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The Impacts of Climate Change on Chinese Agriculture

Hui Ju[1], Xie Liyong[1,2] and Ma Zhanyun[1,3]

[1] *Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences, Beijing, 100081*

[2] *College of Agronomy, Shenyang Agricultural University, Shenyang 110161, PR China*

[3] *Capital Normal University, Beijing 100048, PR China*

Abstract: The future climate change will most likely have adverse impacts on Chinese agriculture, especially the cropping system (CS). With a predicted temperature rise of 1.4°C and precipitation increase of 4.2% by 2050, current double cropping system (DCS) in most regions of China will be replaced by different combinations of triple-cropping system (TCS). The boundary of TCS will extend northwards as much as 500 km, from the Yangtze River Valley to the Yellow River Basin. The region of DCS will move to the central part of current single cropping system (SCS) region, and the area of SCS will decrease by 23.1%. Climate warming will also affect the layout of China's main crop varieties. In the north of China, winter wheat will be replaced by semi-winter wheat; high-temperature-resistant rice varieties will gradually extend to the northern rice area, and the early ripening varieties in the northeast will be gradually replaced by middle and late ripening varieties. If no measures are taken to adapt to these changes, by the middle of the 21st century the production of several crops, including wheat, rice and corn, will decrease by a maximum 23%, and the changes in production will vary among different regions. There will be significant reduction in the main producing region, but smaller reduction or even a slight increase in some minor regions. The production of corn and rice in the northern part of the northeastern region will increase, and so will wheat and corn in the north of northeast China, benefiting from the precipitation increase in the future. By the 2080s the production of rain-fed wheat will decrease by 23.7%, and the rain-fed rice by 12.7%, whereas the rain-fed corn will increase. Compared with the current production, the irrigated wheat, corn and rice will reduce by 20.2%, 24.7% and 5.4%, respectively. As a result of climate change, the C/N ratio of crops in China will increase and the protein content and quality will decrease. The use of pesticide and weedicide will increase due to more prevalence of crop pests, diseases and weeds. Climate warming will increase the evaporation losses during the crop growing season, and increase the need for irrigation water.

Key words: Climate change, Chinese agriculture, impacts, crop production, food security.

Global warming caused by the increasing greenhouse gas has become the focus of the whole world. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) made it clear that the global average surface temperature has risen by 0.74°C in the last 100 years (1906-2005), and 11 of the 12 warmest years since 1850 occurred during the recent years of 1995-2006 (except 1996). It is estimated by the study of multi-mode and multi-emission scenarios that, by the end of the

21st century, the increase of greenhouse gas caused by human activities will raise the earth's average surface temperature by 1.1-6.4°C, as compared to that in 1990, and the average sea level will rise by 18-59 cm. Although the estimated result has a certain degree of uncertainty, the climate change impact on human beings has been widely recognized. The four assessment reports from IPCC have clearly pointed out the impact of climate change on agriculture, with an opinion that the developing countries are more vulnerable to adverse effects, including the threat of food shortage.

China is a large agricultural country, in which hundreds of millions of people rely on agriculture for survival, and the population is still growing. The agricultural production directly relates to the social stability and sustainable development, and agriculture is one of the most sensitive fields to climate change due to China's huge agricultural population, large agricultural areas, complex geographical types and significant climate differences. Besides, weather condition has always been one of the decisive factors to influence the stability of China's agricultural production because of the agricultural resource condition and management mode in the country. Although there are still many uncertainties in research on the impacts of climate change on agriculture, it is certain that the future climate change will impact agricultural production, which is mainly negative, and will directly threaten China's food security (Zhang, 1999; Lin, 1997). For sustainable agriculture, as well as for national security and stability, it is necessary to identify the impacts of climate change on China's agricultural production, food supply capacity and food security, and to take actions to avoid or reduce the risk of climate change.

Climate Trend in China

Observed trend

The main feature of future climate change will be rising temperature. During the last 100 years the temperature in China rose by 0.5-0.8°C, particularly noticeable during the past 50 years (mainly in the middle and late 1980s). From 1951 to 2001, the overall rise in China's average annual temperature was by 1.1°C. The increase was more in the north than in the south. All four seasons have recorded an upward trend in average temperature, the most obvious being winter, followed by spring (National Assessment Report on Climate Change, 2007).

The warming leads to the increase of water evaporation, and as a result, there is a corresponding increase in precipitation. In the 20th century, the global land precipitation has increased by about 2% (Jones and Hulme, 1996; Hulme *et al.*, 1998). In the past 100 years, the annual precipitation in China did not change significantly, with only a slight reduction and certain fluctuations between years and between decades. Viewing from the seasonal changes in precipitation, there was a reduction of 27.3 mm in autumn and an increase of 20.6 mm in spring, while the changes in summer and winter were significant. During the last 50 years, precipitation increased slightly in China, with significant regional differences. There was a downward trend in annual precipitation in the eastern part of northeast

China, Huang-Huai-Hai Plain and the Shandong Peninsula, the Sichuan Basin and the Qinghai-Tibet Plateau, while an upward trend was noticed in the rest of the areas (National Report on Climate Change, 2007).

Future climate change

Compared with the year of 2000, the annual average temperature in China will increase by 1.3-2.1°C by 2020, 1.5-2.8°C by 2030, 2.3-3.3°C by 2050 and 3.9-6.0°C by 2100. The northeast and northwest regions will have the most significant increase, and the winter temperature will rise significantly. The precipitation will also increase significantly, and the rate of increase may reach 11-17% (Table 1). The northwest, northeast and southern China may witness a more remarkable increase, while the Bohai Sea coastal region and the Yangtze River estuary area may become drier. It is estimated that the country's average annual precipitation will increase by 2-3% by 2020, and 5-7% by 2050. There will be more rainy days in north China, and the number of precipitation days in the northwest, northeast and southern China may increase significantly. The spatio-temporal variation in precipitation change is large, and different models lead to significantly different results.

China's winter cold wave may continue to decrease in the 21st century, while the summer hot days may increase in some areas, and warm winter and warm summer may be seen more frequently. There will be more days of heavy precipitation in the country's southeastern and southwestern regions, and the frequency of sandstorms in northern China may be maintained at a relatively low level, or even be further reduced.

Impact of Observed Climate Change on Agriculture

Climate change affects agriculture mainly through temperature, precipitation, CO_2concentration, extreme weather/climate events, etc., which may produce different impacts in different regions and seasons. Meteorological factors will have a direct impact on the crop yield and quality through temperature, precipitation, atmospheric composition, while extreme climate will have an indirect impact through the distribution and/or frequency of the soil, plant diseases and insect pests, weeds and other related factors.

Farming system adjustment

Temperature rise so far has improved the agricultural conditions, which is obvious in China's northern region. Cold damages are reduced and planting period has been extended by the higher temperature. For example, the frequency of freezing damage (grade = 4) to apple production in Liaoning Province has reduced from 80% in the 1950s to 20% now and the degree of cold damage has significantly decreased (Li *et al.*, 2003). In Jilin province, the period of corn ripeness has been extended by 7-10 days than before, and the planting area of middle-late ripening varieties is expanding fast (Pan, 1998). Temperature rise has also improved the effective accumulated temperature for crop growth in northwestern region. Comparing 1987-2003 with 1961-1986, the active accumulated temperature in Gansu Province during the period with a daily average temperature ≥ 0°C has on an average increase by ≥161°C, while the annual and decadal values of the negative accumulated

Table 1. Future changes in temperature and precipitation in China under different scenarios (relative to the average of 1961-1990)

Period	Emission scenarios									
	A2					B2				
	Annual average	Spring	Summer	Autumn	Winter	Annual average	Spring	Summer	Autumn	Winter
Temperature										
2020s	1.4	1.5	1.4	1.2	1.4	1.5	1.8	1.5	1.4	1.5
2050s	3.0	3.2	2.7	2.6	3.3	2.7	2.9	2.4	2.4	2.9
2080s	4.9	5.4	4.5	4.4	5.5	3.6	4.0	3.3	3.2	3.9
Precipitation (%)										
2020s	1.0	4.0	0.0	-2.0	5.0	3.0	5.0	3.0	1.0	5.0
2050s	5.0	9.0	5.0	-1.0	12.0	5.0	10.0	5.0	-1.0	12.0
2080s	11.0	15.0	11.0	7.0	22.0	9.0	14.0	9.0	2.0	20.0

temperature with a temperature <0°C have also shown a warning tendency (Liu Deyang *et al.*, 2003). The fruit plants, having low resistance to cold, are becoming popular in northwestern areas. Grapes and apples, which were planted only by families on small scales in the past, are being planted on large scale, thus promoting the regional economic development of wine-making and fruit- processing (Ju *et al.*, 2007).

As the regional temperature rise conditions are changing, China's long-term agricultural production structure and planting patterns are also changing, helping multi-cropping system in the middle and high latitudes and in the high plateau regions (Xu *et al.*, 1999; Deng *et al.*, 2006). In the northeast, the annual average temperature was 5.25°C during 1961-1990, which increased by 1.38°C during 1995-1998, favoring winter wheat's expansion towards the north and west. As a result, the winter wheat planting has been expanded from Dalian and Liaoning to Shenyang. The cold damages have been reduced and the cultivated area of late maturing varieties has expanded. In the 1990s, the total grain production in the northeast area was two times more than that before early 1980s, which partly benefited from the climate warming (Wang *et al.*, 2003). During the period 1986 to 1995, the multiple-cropping index of China's arable land has increased by 9.5%. In the northeastern region it reached 102% (Du *et al.*, 2007). Over the past 20 years, the area under rice in Heilongjiang Province has expanded rapidly, and the areas where rice could not be planted earlier because of the temperature limit, such as Yichun and Heihe, can now be planted with rice (Pan *et al.*, 2002).

Although the temperature rise is providing more heat resources for agricultural production, there are many adverse effects, and some traditional technologies are losing their previous advantages. For example, the winter on-farm irrigation in the northern region used to prevent plant diseases and insect pests, and preserve soil moisture and loosen soil for the next year's planting. With the rise in temperature, watering in winter has gradually diminished but the depletion of water resources has become faster as the evaporation of soil moisture is increasing. In the northwestern areas where evaporation is higher than precipitation, even if there is heat improvement, water availability will remain a major constraint for cropping.

Agro-environment degradation

Water availability: The warming is leading to a more serious gap between water supply and demand, as drying trend is evident in the northern region (Yan, 2000; Lin, 2001). Due to the temperature rise, snow melting is earlier, and the rainy season is shifting to earlier dates, so the summer drought is now more serious. This is more severe especially in the arid and semi-arid regions of northern China (Ye *et al.*, 2006). Over the past 20 years, soil moisture in China's Loess Plateau has declined, the warming and drying of north China is evident, and the decreased availability water in the northern region is more widespread (Chen and Dong, 2008; Ju *et al.*, 2007).

Presently, 300 million mu (Chinese unit of area, equal to 666.7 m^2) of farmland in China is suffering from drought, 1.4 billion mu of grassland lacking water, and 40 million people and 30 million livestock have drinking water problem. The dryness and warming will further exacerbate the situation, causing a more obvious gap between the supply and demand of water resources in the north, northwest and northeast regions of China. The grassland of Inner Mongolia is experiencing a warming trend over the past 20 years, especially a temperature rise in winter and an intensified drought in spring, as a result of which productivity and grazing capacity of grassland has decreased significantly (Li *et al.*, 2003). In the middle and late 1990s, the dry-river problem occurred in lower reaches of the Yellow River, and it is estimated that area under irrigation will be reduced by over 1% and the grain production will be significantly reduced if the amount of available water is reduced by 1%. Agricultural production in the north, which is already short of water, faces more difficulties. Meanwhile, the flood-affected area has increased over the past 10 years in southern China, e.g., Yangtze Valley flood in 1998 and Huaihe River Valley flood in 2003 (Ye *et al.*, 2006).

Soil fertility: One of the consequences of warming and increased evaporation, has been soil salinization and desertification in arid and semi-arid areas. The inappropriate irrigation has resulted in secondary salinization of extensive area, causing a decline in productivity of farmland and increasing desertification (Wang *et al.*, 2001).

There has also been increased activity of soil microbes, higher loss of organic matter and nitrogen, accelerated soil degradation and erosion process, which have weakened the agricultural ecosystem's ability to withstand natural disasters (Tian, 2001). In the last 20 years, sandstorm has become more evident and serious in the grassland of Inner Mongolia, where the farmland and pasture, are often buried, causing a decline in grassland productivity and grazing capacity, and serious losses to animal livestock industry. The drought in the northeast has caused soil salinization and desertification in parts of the region, and reduced the environmental quality of agricultural production. The unique topography and climate of China's southwestern mountain areas has resulted in frequent natural disasters, serious soil erosion, a decline in soil quality, a great loss of soil fertility, and a serious drop in grain production. There is an annual reduction of 4.9 million tons of grain due to soil erosion from the sloping farmland in Sichuan Province, which has seriously affected the development of the local agricultural economy.

Pests and diseases: Climate warming would aggravate the epidemic diseases and insects as well as the spread of weeds. At present, some diseases and pests, which were never or seldom seen before have been reported in northern China, and there has been an increase in the number of species, quantity, and area, especially in spring and autumn. Temperature rise in winter makes it easy for many pests and pathogens in the north to survive through winter, leading to a larger basic number of insects and pathogens. It also shifts the on set of infestation of the pests to an earlier date, and delays their winter dormancy period. Thus there are more generations of pests in a year, which increases the probability of repeated damages of the farmland. The increased CO_2 concentration leads to a decline of nitrogen for the plants, forcing pests to eat more to meet their physical needs for protein. Changing crops and increasing multiple cropping indices may be more conducive to the spread and damage caused by pests and pathogens. For example, the 1987 large-scale outbreak of rice plant hopper in Yangtze River Delta had a close relation to the early warm winter and little rainfall in the south. In addition, the temperature rise has significant impact on the breeding, wintering, migration and other habits of crop pests, which expands the geographical scope of diseases and insects of crops and livestock.

Extreme events intensity and frequency

Extreme climate events are causing substantial reduction in agricultural production in China and the fluctuations in grain yields. Every year, about 50 million hectares area and a population of 400 million in China are affected by various meteorological disasters, causing an average economic loss of over than RMB 200 billion Yuan, equivalent to 1.0-3.0% of the gross domestic product.

Of the meteorological disasters, drought has the greatest impact, followed by flood and hail storms. According to the 1950-2001 drought statistics, China's average annual drought-hit areas are more than 20 million hectares. The annual loss of grain due to drought is more than 14 million tons, accounting for 4.7% of the grain output of the same period (Cheng, 2000). Early in 2008, a rare freezing rain and snow disaster happened in the middle and lower reaches of the Yangtze River to the Jiangnan regions when the largest number of consecutive low-temperature days, the largest amount of continuous snowfall and the largest number of consecutive frozen days were recorded since 1951. The probability of such a disaster is once in 100 years (Wang *et al.*, 2008). According to the statistics of China Ministry of Civil Affairs, the freezing rain and snow disaster of 2008 affected a population of 100 million, with a direct economic loss of over RMB 150 billion Yuan, which is the most serious in the category during the past 50 years.

Extreme climate damages have impacts on heat resources, crop planting schedules and patterns, crop diseases, pests and weeds, crop growth, yield and quality, and also the threat of desertification, salinization, etc. (Wei *et al.*, 2007). Extreme climate also poses deadly hazards on livestock production. The general livestock mortality in China's pastoral area is around 5%, but in the years with cold wave, blizzard, rapid cooling, and other disasters, the rate can be as high as 24%.

Future Impacts of Climate Change on Agriculture

Fertilizer and pesticide application

Climate change will alter the requirement of fertilizer, and climate warming will lead to a larger emission of available nitrogen. Fertilizer effect is very sensitive to the change of temperature. Between 15-28°C, the available nitrogen emission will increase by about 4% with 1°C temperature rise, and the emission period will be shortened to 3.6 days; the application amount of N will be increased by about 8% and 16% along with 2°C and 4°C temperature increases, respectively (Yan, 2000). Therefore, to maintain the existing fertilizer efficiency, the fertilizer requirement will increase, which not only requires farmers to invest more on fertilizer, but also poses a harmful effect impact on the soil and environment because of the volatilization, decomposition, and contamination of groundwater.

China's current agricultural losses caused by pests and diseases accounts for about 20-25% of the total agricultural output value, and the future climate change will significantly increase the infestation of crop pests and diseases. Warmer winters will increase the incidence and area of plant diseases and insect pests (Shi Peijun *et al.*, 1997). The crops might also suffer heavier damages because of the extension of the period conducive for pest and disease infestation in a year (EPA, 1995). For example, after the CO_2 doubling, the generation of armyworm in a year will double, too. In the aestivation regions of wheat yellow stripe rust in Qinghai, Gansu and Sichuan Province, temperatures increase more in winter than in summer, which will be conducive to the wheat yellow stripe rust to survive the winter and summer, and spread southwards. Besides, the spread of weeds will be more severe, which means more pesticides and weedicides need to be applied.

Irrigation regime

Climate warming may increase the surface evaporation, change regional precipitation and precipitation distribution, and intensify the conflict between the supply and demand of water resources. Due to climate warming, China's agricultural and pastoral areas will lose more water losses. The evaporation in agricultural and pastoral areas will increase by 5% to 10% if the surface temperature rises by 1°C (Zhu, 1996). Although climate change in some areas may lead to increased precipitation, the soil moisture will eventually reduce by about 11% because of increased evaporation (She, 1997), and the agricultural irrigation water demand will increase significantly, especially in arid and semi-arid areas. It is estimated that China's irrigation water consumption will be increased by 10% for each 1°C increase in temperature (Liu, 2002; Deng, 1996).

Climate change will increase China's agricultural water supply capacity in the north. As for irrigated agriculture in the arid northwest region, there will be more melting glacier water so the irrigation water supply will increase, and the irrigated area will be expand. However, if the glaciers shrink and there is less melting, the irrigated agriculture will suffer from dwindling water sources (Kong *et al.*, 2002). As for North China's Huang-Huai-Hai Plain, a reduction of 20% in annual rainfall will increase the irrigation needs by 66-84%. This will be a huge pressure in an already scarcity zone (Zhang *et al.*, 1993).

Future climate warming could increase the potential evapotranspiration in crop growing season, exacerbate the evaporation of soil, and reduce the effectiveness of soil moisture. Therefore, more irrigation water will be required, and the conflict between water supply and demand will be intensified. A considerable portion of China's agricultural area is located in the north, where the amount of water is relatively small. Due to the limited supply of water resources and more agricultural water requirement as a result of climate warming, it is bound to lead to the over-use of the surface and underground water resources, which may disturb the normal water cycle, and result in an uneven distribution of water resources, thus affecting agriculture, livestock husbandry, fisheries and other sectors.

Farming system and planting area

China has a variety of cropping systems. With the exception of the northeast and northwest regions, which are mainly dominated by single cropping system (SCS), most of the agricultural areas give priority to the multi-cropping systems (including inter-cropping and multiple cropping). A study on impacts of climate change on Chinese agriculture showed that, when the annual average temperature increases by 1°C, the continuous days with ≥10°C accumulated temperature will extend by 15 days or so, and the crop-growing areas will move northwards (Yang *et al.*, 2005). According to predictions through the synthetic models of global socio- economic scenario IS92a and 7 future climate scenarios of GCM, the temperature by 2050 in China will rise by 1.4°C compared with the standard period of 1951-1980, and the precipitation may increase by 4.2% (Hulme, 1992). China's area of single cropping will be reduced from the current 62.3% to 39.2%, the area of double cropping will be shifted from 24.2% to 24.9%, and the area of triple cropping will be increased from 13.5% to 35.9% (Wang, 2002). Climate warming will make the season suitable for crops growing earlier than expected in the north of the Yangtze River, especially in the mid-latitude and high altitude areas, and will delay the date of termination, so the potential growing season of agricultural production will be extended (Lin Erda, 1997). As a result, climate change may increase China's multi-cropping systems.

If we only analyze a single factor of temperature or precipitation, climate change may play a certain role in promoting the adjustment of agricultural planting structure, because climate warming will improve the current conditions of heat, and the increase in precipitation can alleviate drought in some areas. But in practice, when making the agricultural structure adjustment in accordance with the climate change, a detailed analysis of advantages of climate change is required, including the matching condition of the water and heat during crop growing period, and the problem of whether the precipitation increase could make a compensation to increased evaporation caused by warming, and so on.

Crop production

Rice, wheat, corn are China's three major grain crops, and their production has a direct bearing on China's food security. The main concern about the impacts of China's climate change on agriculture, is the production of grain crops (Yan *et al.*, 2000; Zhang, 2001).

Under the 2030 climate change scenarios generated by three GCM equilibrium models[1] (GFDL, MPI and UKMOH), the winter wheat, rice and summer corn in China's irrigated areas are likely to have reduced in production by about 0.2-23.3%, 8.0-13.7% and 11.6-0.1% respectively. If combined with the output changes in other non-irrigated districts, the production of the three major crops will possibly be reduced by an average of 5 to 10% (Lin *et al.*, 1997; Wang, 2002). Applying the climate change scenarios of A2 and B2 from PRECIS[2] of the British HADLEY center and combining with the improved CERES crop model series, the latest research indicates that, if we do not consider the role of CO_2 and irrigation under the current level of technology, compared with the yield in the base year (1961-1990), the output of rain-fed wheat in China will have an average decrease of 12-20%, the rain-fed corn 15-22% and the rain-fed rice 8-14%. If we can meet the irrigation requirements, the output of wheat, corn, and rice will have smaller average reductions of 3-7%, 1-11% and 5-12%, respectively. While taking the fertilizer effect of CO_2 into consideration, the output of rice and corn will have a reduction of less than 3% under the B2 scenario; all others will have an average increase of 3-25%. As for the total output of all areas, without taking the role of CO_2 into account, wheat, rice and corn will reduce by 4-7%, 5-12% and 2-12% respectively. In the 2080s, the reduction trend of production for the three the crops will be more.

The wheat production will increase in parts of north China and in the middle and lower reaches of the Yangtze River, while in the northeast spring wheat areas and the southwest winter wheat areas it will decrease. The major areas with corn output reduction will include the central and southern part of the northeast China, central Sichuan Basin, central and eastern part of North China Plain, the lower reaches of the Yangtze River, while the northern parts of the northeast China will have significant increase. The areas with rice output reduction will mainly include most part of the Northeast Plain and North China Plain, and the vast region of Huaihe and the south of Yangtze River, while the

1 Equilibrium mode: to increase the concentration of CO_2 to two times of the pre-industrial level and to simulate characteristics of the global and regional climate change. For example, the American Geophysical Fluid Dynamics Laboratory model (GFDL), the UK Meteorological Bureau Model of High-resolution (UKMOH), and the Germany Model of Paiksbulank Institute (MPI).

2 PRECIS (Providing Regional Climates for Impacts Studies): the regional climate mode researched by the HADLEY center of UK Meteorological Bureau, and A2, B2 are different scenarios of greenhouse gas emissions.

production increase is expected mainly in the mountainous regions of Sichuan and Hubei Province. In general, with the current level of technology, China's output reduction areas in the 2080s will be mainly in the northeast, northwest and the middle and lower reaches of the Yangtze River.

However, the above trends do not consider the trend of output reduction, the fertilizer effect of CO_2, but the fertilizer effect of CO_2 and its long-term performance need further studies.

Cash crop sensitivity

China's traditional cash crops, such as cotton, soybean and peanut, play an important role in increasing farmers' income.

According to the studies based on the climate change scenarios projected by the three GCM Equilibrium models (GFDL, MPI and UKMOH), for the pyrophilous crops like cotton, climate warming will gradually replace the current varieties with the relatively late maturing types. There will be more obvious changes in variety in the middle and lower reaches of the Yangtze, the Huang-Huai region and the eastern part of Xinjiang Province. The potential of cotton production in future will be higher under the changing climate. The cotton areas in the Yellow River Valley, northern part of Yangtze River Basin and Xinjiang Province will register an increase over 35%. The cotton areas in the Liaohe River Basin, Hosi Corridor and the south part of the Yangtze River Valley will have an increase of upto 30%. However, there will be regional differences in the potential of production increase; few areas may have a downward trend in production, such as the eastern part of Xinjiang Province and the northern margin of southern Xinjiang (Lin *et al*., 1997). Applying other models like HadCM2 and ECHAM4[3], simulation studies for the years 2030 and 2056 showed that, China's cotton production, after a short-term increase; would be adversely affected by climate changes unless adaptive measures are taken, the increase in cotton production will drop back or fall down before 2050 (Song, 2004).

Under the future scenario of CO_2 rise (GFDL, MPI and UKMOH), the majority of China's soybean-producing areas will show a decline in production. With lack of irrigation, the reduction in the northeast China will be up to 15%, and there will be slight reduction of about 1-2% for the summer soybeans in the Huang-Huai-Hai Plain as well as the autumn soybeans in the south of Yangtze River and South China. With irrigation, the increase in the northern part of northeast China will be quite large, while there will be a reduction of 1-2% in the south of Yangtze River, South China, and other eastern regions. The transient models (HadCM2 and ECHAM4) also show basically the same results as that of the equilibrium model. The northeast China's soybean yield increase is more typical in Heihe, Heilongjiang Province; there are also yield reductions of different degrees in most areas such as the south of Yangtze River, etc. The extent of reduction in irrigated soybeans is less than that of rainfed

[3] Transient mode: The concentration of CO_2 changes gradually. When there are no measures taken to reduce emissions, the greenhouse gas emission rate has an annual increase of 1%, while that rate is 0.5% if measures are taken.

soybeans, indicating irrigation can mitigate the adverse impacts of climate change on soybeans. For leguminous crops, the CO_2 increase can enhance the nitrogen fixing capacity through more efficient photosynthesis, but temperature rise will reduce the nitrogen fixation and increase energy consumption during nitrogen fixation. Climate change will decrease the oil content and iodine value of the legume, while the protein content will be increased (Wu *et al.*, 2004). Therefore, in the processing of agricultural products, different qualities and characteristics need to be considered and utilized accordingly.

Under the rising CO_2 concentration the production will decline in China's major peanut growing areas. The rainfed peanuts will have an average reduction of about 4.7-6.0%; except in the northeast region, the irrigated peanuts will also have different levels of yield reductions in other growing areas, but the overall rate of reduction will be lower than in the rain-fed peanuts, which is about 2.5-4.8% (Lin *et al.*, 2007).

Livestock and fishery

According to the model-based calculation of the net primary productivity and measured ground biomass, the productivity of grassland in Inner Mongolia is declining since 1993 (Li, 2003). In the future climate change scenarios, the growth of grass will change along with the changes in temperature and precipitation, thus affecting the productive capacity of grazing animals (Shao, 1995). Researchers predict that by 2030 the weight of grazing beef cattle in Inner Mongolia will increase by 4.7% and 5.2% in the GFDL and UKMOH scenarios, respectively, and will decrease by 9.8% in the case of MPI. Different results come from different scenarios and different spatiotemporal configurations of temperature and precipitation, which affect the production capacity of forage grasses, and therefore indirectly affect the grazing cattle (Li *et al.*, 1997; Intergovernmental Panel on Climate Change, 2000). In addition, climate change will also adversely affect the production of forage crops, reduce the forage availability, and accordingly decrease livestock productivity.

Fishing ground and fishing season are directly affected by the ocean current and ocean temperature, which are closely related to the climate; therefore, the production of fishery is quite sensitive to climate change. Using the fishery model (FISH BIOENERGETICS MODEL2), the dynamic simulation of the growth of main Chinese coastal species, such as ribbon fish, small yellow croaker, and yellow croaker (Liu, 2000), indicates that changes in water temperature will directly affect the fish's growth, food intake, egg laying, migration, death, population size, etc., and will ultimately affect the quantity, quality, development and utilization of fishery resources. The productivity and catches of the main economic species in China's four major sea areas, Bohai Sea, Yellow Sea, East Sea and South Sea, will decrease to different degrees. In the scenarios of HadCM2 with an annual CO_2 rise at a rate of 1%, the reduction rate of economic fish production in the year 2030 and 2056 will be 5-15%, and the reduction rate of catches will be 1-8%.

Agricultural Vulnerability

Agricultural vulnerability and spatial distribution

China's agriculture is vulnerable. The vulnerability particularly lies in the low agricultural resources per capita and the increasing pressure of population growth. Climate change will increase the vulnerability of agriculture, change the current distribution agricultural spaces, reduce the output of major crops, deteriorate the agricultural production environment, and endanger regional food supply capacity, and so on. Due to China's various types of agro-ecosystem, there are significant differences between regions in agricultural production and economic input capacity. The current assessments of vulnerability are only some preliminary results based on current scientific and technological abilities.

Taking the irrigated land area as a measure, the northeast, northwest, and southwest areas could be more vulnerable to the severe arid climate. If measured by the land-use pattern, the northwest region is vulnerable to the future climate change; considering the current level of agricultural production, the northeast and northwest are vulnerable areas; viewing from the distribution probability of regional meteorological disasters, the north, northeast, and northwest China show vulnerability. According to farmers' economic level, which can partly reflect farmers' ability in dealing with climate change, the vulnerability of non-coastal areas is higher. Comprehensive evaluation shows that, the vulnerable regions are basically concentrated in the north and northwest China, among which Shensi province and Inner Mongolia have highest vulnerability, followed by the Gansu, Shaanxi, Qinghai, Ningxia, and Hebei Provinces (Lin and Wang, 1994). The regions with high vulnerability usually have poor natural and economic conditions and environmental problems.

Climate change will bring about additional pressure on China's agriculture and grain production. According to the estimates of China's agricultural production potential, it is possible that the food production meets the demand of 650 million tons for the peak population of 1.6 billion, but climate change increases the difficulty in reaching this target, so additional governmental investment is needed. Because of the climate change, US$ 0.8-3.48 per year will be invested as additional capital, otherwise the agricultural loss will be US$ 3.2-8.0 per year.

Food supply and demand

Rice, corn and wheat are China's three major food crops, and their production has a bearing on the country's food security.

Through a comprehensive analysis of China's economy, population, land use and other factors, Yao and He (1998) predicted that the problem of food supply and demand in China would be more serious in the future (2005-2050). Beginning from the year of 2010, there will be a widening of the gap between China's food supply and demand, and the largest gap will take place in 2040 or so, accounting for about 10% (about 68 million tons) of the food demand, For the rest of the years, the shortage may account for less than 10%. According to other estimate, this gap should be below 8% if China wants to become a moderately developed country (Wang *et al.*, 2001).

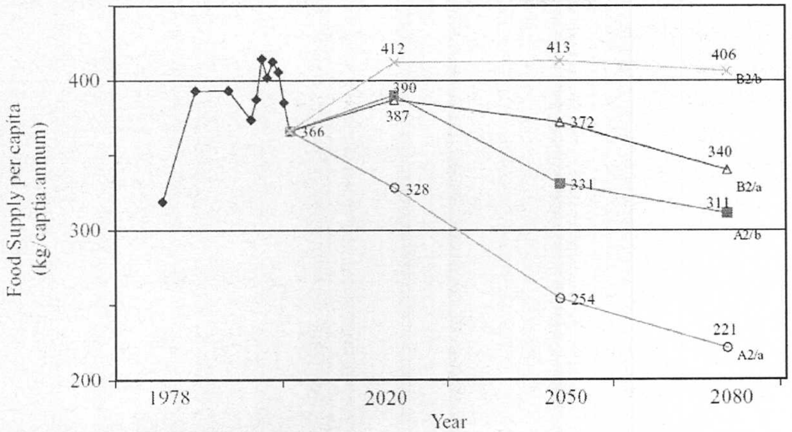

Fig. 1. The change in cereal supply per capita during 1978-2080 in China, 1978-2000 is extracted from Yearbook of China's agriculture, data from 2000 to 2080 are the results of simulation runs (a) without CO_2 direct effects; (b) with CO_2 direct effects.

However, Cai Chengzhi *et al.* (2008) hold the opinion that China's total crop yield potential will be up to 714 million tons by 2030. Together with other minor crops, the total grain demand of 659 million tons can be surely met. Without considering the CO_2 fertilizer effect and adaptive actions, the yield of China's major crops, such as wheat, corn, and rice, will continue to decline if the temperature rise in the future is 3°C (Xiong *et al.*, 2007), which will affect China's total grain output. However, if considering the fertilizer effect of higher CO_2 concentration, there is still large space of increased production for the future, among which wheat is the largest one, followed by rice; therefore, climate warming will not pose a great negative impact on China's total grain output. For example, irrigation can ease the yield decrease of the 3 major crops, lowering the reduction of corn and wheat by 5-15% and rice by 5%. If adaptive actions for fighting against adverse impacts can be taken timely and effectively, climate change will not have a significant impact on China's food supplies in the next 30-50 years (Xiong *et al.*, 2005; Xiong *et al.*, 2007; Cai Chengzhi *et al.*, 2008).

Xiong Wei *et al.* (2007) discussed the impacts of climate change on China's future food security in terms of the per capita share (Fig. 1), and two indicators of per capita food, 300 kg (basic food supply for social development) and 400 kg (food supply for social sustainable development), were used in the study for the assessment. The result shows that under the A2 scenario of high-emission, there will likely be a shortage of basic food supply for future social development in 2030; under the B2 scenario of medium and low-emissions, there will be no problem for the future basic food supply of social development, but food demand for the social sustainable development may not be met; however, if the CO_2 effect is considered, the current forecasts of warming will not have a negative impact on China's future food production. Under the A2 and B2 scenarios, the basic food security of the future social development will be guaranteed, and the climate change will not threaten China's food security, and the food supply under the B2 scenario can meet the food needs of social sustainable development.

In short, climate change will result in increased fluctuations in China's food production, the impact of which on future food production cannot be ignored. The further growth of China's future grain production capacity is facing a huge challenge. However, through the adoption of agricultural technology and the improvement of management, the agricultural adaptive measures can fully use the favorable conditions (such as heat, water, CO_2 fertilizer effect, and so on) to ease and reduce the adverse impacts of future climate change, to mitigate the pressure of demand for food and guarantee the safe supply of food.

Uncertainty of the Current Researches

Although the future climate change has become a fact acknowledged by the general public, the studies on impacts of climate change are still limited. We present in this paper a summarized report of the impacts of climate change on China's agriculture, and many aspects of the study still need further investigation and confirmation, including the compensative effect of technology advances, the utilization of new crop varieties, the adjustment of crop cultivation by social needs, and so on. Meanwhile, there are still some uncertainties in climate scenarios, which inevitably lead to wrong estimations and need further studies.

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