Ricardian Model

Applying a Ricardian model based on cross-sectional data comprised of 8,405 households in 28 provinces, Wang et al. (2008a) empirically analyzed the impacts of climate change (temperature and precipitation) on crop net revenue. Results reveal that temperature has a fundamentally different effect on irrigated farming compared to rain-fed farming (Table 4), which is consistent with the scientific research discussed previously. The key findings from the Wang et al. (2008a) study are presented below.[5]

The effects of climate change on farmer income are complex. The average impact of higher temperatures on China's net revenue is negative, while increased precipitation leads to greater net revenue on average.

First, the effects of climate change on farmer income are complex. The average impact of higher temperatures on China's net revenue is negative, while increased precipitation leads to greater net revenue on average. The results of the analysis show that a 1°C increase in temperature results in a decrease in annual net revenue of 10 USD per hectare, and a 1 mm/month increase in precipitation increases annual net revenue by 15 USD per hectare.

When the analysis separates irrigated and rain-fed farmers, we find that warming actually helps irrigated farmers while the incomes of rain-fed farmers are quite vulnerable to temperature increases.[6] Higher precipitation, however, has almost identical effects on irrigated and rain-fed farms.

The analysis also separates the effects of increasing temperatures and precipitation by season. Warmer temperatures in fall and spring are harmful to irrigated farms whereas warmer summers and winters are beneficial (Table 4). Rain-fed farms only stand to benefit from warmer winters and will see declining net revenue due to warming in spring, summer and fall. Wetter winters will benefit both rain-fed and irrigated farmers, and more precipitation in the spring and fall will hurt both types of farmers. Increased rainfall in the summer leads to higher net revenue for irrigated farmers but decreased net revenue for rain-fed farmers.

Warming will likely help rain-fed farmers in very cold places but harm them elsewhere in China, especially in the far south, where the hotter temperatures will be coupled with inadequate and unreliable water supplies.

Finally, the impact of higher temperatures on crop net revenue also varies by region. With irrigated farms, warmer temperatures are more beneficial in the southeast and southwest regions (Figure 1), perhaps because these areas have abundant water resources. In the central region, irrigated farmers enjoy mild benefits from warming. Warming will likely help rain-fed farmers in very cold places but harm them elsewhere in China, especially in the far south, where the hotter temperatures will be coupled with inadequate and unreliable water supplies (Figure 2).

5 The Ricardian model assumes that each farmer wishes to maximize income subject to the exogenous conditions of their farm. If the farmer chooses the crop that provides the highest net income and chooses each endogenous input in order to maximize net income, the resulting net income will be a function of just the exogenous variables (such as climate, soil conditions). With perfect competition for land, free entry and exit will ensure that excess profits are driven to zero. As a consequence, land rents will be equal to net income per hectare. The advantage of the Ricardian model is that it provides an estimate of the benefits derived from adaptation. However, due to data limitation, we do not know how much water farmers used in irrigation and cannot quantify the effect of water in the economic model. If climate change does reduce water supplies, there will be harmful impacts on agriculture.

6 In general, water is scarce in China, particularly in northern China. Per capita water availability in China is 2100 cubic meters, only about 25 percent of the world average (Ministry of Water Resources, 2007). Due to uneven distribution, water is relatively rich in southern China, but in northern China, per capita water availability is only about 500 cubic meters. In the past 50 years, runoff of some major rivers in northern China has declined anywhere from 15 percent (Yellow and Huaihe Rivers) to 41 percent (Haihe River). In addition, the overexploitation of groundwater and the resulting drop in the water table is of serious concern (Wang et al., 2009b). As forecasted by Wang et al. (2009a), water scarcity will become more serious under climate change. By 2030, water scarcity as percentage of total water demand will reach 9.07 percent and 7.97 percent in the Haihe and Huaihe River Basins. Even the Yellow River Basin will be affected: water scarcity will increase to 2.74 percent in 2030.

If the climate becomes warmer, crop ET (evaporation and transpiration) will increase, and crops will require more water to grow. In the rain-fed areas, there are no supplementary sources of irrigation; crop growth depends completely on rainfall. Therefore, in such areas (that is, those with limited water supply from rainfall, but with no sources of alternative supplies of water from irrigation), farmers are especially vulnerable to warming.

5. ADAPTIVE RESPONSES TO CLIMATE CHANGE MADE BY GOVERNMENTS AND FARMERS

Most of the results in the studies discussed above are in some sense static analyses. They do not account for the efforts undertaken by government officials and farmers to respond to the effects of climate change. If they are able to adapt adequately, it is possible that China's agricultural sector can actually take advantage of changes in temperature and rainfall. Future agricultural production will depend on the ability of these actors to make effective responses. The ultimate magnitude of the effect of climate change will also depend on these adaptations.

5.1 Adaptive Responses—the Government

While China has been working toward reducing its contribution to global climate change, it has only recently begun to address climate change adaptation.[7] According to *China's National Climate Change Program,* established in 2007, the government is considering a number of strategies and activities in its efforts to help the agricultural sector adapt to climate change; a few examples are highlighted below.[8]

Improve agricultural infrastructure. A number of opportunities exist for the government to invest in infrastructure that could facilitate adaptation. First, the government is considering accelerating the construction of supporting facilities in large-scale, water-saving irrigation projects. There are also efforts to build new smaller-scale irrigation and drainage projects in areas that are currently not irrigated. Officials have suggested that they intend to control the spread of middle- and low-productivity agricultural zones and strengthen the restoration of degraded farmland. For example, in areas that are currently affected by salinization or alkalinization, investments in soil improvement can make them more productive as temperatures rise and rainfall changes. Finally, there are plans to accelerate the construction of water storage projects and projects that enhance water utilization—especially in mountainous and desert areas.

Strengthen research and development for new technologies. One of the main roles of government has been investment in the research and development of agricultural technology, especially in systems that are dominated by smallholders and lack investment by large private agricultural seed and/or research companies. Specifically, the government should both continue and expand breeding programs to encourage research on seed varieties with traits that promote resistance to drought, water-logging, high temperature, diseases and pests.[9] In addition to these programs, the government has pushed for research to better understand the magnitude, source and mechanisms of climate change and its consequences. For technologies that have already been developed, the government needs to establish the means for transferring and promoting them to all farmers. In recent years, the extension system has deteriorated, and efforts should be made to restore its effectiveness.

The government should both continue and expand breeding programs to encourage research on seed varieties with traits that promote resistance to drought, water-logging, high temperature, diseases and pests.

5.2 Progress on Implementation of Government Adaptation Strategies

Although many adaptation strategies are still in the planning stages, China has nonetheless made some tangible progress on implementation. Specific examples are discussed below, and there are undoubtedly

7 For at least the past 10 years, China's government has addressed the issues of increasing energy efficiency and reducing GHG emissions. This effort is being led by personnel in the Ministry of Agriculture; Ministry of Science and Technology and the State Environmental Protection Agency.

8 Unfortunately, the role of trade has not been considered in the current climate change strategy.

9 This research is underway for many kinds of crops, including rice, wheat, maize, and vegetables.

many more. Future research should provide more comprehensive documentation of these projects and analyses of their strengths, weaknesses and other lessons.

First, there have been efforts to increase the political profile of and public investment in climate change research, and special funding arrangements have been established for climate change adaptation. The first such project in China was announced in 2007 (Zhang, et al., 2008). As part of this program, several provinces have already begun to invest in technologies that will promote more reliable rainfall, such as cloud seeding—dispersing substances such as dry ice or silver iodide into clouds to induce rain—in Sichuan and Tibet and rainfall harvesting in Xinjiang. In Ningxia province, the provincial Science and Technology Department also plans to invest in improved climate forecasting. The provincial Academy of Agricultural Sciences has launched studies on agricultural adaptation, including improved crop varieties and ecological migration. As these projects were only recently initiated, their effectiveness has not been assessed and documented.

Second, there has been increased experimentation with different types of insurance policies. Since 2002, agricultural insurance coverage in China has seen rapid and sustained development as the government has increased its investment in this industry. In 2007, premium income and insurance payments both hit record highs and were more than 400 percent higher than the previous year.[10] In some provinces, insurance schemes have been provided by the government (Zhang, et al., 2008); in others, the government has encouraged mutual insurance associations. The China Insurance Regulatory Commission has been studying both the past and potential future impacts of climate change on the insurance industry. In 2007, they issued a notification to emphasize the need to account for the effects of more frequent extreme meteorological events and called for more innovations in insurance products. In 2006, Zhejiang province launched a pilot project that offers integrated agricultural insurance. A government-subsidized program, the insurance policies are offered and administered by a non-commercial agricultural insurance company. The basic premise is to provide insurance for household losses, which will be in greater demand in a world that suffers from more severe weather events.

5.3 Adaptive Responses—Farmers

In addition to government officials, farmers have an incentive to implement adaptation strategies. In this section, we review a few of the options farmers have in responding to climate change.

Crop choice. Based on empirical analysis of 8,405 farmers in 28 provinces in China, Wang et al. (2008b) showed that across China, farmers in warmer places are more likely to produce cotton, wheat, oil crops and maize and less likely to grow rice, soybeans, vegetables, potatoes and sugar. These results indicate that they are already beginning to make planting shifts according to local climatic conditions. In wetter locations, farmers are more likely to plant rice soybeans, oil crops, sugar, vegetables and cotton and less likely to grow maize, potatoes and wheat. Field studies in single provinces also find similar behavior among farmers. Lin et al., (2008) indicates that in Ningxia Province, farmers faced with drought are inclined to choose a crop that is more adaptive, multi-functional and high yielding, with better economic returns under such conditions. Primary examples include maize, potatoes and sunflowers.

[Farmers] are already beginning to make planting shifts according to local climatic conditions. Farmers faced with drought are inclined to choose a crop that is more adaptive, multi-functional and high yielding, with better economic returns under such conditions.

Irrigation. Wang et al. (2008b) documented that farmers in locations with more rainfall are less likely to irrigate. In part, this is because they are able to get sufficient moisture without the expense of irrigation. However, the analysis also suggests that the marginal effects of climate change on irrigation choice depend

10 China Insurance Regulatory Commission: http://www.fdic.gov/about/intlaffairs/presentations/SessionOne-ChinaInsuranceRegulatoryCommission.doc.

on the distribution of seasonal rainfall and temperature. As a result, irrigation choice will vary from place to place.

Increased investment in irrigation infrastructure. Farmers, like the government, can invest in irrigation facilities. This is especially easy to see in areas of northern China that already face diminished access to surface water for a variety of reasons—not necessarily related to climate change. In these areas, farmers have turned to use of groundwater to maintain or improve productivity (Wang et al., 2009b). The share of land in north China irrigated by groundwater increased from less than 30 percent in the early 1970s to nearly 70 percent in 2004 (Wang et al., 2007). Over the past three decades, individual farmers have become the major investors in tubewells—water wells made of a tube or pipe bored into an underground reservoir with an electric pump at the top to pull water for irrigation. The share of individual tubewells increased from less than 10 percent in the early 1980s to more than 80 percent twenty years later. Researchers also found that in dry land areas, farmers will invest in rainwater harvesting facilities, such as water storage tanks (Ju et al., 2008).

Adoption of water saving technologies. Based on a field survey in six provinces in northern China, Blanke et al. (2007) found that when faced with increasing water shortages (which would be the case in some areas after climate change), farmers will adopt water saving technologies. According to survey data, by 2004 at least 42 percent of villages (compared to less than 10 percent of villages in the early 1980s) were using a number of different types of household-based water saving technologies such as plastic sheeting, drought resistant varieties, retaining stubble/employing low-till methods, and surface level plastic irrigation pipe.

Faced with climate change and the prospect of increasing water scarcity, farmers have already shown a willingness to plant crop varieties with better resilience to adverse weather.

Adopting new crop varieties to reduce weather-related risk. Faced with climate change and the prospect of increasing water scarcity, farmers have already shown a willingness to plant crop varieties with better resilience to adverse weather. The 2007 GEF/SCCF project report of Hebei, observed that farmers in Cang County in Hebei province selected drought-resistance crop varieties (including new varieties for wheat, cotton and maize) in response to decreased water availability. In addition, farmers planted productive and disease-resistant varieties (mainly for wheat) in some parts of Jiangsu Province. In Henan Province, certain winter wheat varieties were selected following a higher frequency of warm winters. Current development of heat tolerant and pest-resistant wheat varieties is at least in part a response to the early effects of climate change.

6. GREENHOUSE GAS EMISSIONS AND MITIGATION POLICIES IN THE AGRICULTURAL SECTOR

A number of different sources provide data on China's emission of greenhouse gases. The Climate Analysis Indicators Tool (CAIT) from the World Resources Institute provides data on China's GHG emissions from 2005. Total emissions were 7,234.3 million tons of CO_2 equivalent (tCO_2e); 5,592.4 million tons were from CO_2, 853.3 million tCO_2e were from CH_4, and 684.1 million tCO_2e were from N_2O.

Chinese researchers have provided their own estimates for China's emissions in 2004 and report that total GHG emissions were about 6,100 million tCO_2e (5,600 million tons of net emissions). Of this total, 5,050 million tons were from CO_2; 720 million tCO_2e were from CH_4; and 330 million tCO_2e was from N_2O (PRC, 2007). From 1994 to 2004, the annual average growth rate of GHG emissions was around 4 percent. During this same time period, the share of CO_2 in the total amount of GHG emissions increased from 76 to 83 percent.

The most recent emission data officially recognized by the Chinese government come from 1994 and are contained in the *Initial National Communication on Climate Change of the People's Republic of China.* According to this report, total emissions in 1994 were 4,060 million tCO_2e (3,650 million tons of net emissions). Of this total, 3,070 million tons were CO_2, 730 million tCO_2e were from CH_4 and 260 million tCO_2e were from N_2O.[11]

Internationally, there is a debate on the actual amount greenhouse gases being emitted in China. The Netherlands Environmental Assessment agency was the first organization to state that beginning in 2006, Chinese carbon dioxide emissions, the main GHG, exceeded those of the United States (Rosenthal, 2008). Leggett et al. (2008) also claimed that China is now the largest emitter of GHG globally, reporting that total GHG emissions in China reached 7,527 million tCO_2e in 2005 compared to 7282 million tCO_2e in the U.S. However, due to limitation on data and estimation approaches, Chinese officials and experts do not agree with the above numbers and do not think China has become the largest GHG emission country (http://www.huanjingbaohu.com/huanbao-4341-1-1.html).[12] Within China, the general agreement is that China is still the second largest GHG emitter in the world. According to the National Climate Change Program, in 2004, GHG emissions in China totaled 6,100 tCO_2e, which was lower than the United States (estimated at nearly 7,000 tCO_2e).

Regardless of the disagreement over the total contribution of GHG emission from China, the per capita GHG emissions in China are much lower than those of the United States and many other industrialized countries. For example, in 2004/2005, per capita GHG emissions in China were only 4.6 metric tons based on China's data. Leggett et al. (2008), estimate per capita GHG emissions in China at 5.7 metric tons in 2005, about 24 percent of that in the US (25 metric tons per capita). That same year in Russia and Japan, per capita GHG emissions reached 15 and 11 metric tons respectively. Furthermore, China's emissions per capita are also below the world average of 7 tons.

In addition, along with the steady social and economic development, emissions intensity, defined as the CO_2 emissions per unit of GDP, has been declining (PRC, 2007). According to the IEA, China's emission intensity fell to 2.76 $kgCO_2$/US$ (constant 2000 U.S. dollar) in 2004, as compared to 5.47 $kgCO_2$/US$

11 As reported by some officials, China has begun work on the *Second National Communication on Climate Change of the People's Republic of China* through the updated GHG emission data. However, this second round of work has not been completed.

12 Regarding the estimation of GHG by country, the IEA report stated, "it is stressed that the uncertainty in the resulting dataset at the national level may be substantial for both methane and nitrous oxide, and even more so for the F-gases. The uncertainty is caused by the limited accuracy of international activity data used and in particular of emission factors selected for calculating emissions on a country level." IEA. Op. cit., p. III.12.

in 1990, a 49.5 percent decrease. During the same period, the emission intensity worldwide dropped only 12.6 percent, and that of the OECD countries dropped 16.1 percent.

6.1 Emission from the Agricultural Sector

CAIT reports that GHG emissions from China's agricultural sector made up 15.4 percent of total emissions in 2005. Nitrous oxide emissions from agriculture accounted for 88.6 percent of all N_2O emissions, and agriculture's methane emissions constituted 59.4 percent of China's total methane emissions. Within the agriculture sector, 54.5 percent of GHG emissions were from nitrous oxide and 45.5 percent were from methane. By comparison, the *Initial National Communication on Climate Change* indicates that greenhouse gas emissions from agricultural sources constituted 17 percent of China's total greenhouse gas emissions in 1994. Nitrous oxide emissions from agricultural sources accounted for 92.5 percent of China's total nitrous oxide emissions, and the methane emission from agricultural activities amounted to 50.1 percent of China's total methane emissions in the same year (Table 5). To show how China's agricultural sector compares with other nations, Appendix Table 2 summarizes GHG emissions from agriculture as a percentage of total emissions for selected countries in 1995 and 2005.

Nitrous oxide emissions from agriculture accounted for 88.6 percent of all N_2O emissions, and agriculture's methane emissions constituted 59.4 percent of China's total methane emissions.

Agricultural nitrous oxide emissions in China mainly come from the application of fertilizer. In 1994, the total emission of nitrous oxide from the application of fertilizer reached 628 thousand tCO_2e and accounted for 80 percent of total nitrous oxide emissions in the agricultural sector (Table 5). Other sources of nitrous oxide include pasture management, the burning of excrement (livestock wastes) and crop residues.

Agricultural emissions of methane mainly come from the keeping of ruminant animals and the cultivation of paddy fields. In 1994, the total emission of methane from the ruminant animals reached 10,182 thousand tCO_2e, which was 59.2 percent of the total emissions of methane in China's agricultural sector (Table 6). The second largest methane emission source, rice production, accounted for 35.8 percent of agricultural methane emissions (or 6,147 tCO_2e) in 1994.

Agricultural nitrous oxide emissions in China mainly come from the application of fertilizer. Agricultural emissions of methane mainly come from the keeping of ruminant animals and the cultivation of paddy fields.

6.2 Mitigation Policies in the Agricultural Sector

China actively participates in worldwide efforts to address climate change and has acknowledged its interest in international cooperation in this regard. For example, China's leaders have endorsed the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. In June 2007, China's government released China's National Plan for Coping with Climate Change (NDRC, 2007). Beginning in 2010, the plan calls for the implementation of policies and measures concerning control of greenhouse gas emissions that will begin to make substantive progress toward significant results of reducing energy intensity per unit of GDP by 20 percent compared with 1995 levels. The national policy endorses efforts that enhance China's ability to adapt to climate change. There are also specific provisions in the plan to support climate change-related research. Following the Copenhagen Accord, China submitted a Nationally Appropriate Mitigation Action Plan (NAMA) to the UNFCCC Secretariat. This letter does not reference the Accord but does pledge that China will reduce GHG emission intensity 40-45 percent by 2020 compared with the 2005 level and will increase forest coverage by 40 million hectares (Su, 2010).

Recent policy directives and the creation of new institutions testify to the higher level of attention devoted to climate change. As part of this effort, the government issued a white paper titled "China's Policies and Actions for Addressing Climate Change"

(PRC, 2008). The paper's mitigation plan, which emphasizes energy conservation and improved efficiency, focuses primarily on China's industrial sector, but the government also recognizes that all industries have roles to play in reducing emissions. Furthermore, the paper shows that China believes international cooperation is essential in addressing climate change and has indicated a willingness to do its fair share. To provide government leadership on this issue, the National Leading Committee on Climate Change was established, with Premier Wen Jiabao as chairman and 20 national ministries as members. The National Development and Reform Commission (NDRC) was asked to coordinate the new committee under the leadership of Premier Wen Jiabao. According to China's National Climate Change Program, the government is planning to take actions in several dimensions to promote mitigation activities in the agricultural sector.

Recent policy directives and the creation of new institutions testify to the higher level of attention devoted to climate change.

Strengthen the establishment and implementation of laws and regulations. The first step is for China to implement a set of laws and basic regulations that support climate mitigation measures, through two primary means. First, the nation wants to gradually improve its system of laws and regulations based on existing regulations: the Law of Agriculture of the People's Republic of China, the Law of the Grasslands of the People's Republic of China, and the Law on Land Management of the People's Republic of China. Once these are amended, they need to be harmonized with the associated administrative rules and regulations. It is thought that this is a necessary step before agricultural land, pasture land and forests can be used on a large scale for carbon storage. Second, the government wants to create a policy environment that promotes the protection of farmland and pasture land and strictly controls any redevelopment of land that is being used for carbon storage or is part of a fragile ecosystem.

The government wants to create a policy environment that promotes the protection of farmland and pasture land and strictly controls any redevelopment of land that is being used for carbon storage or is part of a fragile ecosystem.

Intensify ecological agriculture in highly-intensive production areas. The government is seeking to promote ecological agriculture in a number of different ways. First, it will begin implementing projects to prevent and control agriculture non-point source pollution and extend technologies concerning the reasonable use of chemical fertilizers and pesticides to improve the farmland quality and reduce carbon emissions. Second, agricultural officials are seeking ways to implement a new round of soil fertility programs. These programs are focused on teaching farmers how to better manage fertilizer application and promote the increased use of organic fertilizer as a means of increasing soil fertility and reducing emissions of nitrous oxide.

One example of government work in this area is the Green for Grain Program. The program began in 1999, and is one of the world's most ambitious conservation set-aside programs. From 1999 to 2006, the accumulated cultivated land that has been shifted to forestry under this program was 24.3 million hectares, nearly 19 percent of total cultivated land in China (NSBC, 2007). The marginal nature and lower productivity of lands enrolled in the program meant that total agricultural output experienced only a modest decrease (Xu et al., 2006). The main idea of this program is to retire land that has the highest potential of contributing to soil erosion. This program has improved the ecological environment and enhanced the region's resilience to natural disasters such as flooding and drought. Grain for Green may also lead to increased productivity on existing land by inducing additional investment and intensification of production on land best suited for growing crops (Xu et al., 2006).

Enhance the development and transfer of new technologies. The government believes it is important to both develop new technologies and improve access to the latest technological advancements. Accordingly, they will support research that seeks to select and breed rice varieties with high yields and low GHG emission rates, such as semi-dry rice cultivation technology. China's Ministry of Science and Technology (MOST) and the Ministry of Water Resources are also funding research on methods of irrigation that will reduce emissions. There are also programs to develop micro-organism technology to reduce methane emissions from rice paddies and enhance/refine the technologies for household-type biogas digesters. Additionally, agronomic technologies such as effective utilization of crop residues are being promoted. China also knows that there is a need to develop and extend key technologies that will produce environmentally sound fertilizers that reduce nitrous oxide emissions from cropland. Finally, efforts are needed to develop and promote low- and no-tillage technologies that can be used to increase carbon storage in croplands.

China also knows that there is a need to develop and extend key technologies that will produce environmentally sound fertilizers that reduce nitrous oxide emissions from cropland.

6.3 Practical Mitigation Actions

Increasing fertilizer use efficiency. In China, fertilizer use efficiency is low: fertilizer use for wheat is 220 kg per ha in China, while the world average level is only 127 kg per ha (IFA et al., 2002). Usage for maize and paddy is also much higher than world average levels. Due to overuse, a large share of fertilizer cannot be absorbed by the crops that are in the ground. Much of the nutrients are lost to the environment. Researchers show that if farmers were to apply the site specific nutrient management technology, the use of fertilizer could be cut about 20-30 percent (Peng et. al., 2006, Hu et. al., 2008; Huang et. al., 2009). Huang et al., (2009) show that farmers' lack of knowledge on crop yield response is a major reason for their overuse of fertilizer in China. In addition, improving fertilizer efficiency has an abatement potential of 40 megatons of CO_2e (McKinsey & Company, 2009). More importantly, it is possible that this could come at a low or even a negative cost. If the reduction in fertilizer did not reduce yields, then it would be a win-win situation. Considering the potential benefit of reducing fertilizer use, the Ministry of Agriculture in 2005 began promoting site-specific fertilizer use technology through agricultural extension system aimed at calibrating fertilizer dosage according to soil characteristics and type. If such technologies become more widespread, fertilizer efficiency could be improved by up to 5 percent without negatively impacting crop output.

Researchers show that if farmers were to apply the site specific nutrient management technology, the use of fertilizer could be cut about 20-30 percent

Changing from traditional to conservation tillage. Conservation tillage (CT) has been highlighted in several studies as an important technique to create carbon sinks (Lal et al. 1999; ECCP, 2003; Barker et al. 2007). Despite the widespread adoption of CT technology in other countries such as the US, Canada and Brazil, adoption in China is relatively low. Wang et al. (2009c) found that in the mid-2000s, the adoption rates of the full CT technology package, which includes both no/reduced tillage and residue retention together, was only around 1 percent. Although the adoption of partial CT technology (*either* no/reduced tillage *or* residue retention) in China is higher and rising steadily, it is not widespread enough to become a true technological force. Since the early 2000s, the central government has promoted the adoption of CT and established demonstration pilot projects in more than 10 provinces. According to Wang et al. (2009c), if the government decided the environmental benefits were great enough, they might consider offering a subsidy to those that adopt CT practices in the future. In addition, policies are needed that nudge farmers toward the technology, such as regulations that ban residue burning. If there are initiatives to extend CT technology, more farmers will likely adopt these methods.

Extending intermittent irrigation and adopting new seed varieties for paddy fields. Emissions from rice paddy fields are one of the major sources of methane gas emissions in China. Research has demonstrated that irrigation methods used and the varieties that are planted are the two key determining factors that influence the rate of methane emissions from paddy fields (Dong et al., 2008). Studies have found that compared with flood irrigation, adoption of intermittent irrigation can reduce methane emissions between 30 and 46 percent (Wang et al., 1998;

Wang, 2001; Li et al., 1998). The Ministry of Water Resources and the Ministry of Agriculture have both supported the expansion of intermittent irrigation over the past decade. In addition to irrigation methods, adoption of certain seed varieties can substantially reduce methane emissions (Huang, 2006). Other researchers have found that hybrid rice varieties can reduce methane emissions 5 to 37 percent compared with conventional varieties.

7. CONCLUSION

This report has reviewed and documented some of the likely impacts of climate change on China's agricultural production, trade and farmer income. It also has sought to provide insights into the adaptation and mitigation policies that China is promoting. In summary, there are a number of generalizations that can be drawn.

Studies by natural scientists show that climate change will have a significant impact on agriculture, primarily through affecting crop yields. The extent of the changes in yields highly depends on the crop being considered and on assumptions related to the CO_2 fertilization effect. Across all scenarios analyzed, irrigated crops are generally expected to fare better than rain-fed crops. When the CO_2 fertilization effect is considered, wheat yields increase the most. In scenarios that do not include CO_2 fertilization, rain-fed maize and rice would see the greatest declines, although yields for all crops would decrease. In addition to impacts on crop yields, China's cropping system will experience moderate changes due to climate change. Most studies predict that under climate change, both the planting and harvesting date of crops will shift because of warming temperatures. As planting seasons will be lengthened, more area will come under cultivation (mostly in northern areas). In addition, land—especially in the Yangtze River Basin—will be cultivated with increasing intensity. While few studies are available in the livestock sector, the existing literature shows evidence of negative impacts of climate change on livestock production.

Economic studies show that climate change will affect not only agricultural production, but also agricultural prices, trade and farmer income. The economic research further indicates that market response to the production shocks resulting from climate change will lessen the impacts on agricultural production predicted by natural scientists. Agricultural production is projected to decrease in China if the effects of CO_2 fertilization are not considered. When CO_2 fertilization is taken into account, the decline in rice production is less severe, and wheat and maize production actually increases. Prices increase without CO_2 fertilization in response to lower production levels, and conversely, price decrease when production increases due to CO_2 fertilization.

China's trade in grains will in turn be affected by changes in production and price levels. As prices increase and production decreases in the scenarios without the CO_2 fertilization effect, Chinese exports will decrease and imports will increase to help stabilize domestic availability. In response to the increased production and falling prices under the CO_2 fertilization scenarios, exports will increase and imports will decrease. China's self-sufficiency in the crops considered here will not change significantly under any of the scenarios: China will remain a net exporter of rice and wheat (with the exception of wheat under scenario S1) and remain a net importer of maize. Analysis of the effects of climate change on rural incomes indicates that higher temperatures will decrease incomes but more precipitation will increase incomes. Rain-fed farmers are predicted to be more adversely affected than irrigated farmers, and impacts on income also vary widely by region and by season.

China's government will have to make a great effort in response to climate change. The government must promote policies and invest funds in adaptation. In addition, it must focus regulatory and legislative efforts, as well as investment activities, on mitigation. Much has already been done—both in terms of planning and implementation of responses. On adaptation, the government strategy is threefold. First it will seek to support the development of new technologies and identify additional measures to deal with future climate change. Second, the government needs to reform China's extension system to improve the access to knowledge by local people. Third, the government needs to enhance institutional awareness, capacity and cooperation.

Finally, we have shown that when given the right incentives, farmers do adapt, but changes implemented by farmers cannot fully offset the negative impacts of climate change. Farmers choose crops carefully and appropriately, help with investments in irrigation when possible (and when needed), and adopt water saving technologies and low till technologies when the incentives are right. Working with farmers by setting an enabling policy environment is the number one role of governments. The government should ensure that it fulfills this function in the areas of climate change adaptation and mitigation.

REFERENCES

Barker, T., Bashmakov, I., Bernstein, L., Bogner, J.E., Bosch, P.R., Dave, R., Davidson, O.R., Fisher, B.S., Gupta, S., Halsn, K., Heij, G.J., Ribeiro, S.K., Kobayashi, S., Levine, M.D., Martino, D.L., Masera, O., Metz, B., Meyer, L.A., Nabuurs, G.-J., Najam, A., Nakicenovic, N., Rogner, H.-H., Roy, J., Sathaye, J., Schock, R., Shukla, P., Sims, R.E.H., Smith, P., Tirpak, D.A., Urge-Vorsatz and D., Zhou, D., 2007. Technical Summary. In: Metz, B., O., R.D., Bosch, P.R., Dave, R., Meyer, L.A. (Eds.), Climate Change 2007 Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK and New York, NY.

Blanke, A., S. Rozelle, B. Lohmar, J. Wang and J. Huang, 2007. Water Saving Technology and Saving Water in China, *Agricultural Water Management,* 87(2007): 139-150.

Deng, K., H.Jui, X.Wei and X. Yang, 2006. Research Progress on the Impacts of Climate Change on China's Agriculture, Chinese Agricultural Science Bulletin, Vol.22 No. 5 2006 May: 439-441.

Dong, H., Y. Li, X. Tao, X. Peng, N. Li, and Z. Zhu, 2008. China's Greenhouse Gas Emissions from Agricultural Activities and Its Mitigation Strategy, Transactions of the CSAE, 2008, 24 (10): 269-273.

ECCP, 2003. European Climate Change Programme (ECCP). Working Group Sinks Related to Agricultural Soils. Final Report: 75.

Hu, R., J. Cao, JK. Huang, S. Peng, JL. Huang, X. Zhong, Y. Zou, J. Yang g, R. J. Buresh, 2007. Farmer participatory testing of standard and modified site-specific nitrogen management for irrigated rice in China, *Agricultural Systems,* 94(2007): 331-340.

Huang, J., R. Hu, J. Cao, and S. Rozelle, 2008. Training Programs and in–the–field Guidance to Reduce China's Overuse of Fertilizer Without Hurting Profitability, *Journal of Soil and Water Conservation,* Vol. 63, No. 5 (2008): 165-167.

Huang, Y., 2006. Emission, Mitigation and Strategies of Greenhouse Gases in China, *Research on Quaternary Period,* 26 (5): 722-732.

Huang, J. and J. Yang, 2005. China's Rapid Economic Growth and Its Implications for Agriculture and Food Security in China and the Rest of World, Report Submitted to Food and Agriculture Organization of United Nations (FAO).

IFA et al., 2002. Fertilizer Use by Crop. Rome: International Fertilizer Industry Association (IFA), International Fertilizer Development Center (IFDC), International Potash Institute (IPI), Phosphate and Potash Institute (PPI), and Food and Agricultural Organization of the United Nations (FAO).

IPCC, 2007. A Report of Working Group One of the Intergovernmental Panel on Climate Change — Summary for Policy Makers. Intergovernmental Panel on Climate Change.

Ju, H., D. Conway, Y. Li, A. Harvey, L. Erda and S. Calsamiglia-Mendlewicz, 2008. The Impacts of Climate Change on Chinese Agriculture — Phase II, Adaptation Framework and Strategy Part 2: Application of the Adaptation Framework: A Case Study of Ningxia, Northwest China, Report to DEFRA (now DECC) and DFID, ED02264, Issue 2, October 2008.

Lal, R., Kimble, J.M., Follet, R.F., Cole, C.V., 1999. The Potential of U.S. Cropland to Sequester Carbon and Mitigate the Greenhouse Effect. Lewis Publishers, Boca Raton, USA, ISBN: 1-57504-112-X: 128.

Leggett, J. A., J. Logan, A. Mackey, 2008. China's Greenhouse Gas Emissions and Mitigation Policies, CRS Report for Congress, Congressional Research Service, http://www.fas.org/sgp/crs/row/RL34659.pdf.

Li, J., M. Wang and D. Chen, 1998. Methane Mitigation Approaches and Assessment in the Paddy Field in China, *Atmospheric Science,* 22(3): 354-362.

Lin, E. et al., 2006. National Assessment Report of Climate Change (II): Climate Change Impacts and Adaptation. Advances in Climate Change Research, 2006. 2(2): 51-56.

McKinsey & Company, 2009. China's Green Revolution: Prioritizing Technologies to Achieve Energy and Environmental Sustainability, Designed by New Media, Australia.

NDRC (National Development and Reform Commission), 2007. China's National Climate Change Program, National Development and Reform Commission, People's Republic of China, Beijing.

NSBC (National Statistical Bureau in China), 2007. Statistical Yearbook in China, National Statistical Bureau, Beijing.

Peng, S., R.J. Buresh. J. Huang, J. Yang, Y. Zou, X. Zhong, G. Wang, F. Zhang, 2006. Strategies for overcoming low agronomic nitrogen use efficiency in irrigated rice systems in China. *Field Crops Research,* 96(2006): 37-47.

PRC (People's Republic of China), 2008. China's Policies and Actions for Addressing Climate Change, State Council Information Office of the People's Republic of China, Beijing.

PRC (People's Republic of China), 2007. China's National Assessment Report on Climate Change. Beijing: Science Publishing House.

Ren, G., 2007. *Climate Change and Water Resources in China,* China Meteorological Press, Beijing.

Rosenthal, E., 2008. China Increases Lead as Biggest Carbon Dioxide Emitter, *New York Times,* June 14, 2008.

Su, W., 2010. "Communication of China's Autonomous Domestic Mitigation Actions." Submitted to the UNFCCC. http://unfccc.int/files/meetings/application/pdf/chinacphaccord_app2.pdf.

Tor, R., 1995. The damage costs of climate change: towards more comprehensive estimates. Environmental and Resource Economics, 5: 353-374.

Wang, J., J. Huang and J. Yang, 2009a. Climate Change, Water Security and Agricultural Development in 3H Region. Report Submitted to the World Bank *(in draft).*

Wang, J., J. Huang, S. Rozelle, Q. Huang and L. Zhang, 2009b. Understanding the Water Crisis in Northern China: What Government and Farmers are Doing, International Journal of Water Resources Development, Vol. 25, No. 1, 141–158, March 2009.

Wang, J., L. Zhang, J. Huang and S. Rozelle, 2009c. Adoption of Conservation Technology in the Yellow River

Basin: Empirical Research on the Determinants, Resources Science, 31 (4): 641-646.

Wang, J., R. Mendelsohn, A. Dinar, J. Huang, S. Rozelle and L. Zhang, 2008a. The Impact of Climate Change on China's Agriculture, Agricultural Economics, 40 (2009) 323-337.

Wang, J., R. Mendelsohn, A. Dinar and J. Huang, 2008b. How China's Farmers Adapt to Climate Change? World Bank Policy Research Working Paper, 4758.

Wang, J., J. Huang, S. Rozelle, Q. Huang and A. Blanke, 2007. Agriculture and Groundwater Development in Northern China: Trends, Institutional Responses, and Policy Options, Water Policy, 9 (2007), No S1: 61–74.

Wang, Z, 2001. Methane Emissions in the Paddy Field in China, Science Publishing Press, Beijing: 216-219.

Wang, Z., Y. Xu and Z. Li, 1998. Emission and Control of Methane in the Paddy Field in China, *Crop Magazine,* 3: 10-11.

World Resources Institute, 2010. Climate Analysis Indicators Tool (CAIT) version 7.0. Washington, DC. Available at http://cait.wri.org.

Xiong, W., D. Conway, Y. Xu, J. H, S. Calsamiglia-Mendlewicz and L. Erda, 2008. The Impacts of Climate Change on Chinese Agriculture – Phase II, National Level Study: The Impacts of Climate Change on Cereal Production in China, Report to DEFRA (now DECC) and DFID, ED02264, Issue 2, October 2008.

Xu, Zhigang, Jintao Xu, Xiangzheng Deng, Jikun Huang, Emi Uchida and Scott Rozelle, 2006. Grain for Green versus Grain: Conflict between Food Security and Conservation Set-Aside in China, World Development 34(1): 130-148.

Zhang, J., G. Wang, 2007. *Impact Research of Climate Change on Hydrology and Water Resources,* Science Publishing House, Beijing.

Zhang, L., R. Luo, H. Yi and Stephen Tyler, 2008. Climate Adaptation in Asia: Knowledge Gaps and Research Issues in China, Final Report to IDRC and DFID, Digiscan Pre-press, Kathmandu, Nepal.

TABLES AND FIGURES

Table 1: Impacts of climate change on crop yields under various climate scenarios

Scenarios			Rice		Maize		Wheat	
			Rain-fed	*Irrigated*	*Rain-fed*	*Irrigated*	*Rain-fed*	*Irrigated*
A2	With CO_2 fertilization	2020s	2.1	3.2	9.8	-0.6	15.4	13.3
		2050s	3.4	6.2	18.4	-2.2	20.0	25.1
		2080s	4.3	7.8	20.3	-2.8	23.6	40.3
	No CO_2 fertilization	2020s	-12.9	-8.9	-10.3	-5.3	-18.5	-5.6
		2050s	-13.6	-12.4	-22.8	-11.9	-20.4	-6.7
		2080s	-28.6	-16.8	-36.4	-14.4	-21.7	-8.9
B2	With CO_2 fertilization	2020s	0.2	-0.4	1.1	-0.1	4.5	11
		2050s	-0.9	-1.2	8.5	-1.3	6.6	14.2
		2080s	-2.5	-4.9	10.4	-2.2	12.7	25.5
	No CO_2 fertilization	2020s	-5.3	-1.1	-11.3	0.2	-10.2	-0.5
		2050s	-8.5	-4.3	-14.5	-0.4	-11.4	-2.2
		2080s	-15.7	-12.4	-26.9	-3.8	-12.9	-8.4

SOURCES: Xiong, et al., 2008.

NOTE: 1) A2: a very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines;

2) B2: a prosperous and fair world which, as a result of a general orientation towards sustainable development, features relatively low GHG emissions.

TABLE 2: The impacts of climate change under the A2 scenario on production and prices of three major crops in China under different scenarios (relative to 2030 reference scenario)

	Without CO2 Fertilzation Effect		Without CO2 Fertilzation Effect	
	Only climate change in China	*Climate change in both China and the rest of the world*	*Only climate change in China*	*Climate change in both China and the rest of the world*
	S1	S2	S3	S4
Impacts on Production				
In Thousand Tons				
Rice	-6158	-4889	-4889	-115
Wheat	-4620	-3667	5436	5963
Maize	-12669	-880	5135	5135
In Percentage (%)				
Rice	-5.6	-4.5	-0.1	-0.3
Wheat	-5.0	-4.0	5.9	6.5
Maize	-5.1	-3.6	2.1	2.7
Impacts on Prices (%)				
Rice	14.4	17.6	-1.6	-2.0
Wheat	12.5	15.9	-11.7	-11.4
Maize	6.9	10.9	-3.6	-3.4

SOURCES: Wang, et al., 2009a.

TABLE 3: The impact of climate change under the A2 scenario on exports, imports and self-sufficiency of three major grains in China under different scenarios (relative to 2030 reference scenario) (thousand tons)

	Without Considering CO_2 Fertilzation Effect		Considering CO_2 Fertilzation Effect	
	Only climate change in China	*Climate change in both China and the rest of the world*	*Only climate change in China*	*Climate change in both China and the rest of the world*
	S1	S2	S3	S4
Impacts on exports and imports				
Exports				
Rice	-1949	-116	301	-127
Wheat	-847	-111	826	1363
Maize	-394	-174	227	339
Imports				
Rice	185	59	-13	0
Wheat	959	101	-601	-794
Maize	9742	4811	-3725	-5298
Impacts on self-sufficiency (%)				
Rice	-2.0	0.0	0.3	-0.1
Wheat	-2.0	-0.2	1.5	2.2
Maize	-3.9	-2.0	1.6	2.2

SOURCES: Wang, et al., 2009a.

NOTE: in 2007, China exported 1.36 million tons of rice, 3.07 million tons of wheat, and 4.92 million tons of maize. In the same year, China also imported rice (0.49 million tons), wheat(101 thousand tons), and maize (35 thousand tons).

TABLE 4: Marginal impacts of climate change on crop net revenue

	All Farms	Irrigated Farms	Rain-fed Farms
Temperature (USD/ha/C)			
Spring	-230**	-49*	-143**
Summer	76*	286	-15***
Fall	-29	-458*	-68*
Winter	173**	288**	130**
Annual	**-10***	**68***	**-95****
Annual Elasticity	**-0.09***	**0.62***	**-0.88****
Precipitation (USD/ha/mm/mo)			
Spring	-19**	-22*	-6
Summer	-2	11*	-5*
Fall	-1*	-21**	-4*
Winter	36**	59*	38**
Annual	**15***	**27***	**23***
Annual Elasticity	**0.80***	**1.48***	**1.24***

SOURCE: Wang et al., 2008.
** denotes significant at 10%, ** denotes significant at 5% level*
Yuan converted to 2006 USD using exchange rate of 8 Yuan/USD. We wanted to allow easy comparison of marginal impacts with studies in other countries.

TABLE 5: Nitrous oxide (N_2O) emissions from agricultural activities in China in 1994

Emission Sources	Emission Volume (1000 tCO_2e)	Percentage of Total N_2O Emissions in Agricultural Sector (%)	Percentage of Total N_2O Emission in China (%)
Fertilizer use	628	79.8	55.8
Pasture	110	14.0	12.9
Burning livestock waste	1	0.1	0.1
Management system of animal waste	44	5.6	5.2
Burning crop residues	4	0.5	0.5
Total	**786**	**100**	**92.5**

SOURCE: Initial National Communication on Climate Change of the People's Republic of China

TABLE 6: Methane (CH_4) emissions from agricultural activities in China in 1994

Emission Sources	Emission Volume (1000 t)	Percentage of Total CH_4 Emissions in Agricultural Sector (%)	Percentage of Total CH_4 Emission in China (%)
Ruminant animals	10182	59.2	29.7
Paddy field emissions	6147	35.8	17.9
Management system of animal waste	867	5.0	2.5
Total in agricultural sector	**17196**	**100**	**50.2**

SOURCE: Initial National Communication on Climate Change of the People's Republic of China

FIGURE 1: Marginal Temperature Effect, Irrigated Farms

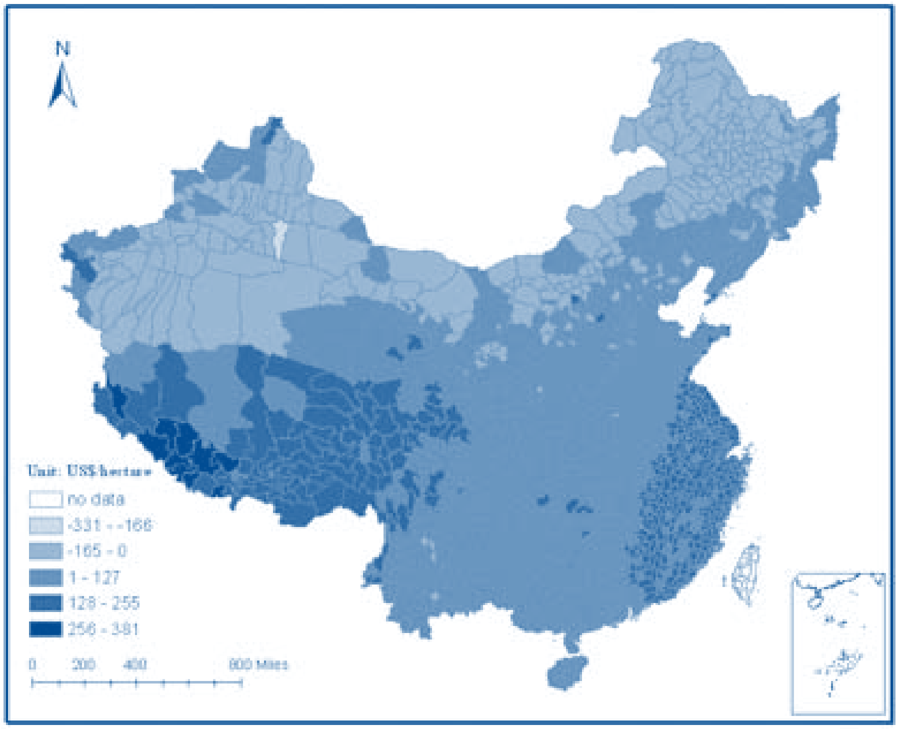
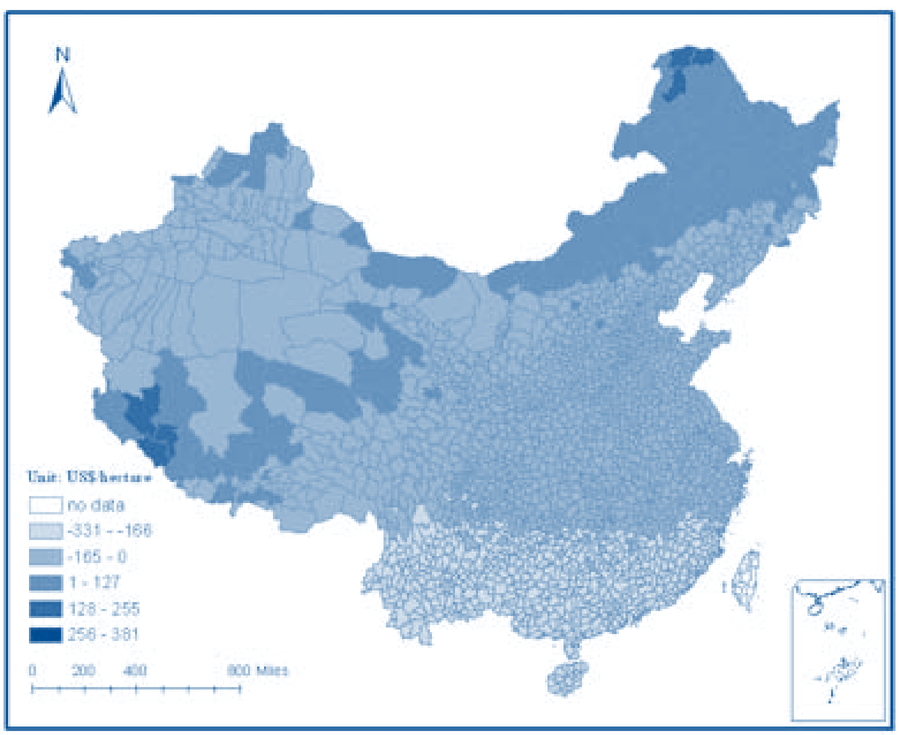


FIGURE 2: Marginal Temperature Effect, Rain-fed Farms



APPENDIX TABLE 1: Agricultural production, trade, prices and self-sufficiency in China in 2006 and 2030 under reference scenario

	Rice	Wheat	Maize
2006 (Base Year)			
Production (million tons)	127.9	105.1	147.8
Price (yuan/kg)	3.01	2.52	2.22
Export (million tons)	1.10	1.73	5.55
Import (million tons)	0.58	1.42	0.03
Self-sufficiency (%)	101	100	104
2030 (Reference Scenario)			
Production (million tons)	109.5	92.1	246.8
Price (yuan/kg)	2.08	2.01	1.92
Export (million tons)	4.7	2.6	2.9
Import (million tons)	0.2	2.1	23.4
Self-sufficiency (%)	104	101	92

DATA SOURCES: Simulated by CAPSiM model by authors.

APPENDIX TABLE 2: Agricultural sector greenhouse gas emissions from agricultural sector in selected countries (percentage of total emissions)

	1995	2005
Australia	21.8	19.7
Brazil	58.5	58.4
China	21.8	15.4
European Union	10.5	10.0
India	25.7	21.6
New Zealand	54.1	48.1
United States	6.8	6.4
World	17.0	16.1

SOURCE: CAIT v 7.0, World Resources Institute 2010.

About the Platform

In 2008 the International Food & Agricultural Trade Policy Council (IPC) and the International Centre for Trade and Sustainable Development (ICTSD) launched The ICTSD-IPC Platform on Climate Change, Agriculture and Trade. This interdisciplinary platform of climate change, agricultural and trade experts seeks to promote increased policy coherence to ensure effective climate change mitigation and adaptation, food security and a more open and equitable global food system. Publications include:

- International Climate Change Negotiations and Agriculture.
  Policy Brief No. 1, May 2009

- Greenhouse Gas Reduction Policies and Agriculture: Implications for Production Incentives and International Trade Disciplines.
  Issue Brief No. 1, by D. Blandford and T. Josling, August 2009

- Climate Change and Developing Country Agriculture: An Overview of Expected Impacts, Adaptation and Mitigation Challenges and Funding Requirements.
  Issue Brief No. 2 by J. Keane, S. Page, A. Kergna, and J. Kennan, December 2009

- Carbon Concerns: How Standards and Labelling Initiatives Must Not Limit Agricultural Trade from Developing Countries
  Issue Brief No. 3, by J. MacGregor, May 2010

- The Role of International Trade in Climate Change Adaptation.
  Issue Brief No. 4, by G. Nelson, A. Palazzo, C. Ringler, T. Susler, and M. Batka, December 2009

- Climate Change and China's Agricultural Sector: An Overview of Impacts, Adaptation and Mitigation.
  Issue Brief No. 5 by J. Wang, J. Huang, and S. Rozelle, May 2010

- Agricultural Technologies for Climate Change Mitigation and Adaptation in Developing Countries: Policy Options for Innovation and Technology Diffusion.
  Issue Brief No. 6 by T. Lybbert and D. Sumner, May 2010

About the Organizations

The International Centre for Trade and Sustainable Development was established in Geneva in September 1996 to contribute to a better understanding of development and environment concerns in the context of international trade. As an independent nonprofit and non-governmental organization, ICTSD engages a broad range of actors in ongoing dialogue about trade and sustainable development. With a wide network of governmental, non-governmental and inter-governmental partners, ICTSD plays a unique systemic role as a provider of original, non-partisan reporting and facilitation services at the intersection of international trade and sustainable development. More information is available at www.ictsd.org.

The International Food & Agricultural Trade Policy Council promotes a more open and equitable global food system by pursuing pragmatic trade and development policies in food and agriculture to meet the world's growing needs. IPC convenes influential policy makers, agribusiness executives, farm leaders, and academics from developed and developing countries to clarify complex issues, build consensus, and advocate policies to decision-makers. More information on the organization and its membership can be found on our website: www.agritrade.org.