5 Impacts of Climate Change and Adaptation in Agricultural Water Management in North China

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Abstract

Water scarcity is one of the key problems in northern China. Efficient use and management of agricultural water resources is an important challenge in China's agricultural food production under a background of climate change. This chapter addresses issues of impacts of climate change and adaptation in agricultural water management in North China. The goal is to understand better the impacts of climate change on agricultural water resources and what measures should be taken to deal with the adverse effects in the North China Plain (NCP). First, the status of agricultural water resources in NCP was analysed. Second, considering that climate change is likely to exacerbate water stress in this area, and exploring the regional crop response to climate change, this study analysed the spatial variability and evolution of crop yield, evapotranspiration (ET) and water use efficiency (WUE) with a process-based crop model in the NCP and identified the contribution of climate change to their enhancement. Third, the impacts of future climate changes under A2 and B1 scenarios (described later in this chapter) on the wheat–maize double-cropping system are assessed. The results show that under IPCC SRES A2 and B1 scenarios, production of winter wheat will increase with slightly intensified ET; in contrast, summer maize production will slightly decline with a significant increase of ET. Also, with agricultural management, maize is more productive than wheat, in that wheat relies more on irrigation than maize, yield level of maize is higher than that of wheat, the water consumption of maize is lower, and the response of maize yield is larger than that of wheat yield to agricultural management. However, the simulation also suggests that wheat is more resilient to climate change than maize. Therefore to say if wheat or maize is more favourable in the NCP depends on the conditions in the future. Finally, in order to mitigate the impacts of climate change on agricultural water use and realize its sustainable utilization, the key adaptive water management strategies in the agriculture sector and how to improve efficiency of agricultural water use through reforming agricultural water management and policies were examined. The following measures can be implemented to reform agricultural water management and policies: improving the performance of participatory irrigation management reform, establishing a water rights system, reforming agricultural water price, and promoting the adoption of agricultural water-saving technology.

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5.1 Introduction

The impact of climate change on the security of water resources is a widespread global concern. It is a great strategic issue in the sustainable development of China. As a big developing country, China is facing a huge challenge in managing water resources to support its economic boom. Its immense territory of 9.6 million km^2 is relatively abundant in water resources, ranking sixth in the world after Brazil, the Russian Federation, Canada, the USA and Indonesia, in that order, in terms of absolute amount of annual runoff. However, given its large population of over 1.3 billion, China's per capita water resources are very low (about one-quarter of the world average), making it one of the most water-scarce countries in the world.[1]

According to the 2nd National Comprehensive Water Resources Assessment in China that started after 2000, the annual mean precipitation in China's mainland was 6178.60 billion m^3, with an estimated annual runoff of 2774.10 billion m^3 for 1956–2000. The total available water resource in China in 2000 was 814.0 billion m^3 (Bm^3). However, the total actual water use in 2000 reached 563.2 Bm^3, where the usable water resources per capita (UWRP) in China and North China were about 628 m^3 and only 359 m^3, respectively. In 2030, China's population will reach 1.6 billion, the total actual water use will increase to 710.1 Bm^3 from 563.2 Bm^3 in the year 2000, and UWRP will go down to 508 m^3 from the 628.0 m^3 of 2000. Thus, water stress in China is significant and has become a bottleneck that limits China's sustainable development.

Water resources constitute one of the most important constraints to food security in China. It has been shown that the total agricultural water use for the whole country was 348.40 km^3 in 2000. The ratio of consumption to withdrawals varies with climatic factors, the crops grown and irrigation efficiency, and typically ranges from 50 to 80%. Basically, about 64% of national agricultural water withdrawals were consumed, resulting in a total of 221.90 km^3 of consumption for the year 2000 (Cao *et al.*, 2012). Thus, just as in most other countries of the world, agriculture is the major water consumer in China. Major agricultural productive areas in China are North China, which is also called the 3H region (Huang (Yellow) River, Huai River and Hai River), North-East China (Song-Liao River) and South China in the monsoonal area. Under the climate change condition, East China, lying in the monsoonal area, is subject to the dual perils of drought and flood. During the past 30 years, drought has become more severe in the already dry north and the water ecology has deteriorated, and extreme flood disasters have increased in the south. All these occurrences have severely restricted the sustainable development of both the economy and society. Future climate change may be expected to have a significant and possibly intensifying effect on the existing pattern of 'north drought and south floods' as well as on the distribution of water resources. This will exert an unexpected influence on the functioning of major engineering projects in China, including those launched to increase food production in the north and north-east, on inter-basin water transfers and on flood control in southern rivers.

Thus a 5-year National Basic Research Program of China (2010–14) on 'The Impact of Climate Change on Terrestrial Water Cycle, Regional Water Resources Security and the Adaptation Strategy for East Monsoon Area of China', supported by the Ministry of Science and Technology (MOST) and led by Professor Jun Xia, was launched in 2009. The project focuses on the major river basins in the eastern monsoonal region of China to investigate the mechanisms of the impact of climate change on water resources and relevant adaptation strategies. The study aims to meet the major strategic requirement of enhancing water resource security for China, focusing on the impact of climate change, vulnerability and adaptation as key issues.

This chapter will address the issue on impacts of climate change and adaptation in agricultural water management in China. The area of North China, i.e. the 3H regions with more water stress and challenges related to drought, environmental issues and social economic development, is especially selected to explain how China will face the big challenges on agricultural water issues, and how to carry out adaptive water management to cope with the impact of climate change. Finally, sustainable utilization of agricultural water resources and adaptive strategies to climate change are presented.

5.2 Climate Change during the Last 60 Years in North China

The NCP is one of the country's granaries, extending from latitude 32°00′ N to 40°24′ N and longitude 112°48′ E to 122°45′ E (Fig. 5.1). It is located in the eastern part of China with an area of 33×10^4 km^2, and is an alluvial plain developed by the intermittent flooding of the Huang (Yellow), Huai and Hai rivers. Administratively, the plain covers seven provinces (mega-cities), including Hebei, Shandong, Henan, Anhui, Jiangsu, Beijing and Tianjin. The 3H region is an important agricultural production base and occupies a decisive position in guaranteeing the nation's grain requirements. It accounts for 26% of the total grain production, although it has only 21% of the planting areas as well as 6.65% of the water resources of China (Shi, 2008). Besides soybean/millet/sorghum, the double-cropping system of

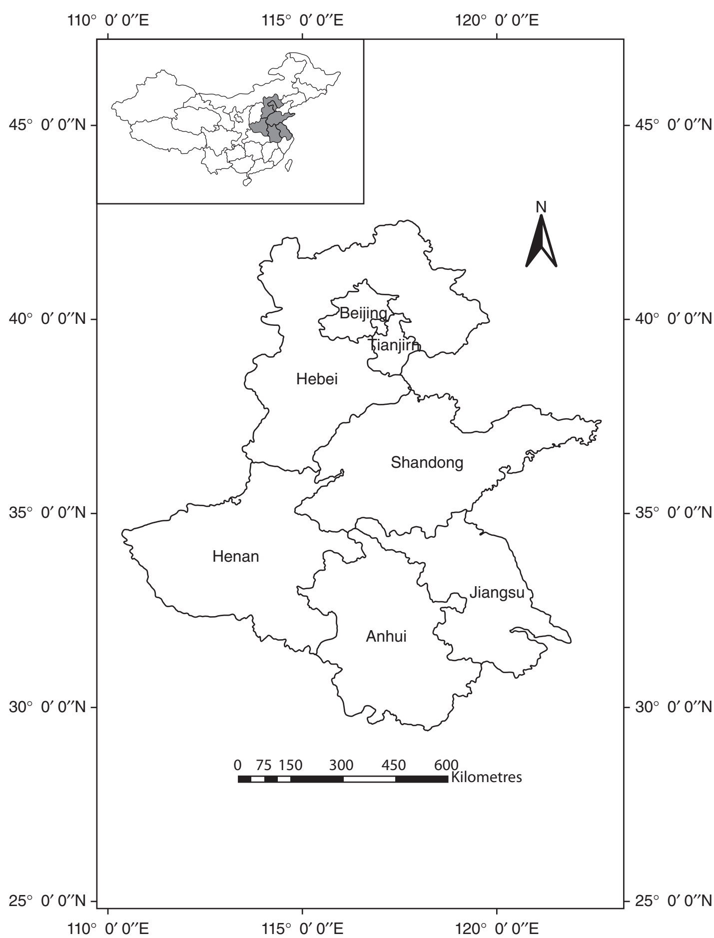

Fig. 5.1. Location map showing the NCP, China.

winter wheat–summer maize prevails in the plain, in which maize is the most common autumn harvest crop. Due to insufficient precipitation in the growing season, the spring crops (such as wheat) usually need supplemental irrigation to obtain favourable production.

The 3H region is located in the East Asian monsoonal zone. The warm temperate climate varies gradually from sub-humid in the southern to semi-arid in the northern part. The annual precipitation is about 500–1000 mm. More than 70% of precipitation falls in summer. The decrease in the regional precipitation year by year since the 1950s is due to impacts of global climate change. Regarding seasonal changes, precipitation in the spring was low in the 1970s, but increased slightly in the 1980s and the 1990s, which showed a decreasing trend. This led to more frequent spring droughts, which limited the growth of crops during the key period of water supply to them. Precipitation in summer witnessed an obvious decline, with drought, temperature and acidification becoming enhanced, raised and obvious, respectively.

Annually, both maximum and minimum air temperatures increased remarkably over the NCP from the 1950s to the 2000s with a rapid increase in the 1990s. The mean anomalies in 1997–2006 were 0.9°C and 1.28°C for the maximum and minimum temperatures, respectively, and the increments in winter are slightly higher than in summer (not shown). The mean daily sunshine duration and wind speed show a declining tendency. The decrease of sunshine is possibly related to more cloudy days and heavy aerosol conditions. The anomalies of sunshine duration and wind speed are about −0.4 h and −0.2 m s^{-1}, respectively, during the last 10 years (Fig. 5.2). It is also worth noting that there are no significant trends in either annual precipitation or water vapour pressure, but the potential evaporation is declining during this period, which mainly results from the attenuated global radiation and air movement (Mo *et al.*, 2011).

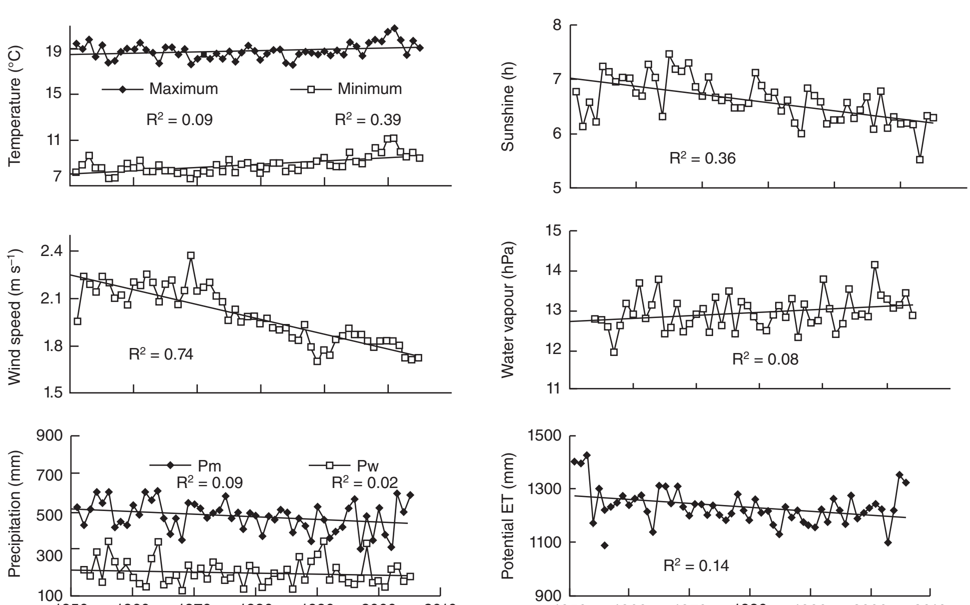

Fig. 5.2. Annual variation of the climatic variables over the NCP during 1951–2006 (potential evapotranspiration is calculated using the Penman–Monteith formula. Pw and Pm are precipitations during the growth season for wheat and maize).

5.3 Water Resources and Their Changes during the Last 60 Years in the North China Plain

Surface water and groundwater resources for a normal year in the 3H region are 128 Bm^3 (after deduction of 20 Bm^3 for silt flushing in its lower reaches). Surface water (including the amount of water entering the region) accounts for 67.5%, with groundwater accounting for 32.5%. Incoming water is quite abundant, but is declining year by year. Per capita water is 600 m^3 and average water per hectare of farmland is 7218 m^3 (Table 5.1). Per capita water resources in 2005 in all provinces of the 3H region were below 1750 m^3, the well-known international water crisis threshold (Zhang *et al.*, 2011). It was less than 500 m^3 in Beijing, Tianjin, Hebei and Shandong, which is below the threshold of severe water shortage. Per capita water resources in 2005 were 518 m^3 and the ratio of surface water to groundwater was 74.5:24.6 in the 3H region. It is forecast that by mid-21st century, per capita water resources in China will be reduced to 1750 m^3.

Water replenishment dropped remarkably due to reduced precipitation, relatively high temperature, increased actual evaporation and the impact of human activities. The primary analysis from the River Commission shows that the surface runoff generated in the whole Hai Luan River Basin during 1980–1989 was only 15.4 Bm^3, 46.5% or 13.4 Bm^3 less than 28.8 Bm^3, the multi-year average during 1956–1979. The arid zone has expanded from NCP south-westward to the upper and middle reaches of the Yellow River (Shaanxi, Gansu, Ningxia), to the Hanjiang Basin, and to the upper reaches of the Huai River since the 1990s. Annual mean water above Huayuankou of the Yellow River during the same period was 46.0 Bm^3, 17.9% or 10.0 Bm^3 less than 56.0 Bm^3, the multi-year average annual runoff. Due to the heavy drought in 1997, the runoff in the upper reaches of Huayuankou was reduced to 31.5 Bm^3, and the actual measured runoff was only 14.3 Bm^3 after deduction of water consumption by the upper/middle reaches. In the 1990s, the drought in Hailuan River was mitigated with increased precipitation close to the multi-year average. But surface runoff had little increase and was still 33.3% or 7.6 Bm^3 less than the multi-year average during 1956–1979 due to dry soil in the prophase, persistent high temperature and enhanced evaporation from the topsoil.

Agriculture needs a large amount of water and is facing more shortage than other sectors in the 3H region. Annual average agricultural water consumption was 9.77×10^{10} m^3 in 1997–2011 and the maximum value was 1.13×10^{11} m^3 in 1997. Agricultural water use has shown a downward trend in general, but the proportion of agricultural water use has been above 67% (Fig. 5.3).

The total water resources of this region are less than 10% of the national water resources, but water diversion for agriculture accounts for about 25% of the total amount of agricultural water use in 2000. It

Table 5.1. Water resources statistics in the 3H region in 2005 (p = 50%).

	Local water resources ($100 Mm^3$)		Volume entering the region ($100 Mm^3$)	Total water resources ($100 Mm^3$)	Per capita (m^3/head)	Farmland ($m^3 ha^{-1}$)
	Surface water	Groundwater				
Shanqian plain	107.4	132.2	148.6	388.2	531	7,706
Hai River low plain	44.3	81.7	98.6	224.6	554	4,949
Binhai low plain	35.1	35.9	59.1	130.1	992	11,651
Huanghuai plain	220.8	164.6	146.7	532.1	620	7,634
3H region	407.6	414.4	453	1,275	600	7,218

For downstream silt flushing of the Yellow River's waterway 20 Bm^3 have been deducted; the calculation is based on 317 counties (cities, districts) of two autonomous municipalities and five provinces with a land area of 346,000 km^2, the farmland area of 1995.

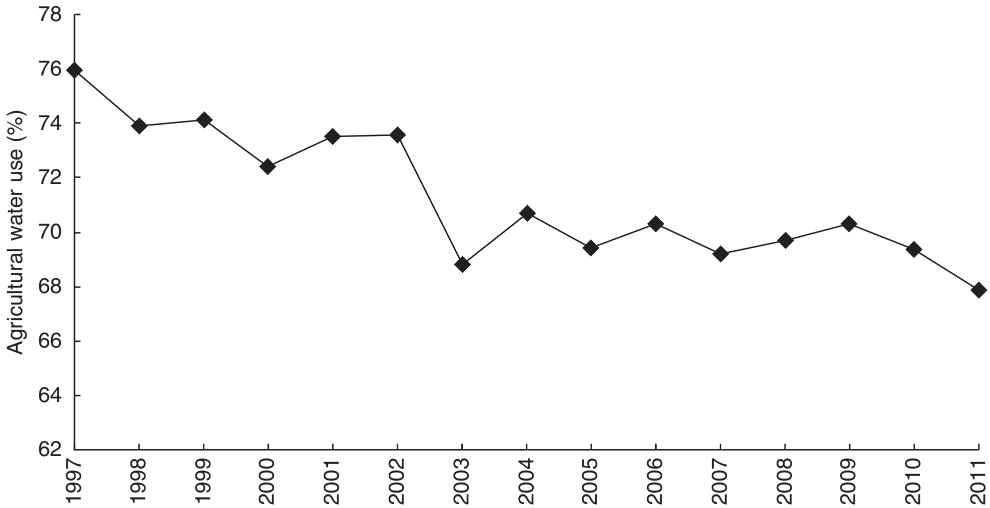

Fig. 5.3. Water diverted for agriculture in the Huang-Huai-Hai region, in 1997–2011.

is predicted that total water consumption of major crops (wheat, maize, cotton) would be $9.74 \times 10^{12}\,m^3$ in 2015 and the agricultural water shortage crisis will further aggravate the situation (Wang *et al.*, 2009). Compared with developed countries, water resources for agricultural use approach nearly 60–70% and irrigation efficiency is very low. The irrigation WUE in the Huaihe and Haihe river basins is 0.5 and 0.56, respectively, while it is above 0.7 in developed countries. Therefore how to improve the irrigation WUE and crop water productivity in the 3H region is an issue worth studying.

5.4 Water Use by Vegetation over the 3H Region

In general, ET showed a higher value in the south than in the north over the NCP and the ET is higher in well-irrigated locations. An example is the south of Henan, Anhui and the north of Jiangsu, which have abundant precipitation and well-covered vegetation. Annual ET of these areas is about 700–900 mm, and 850 mm of this is contributed by the paddy fields and water. Even other areas of the Hebei Plain, except the riverine, urban and mountain areas in the central regions, have an average ET of above 600–750 mm. In contrast, in Cangzhou, Hebei, there are many buildings in the urban area and floodlands along the Huanghe. Because of high salt content in groundwater, lack of irrigation water and low vegetation coverage, there is a lower ET, especially in the growth stages of winter wheat. The annual ET is about 350–500 mm, and the average transpiration of the whole area accounts for 60–70% of the ET.

For the summer and autumn harvest crops, the spatial distribution of ET was different in the crop-growing period and fitted with the seasonal distribution of precipitation. Total ET of the major crops (wheat and maize) in the crop growth period is shown in Fig. 5.4. In the wheat growth period, obviously the ET decreases from south to north. The ET values are between 350 and 450 mm in the southern areas and high values are mainly distributed in the northern part of Jiangsu and Anhui provinces. The ET is about 250 mm in the hilly areas of Shandong Province and the eastern rain-fed agricultural areas in Hebei Province, which is roughly equivalent to the synchronized rainfall. As the land lacks vegetation cover and is mostly sandy, the ET is less than 200 mm along the tidal flats of the Bohai Sea. In better irrigation locations such as the piedmont

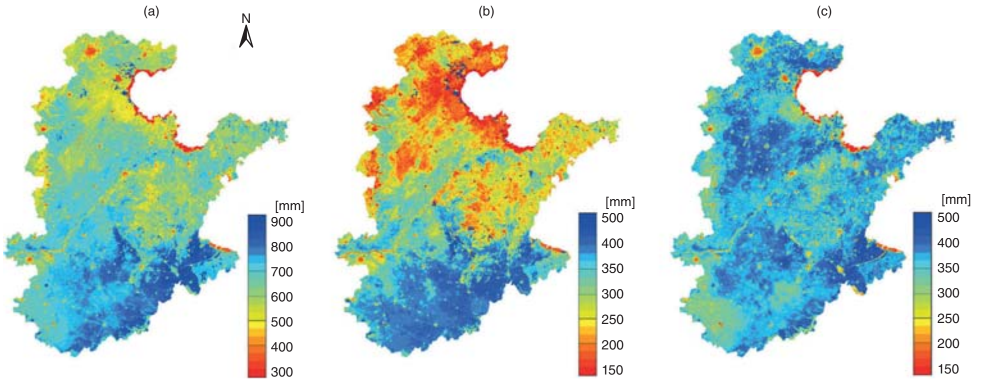

Fig. 5.4. Decadal averages of evapotranspiration (a) on annual total, (b) in winter wheat-growing period and (c) in summer maize-growing period, during 2000–2009.

plain of Taihang Mountain and the eastern part of Beijing, the ET is between 300 and 350 mm.

During the maize-growing season in summer, which is the rainy season in North China, precipitation can meet the crop growing needs but the spatial difference of ET is insignificant. Higher ET of approximately 450 mm is mainly distributed in the northern part of Jiangsu, the eastern Jiaodong Peninsula and most parts of the Hebei Plain. However, in the low hilly region in the western part of Henan Province, because of weak soil water retention capacity and poor vegetation, the ET is low at only about 320 mm. ET is between 360 and 420 mm in most parts of North China.

Overall there is a surfeit of annual precipitation to the south of the Yellow River, but for most parts of the northern regions ET is greater than precipitation (Fig. 5.5). The difference to the south of the Yellow River mainly comes from the upstream mountain reservoirs and groundwater irrigation supplement. Irrigation supplement is variable among regions in this area. The highest irrigation supplement is distributed in the piedmont in the Taihang and Yan mountains, which is about 150–200 mm, accounting for one-third to one-fourth of the total supplement. This indicates that the water use in this area is seriously higher than in the local water resources. In the wheat-growing period, the amount of farmland irrigation is approximately about 200 mm, and the largest irrigation amount comes out in the piedmont of the mountain, which is more than 200 mm. The rain-fed farmland practised some soil water conservation. In the maize-growing season, precipitation is 100–250 mm higher than the ET to the south of the Yellow River. The precipitation can supply enough water resources for the soil water, groundwater and surface water. But to the north of the Yellow River, there needs to be an addition of about 50 mm irrigation water in the piedmont of the Taihang and Yan mountains. In other areas, soil water storage can barely meet the needs for growing maize. Overall, the water supply and demand have a seasonal imbalance in the NCP. The water used for agriculture in spring is heavily dependent on the upstream mountain reservoir storage, runoff from the Yellow River and the deep groundwater.

5.5 Water Resources under Climate Change Scenarios in the 3H Region

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change of 2007, it is a fact that the increase in the concentration of greenhouse gases in the atmosphere is a cause of global climate change. The global average surface

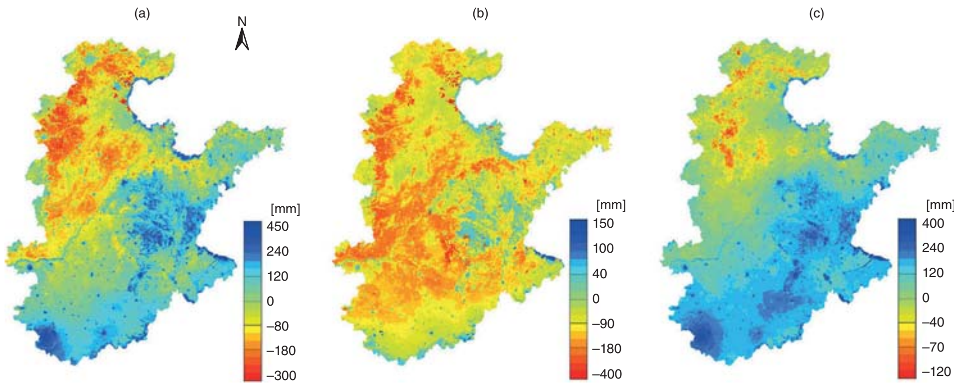

Fig. 5.5. Decadal averages of the differences between precipitation and evapotranspiration (a) on annual total, (b) in winter wheat-growing period and (c) in summer maize-growing period, during 2000–2009.

temperature has increased by around 0.56 to about 0.92°C in the past 100 years (1906–2005). Results have shown that the recent 100-year warming is jointly caused by natural climate fluctuation and anthropogenic activity, but most of the recent 50-year climate change is caused by anthropogenic activity (Ding, 2008).

Many studies have shown that regional warming will be the main feature in the 3H region in the 21st century. By 2030, an increase of 1°C in average temperature in the Yellow River Basin will lead to a 1.3% increase of annual precipitation variability; an increase of 0.9°C in Huai River Basin will lead to an increase of 1.5% precipitation variability. Runoff from rivers in the 3H region will reduce by 4–6% due to augmented evaporation associated with increased temperature. Temperature will increase by 1.1–1.4°C in the 3H region by 2030. There is the possibility of having extremely strong precipitation occurring only every 30–50 years, which will be more frequent in the 2080s and the 2090s in the 3H region. According to forecasts, temperature will significantly increase in the 3H region. The increase will be 1.0°C and 1.2°C under A2 and B2 models in the 2120s. But precipitation is extraordinarily complicated. In the long run; it increases as a whole in the 3H region, but it declines before the 2120s in part of this area and tends to fluctuate more due to temperature rise. Water demands will increase due to higher surface evaporation and crop transpiration.

Climate change is considered as posing the greatest threat to agriculture and food security in the 21st century, particularly in many of the sub-humid and semi-arid regions. As the main food supply area contributes approximately 41% of the total wheat yield and more than 30% of the total maize yield in China, the NCP is vulnerable to climate change (Guo *et al*., 2010). Also, research showed that by 2030, climate change and increasing water demand will bring about increasing vulnerability to this region, especially for the Hai and Yellow river basins, aggravating the water shortage problems in the future (Xia *et al*., 2012a, b). Therefore the issues of how to improve the efficiency of water use, how to adapt the crop systems to climate change and what measures should be taken to decrease the uncertainty of agricultural water resources need to be considered. Under future climate change scenarios in China, possibly the nutrient supply in the soil can be improved to increase crop yield by taking green water management measures to decrease the soil evaporation, thus improving the agricultural WUE to deal with the water resources vulnerability of this region.

5.5.1 The hydrologic responses under climate change scenarios

Under the framework of the Variable Infiltration Capacity Model (VIC), 12 climate scenarios were designed to account for possible variations in the future with respect to the baseline of historic climate patterns (Dan *et al.*, 2012). Results from the six representative types of climate scenarios (+2°C and +5°C warming, and 0%, +15%, –15% change in precipitation) show that rising temperatures for normal precipitation and for wet scenarios (+15% precipitation) yield greater increased ET in the south than in the north, which is confirmed by the remaining six scenarios described below. The largest increase or decrease of ET occurs for a 15% change in precipitation. Rising temperatures can lead to a south-to-north decreasing gradient of surface runoff. The six scenarios yield a large variation of runoff in the southern end of the 3H, which means that this zone is sensitive to climate change through surface runoff change.

5.5.2 The response of crop evapotranspiration under the Special Report on Emission Scenarios A2 and B1

The climate change projections from the runs of the GCM HadCM3, archived by the British Atmospheric Data Centre (http://badc.nerc.ac.uk/home/index.html), for A2 and B1 scenarios developed for the Third Assessment Report (Nakicenovic and Swart, 2000) of IPCC Special Report on Emission Scenarios (SRES) are used to simulate the responses of crop yield, ET and WUE to climate changes in the 21st century for the NCP. The A2 scenario describes a very heterogeneous world of high population growth, slow economic development and strong regional cultural identities. B1 is a rather optimistic scenario assuming a 'convergent world' and putting emphasis on global solutions to economic, social and environmental sustainability. The B1 scenario also assumes high economic growth but with a substantial shift to nuclear energy. The data for the A2 scenario include monthly values of maximum, minimum and mean temperatures, precipitation, relative humidity, wind speed and short-wave radiation. So do the data for B1 scenario, but maximum and minimum temperatures are missing. According to the projections, for example, in the 2090s, atmospheric CO_2 concentration, precipitation and daily mean air temperature will increase by 280 ppm, 16% and 2.8°C for B1 and 470 ppm, 48% and 4.5°C for A2, respectively.

Crop water use (ET) under SRES A2 and B1 scenarios is predicted with the Vegetation Interface Processes (VIP) model (an eco-hydrological model) (Mo and Liu, 2001; Mo *et al.*, 2005). Cumulative ET in the growing stage of winter wheat seems to be affected only slightly by climate change. The cumulative ET amounts gently increase for both A2 and B1 scenarios by less than 6%. As is known, the air warming will intensify ET, whereas both lower stomata conductance resulting from higher CO_2 concentration and growing period shortened by warming will mitigate the rising of total ET amount. As a consequence, the change of ET is not remarkable. Cumulative ET in the maize-growing period will significantly increase over 10% after the 2050s. At the end of the 21st century, the cumulative ET amounts under A2 and B1 scenarios will be 37% and 20% higher than the current values over the maize-growing period, respectively (Mo *et al.*, 2009).

5.6 Adaptive Strategies of Sustainable Agricultural Water Resources Utilization

After several decades of past water policies that focused on increasing water supply by constructing more canals and larger reservoirs (Ross, 1983), China's leaders have started to recognize the need to stem the rising demand for water (Boxer, 2001). In particular, under the pressure of climate change, it has become an urgent task for policy makers to change water management from supply side to demand side. That is, transferring from meeting demand with new resources or 'supply side' to managing the demand itself to postpone or avoid the need to develop new water resources. In order to successfully realize this transfer of management strategies, in 2006 the Chinese government set the target for water saving for the 12th 5-Year Plan period (2006–2010); water use per GDP should be reduced by 20% relative to the 2005 level (National Development and Reform Commission *et al.*, 2006). In 2009, the Ministry of Water Resources clearly proposed to implement water demand management through setting up 'Three Red Lines'[2] for the most stringent water management institution. In January 2013, the State Council in China issued the *Assessment Method for Implementing the Most Stringent Water Management Institution.*

As the main water-using sector in China, a large portion of the water saving has been slated to come from the agriculture sector. Therefore, in order to mitigate the impacts of climate change on agricultural water use and realize its sustainable utilization, the key adaptive water management strategy in the agriculture sector is how to improve agricultural WUE through reforming agricultural policies. This section discusses the reforming of agricultural water management and policies.

5.6.1 Improving the performance of participatory irrigation management reform

From the 1980s, China began to attach importance to enhancing the construction of the water resources management system and developing relevant policies. Thus, in 1981, China made an important decision to shift the focus of water conservancy work to management and proposed 'enhancing operation and management and putting focus on economic benefits' as the main policy of water conservancy in 1983. The *Water Law of the People's Republic of China* promulgated by the State in 1988 has defined the significance of water resources management, and the relevant State policies focus more on water resources management. In 2003, the Ministry of Water Conservancy issued *Suggestions on the Implementation of Small Rural Water Conservancy Engineering Management System Reform* and proposed a plan to establish a management system orienting on encouraging the development of participatory irrigation management. In 2005, the Ministry of Water Resources, the National Development and Reform Committee and the Ministry of Civil Affairs jointly released *Opinions on Enhancing Farmer Water User Association (WUA) Building*. These policy documents provided an important policy guarantee for driving water users to participate in irrigation management. Up to 2011, more than 30,000 water user associations had been established in China.

However, some scholars found that not all the participatory irrigation management was successful (Huang *et al.*, 2010a). Wang *et al*. (2010) found that due to implementation of the Five Principles of WUA,[3] the World Bank-funded participatory irrigation management performed very well in improving WUE. However, based on a large field survey and empirical analysis in four large irrigation districts in the Yellow River Basin, Wang *et al*. (2005) pointed out that the transfers of the irrigation management from collective to WUAs or contracting management are mostly nominal reforms, and such reform had not realized the reform purpose of improving WUE. Whether the reform realized the reform purpose depended on the establishment of the water saving incentive mechanism. If an effective water saving incentive mechanism was established after reform, the irrigation water utilization efficiency increased by 40%.

Therefore in the future implementation process of irrigation management reform, governmental authorities must not only push forward effective irrigation management patterns but also pay attention to the reform pattern of internal system building (e.g. as a water-saving incentive mechanism of administrative supervisors) to guarantee the sustainable and effective exertion of reform performance. If focus is not put on the internal system building of management patterns, the reform performance may be one-off and short-term, and it is hard to promote the sustainable development of water resources and social economy. Thus, government authorities must pay close attention to how to establish a long-term and effective water-saving incentive mechanism to proceed with the improvement of reform performance.

5.6.2 Establishing a water rights system

While reforming irrigation management is one effective way to increase WUE, one key problem of such a reform is its sustainability. The local governments (especially in the upstream areas) do not seem to receive any benefits from reducing water use through reforming irrigation management. The major reason is that there are no mechanisms to compensate local governments that have succeeded in reforming irrigation management and have increased WUE. Their saved water is reallocated to other regions without any benefit for them. As a result, local governments in the Yellow River Basin (YRB) have no incentive to push management reforms; and reforms are unlikely to be sustainable in the long run if they lack local government support. In order to allow regions in the upper reaches of the YRB to receive compensation when they save water, one possible solution is to establish a water rights system.

Since 2000, the Yellow River Conservation Commission (YRCC) has begun to promote the establishment of water rights systems through conducting demonstration projects aimed at reducing water competition among sectors. With increasing water shortages, water becomes insufficient to support industrial development, especially the energy industry, in the upstream provinces such as Ningxia and Inner Mongolia. In order to solve this problem, in 2003 the YRCC established some water rights demonstration sites in the upstream reaches of the YRB. The purpose of these demonstration sites is to reallocate water from agriculture to industry through increasing irrigation efficiency (Li, 2007; Molden *et al*., 2007; Wang, 2007). In 2004, in order to promote the water transfer work in the YRB, the MWR issued the *Guidance on Water Rights Transfer Demonstration Works in Inner Mongolia and Ningxia Provinces*. The YRCC also released two regulations titled *Management and Implementation Measures on Water Rights Transfer in the Yellow River Basin* and *Management Regulation on Water-Saving Engineering*. These regulations have provided the legal foundation for water rights transfers in the YRB.

Despite some progress on water rights transfer, there are still considerable challenges facing both central and local governments regarding the implementation of water rights transfers (Yang *et al*., 2006; Jiang *et al*., 2007). The first is the engineering problem. YRCC considers the construction of water-saving infrastructure to be very slow, thus constraining the progress of water rights transfers. In addition, management of this new infrastructure remains a challenge. The second constraint relates to water rights. While some water rights transfer projects have been established, a general water rights system has not been developed. Water users still have no clear ideas about how many water rights they have. Water rights transfers still depend on administrative power, not on developed water markets. Water rights transfers are still a function of the central and local governments, and are not adjusted by market signals or economic measures. In fact, China still has a long way to go in establishing a real water rights system and water markets. How to effectively promote the system of water rights is still hotly debated by many policy makers and researchers.

5.6.3 Reforming agricultural water price

Since the 1990s, China's water officials have begun to consider reforming the pricing of irrigation water as a key policy instrument for dealing with the nation's water scarcity problem. The objective of the reform is to provide agricultural users with economic incentives to save water through higher water prices. Relying on a set of household-level data, Huang *et al*. (2010b) examined the potential for conserving water through water pricing reform. Their study shows that the water pricing policy has the potential to resolve the water scarcity problem in China. However, because the current cost of water is far below the true value of water in many regions, a large increase in the price of water from the current level is required. Some scholars have also recognized the difficulties of implementing water pricing (e.g. Sampath, 1992; Dinar, 2000). Importantly, Huang *et al*. (2010b) revealed the costs associated with higher water prices. Higher irrigation costs will lower the production of all crops, in general, and that of grain crops in particular. This may hurt the nation's food security goal of achieving 95% self-sufficiency for all major grains in the short run (such as within 5 years). Furthermore, when facing higher irrigation costs, households suffer income losses, although income distribution does not deteriorate.

The goal of the water pricing policy, which is to manage water resources in a sustainable way, does not conflict with the long-run goal of the nation's food security policy. On the other hand, dealing with the negative production and income impacts of higher irrigation cost will pose a number of challenges to policy makers, at least in the short run. One possible solution is to set a water saving target in the agriculture sector to be below the national target of 20% (Huang *et al*., 2010b). In addition to setting a modest water-saving target, if China's leaders plan to increase water prices to address the nation's water crisis, an integrated package of policies will be needed to achieve water savings without hurting rural incomes or national food security. One solution is to develop a subsidy programme in tandem with the water pricing policy that transfers income to households. A subsidy programme is a realistic solution in China's political economy environment. China's agricultural policy has gradually switched from taxing farmers to directly subsidizing them. The tax-for-free reform that targets at eventual elimination of taxation on rural households has been implemented over recent decades (Brandt *et al*., 2005). Hence, a subsidy programme is well in line with the government's policy agenda. In order to play the effective role of subsidy policy on saving water, instead of a grain subsidy, China should consider giving a 'decoupled water-price reimbursement payment' or 'unconditional payment' to farmers.

5.6.4 Promoting the adoption of agricultural water saving technology

In order to increase WUE, promoting water saving technology has been highly addressed by policy makers in China. The Chinese government stated that the promotion of water saving technology is one of the priorities in its water conservancy reforms. Issued in March 2011, the rural and agricultural parts of the 12th Chinese 5-Year Plan highlight the importance of efficiency and technological innovation. In addition, the Chinese government has announced an expenditure of RMB4 trillion (over US$600 bn) on water conservation over the next 10 years and a specific investment of US$6.03 bn to support the adoption of water saving technology on 2.53 million ha.

Existing literature tells us that policy support is one important driving factor that affects farmers' decisions on adopting water saving technology. Policies promoting adoption of water saving technology often aim to overcome farmers' economic and technical constraints. In order to overcome these constraints, direct provision of subsidy has proven to be one important policy measure in increasing the adoption rate of agricultural water-saving technology, especially when the adoption rates are low. Based on an econometric analysis, Liu *et al*. (2008) confirmed the significant positive relationship between subsidies and adoption of some kind of water saving technology in rural China. For technical constraints, providing knowledge and technical advice through extension service activities is an effective way to increase the adoption rate of agricultural water-saving technology. Therefore, in the future, in order to increase the adoption rate of agricultural water-saving technologies it is necessary to establish rational policy support systems, in addition to which, setting up a rational water price policy will also play an important role in encouraging farmers to adopt water-saving technologies.

5.7 Conclusions

In order to explore the regional crop response to climate change, this study analysed the spatial variability and evolution of crop yield, ET and WUE with a process-based crop model in the NCP and identified the contribution of climate change to their enhancement. The impacts of future climate changes under A2 and B1 scenarios on the wheat–maize double-cropping system were also assessed.

The results show that crop production has increased rapidly over the past decade in the NCP. Accompanying production improvement, crop ET has also risen significantly. There exist spatial patterns of crop yield stemming mainly from soil quality and irrigation facilities. Under IPCC SRES A2 and B1 scenarios, production of winter wheat will increase with slightly intensified ET; in contrast, summer maize production will slightly decline with a significant increase of ET. Also, with agricultural management, maize is more productive than wheat, in that wheat relies more on irrigation than maize, yield level of maize is higher than that of wheat, the water consumption of maize is lower, and the response of maize yield is larger than that of wheat yield to agricultural management. However, the simulation also suggests that wheat is more resilient to climate change than maize. If wheat or maize is to be more favourable in the NCP will depend on the conditions in the future. None the less, our results provide a scientific basis and reference for governments' decision making from the perspective of regional climate change response.

In order to mitigate the impacts of climate change on agricultural water use and realize its sustainable utilization, the key adaptive water management strategy in the agriculture sector is how to improve efficiency of agricultural water use through reforming agricultural water management and policies. The following measures can be implemented to reform agricultural water management and policies:

- Improving the performance of participatory irrigation management reform and paying close attention to the reform pattern of the internal system building in establishing the water rights system to proceed with the improvement of reform performance.
- Establishing a water rights system. In order to allow regions in the upper reaches of the YRB to receive compensation when they save water, one possible solution is to establish a water rights system. Establishing a real water rights system and water markets to promote the system of water rights effectively needs further research.
- Reforming agricultural water price. The current cost of water is far below the true value of water in many regions so that a large increase in the price of water from the current level is required. A subsidy programme developed in tandem with the water pricing policy that transfers income to households can achieve water savings without hurting rural incomes or national food security.
- Promoting the adoption of agricultural water saving technology. Establish rational policy support systems, which are necessary to increase the adoption rate of agricultural water-saving technologies. Setting up a rational water price policy will also play an important role in encouraging farmers to adopt water-saving technologies.

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Notes

[1] The Ministry of Water Resources (MWR) completed a nationwide assessment of water resources in 2000, which summarizes the significant challenges China is facing in ensuring the security of its water resources (see Qian and Zhang, 2001; Xia *et al*., 2011).

[2] 'Three red lines' refer to the total water use, efficiency and dirt holding capacity, with particular emphasis on the 2030 total water, which is controlled at 700 Bm^3.

[3] Principle 1 is adequate and reliable water supply: a WUA is organized only to see that adequate and reliable water supply is available and whether on-farm delivery infrastructure is in good condition and can be properly maintained by its members. Principle 2 is legal status and participation: a WUA should be the farmers' own organization, a legal entity and have a leadership elected by its members. Principle 3 is that WUAs are organized within hydraulic boundaries: the jurisdiction of a WUA should be the hydraulic boundaries of the delivery system. Principle 4 is that water deliveries can be measured volumetrically: a WUA should be able to receive its water under contract from its water suppliers and it should be able to measure the water volumetrically. Principle 5 is that a WUA equitably collects water charges from members: a WUA should equitably assess and collect water charges from its members and make payment for the cost of water.

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