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Challenges and adaptations of farming to climate change in the North China Plain

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Abstract Climate change has been a concern of policy makers, scientists, and farmers due to its complex nature and far-reaching impacts. It is the right time to analyze the impacts of climate change and potential adaptations, and identify future strategies for sustainable development. This study assessed changes in climatic factors (e.g., temperature and precipitation) at three typical sites (i.e., Luancheng, Feixiang, and Huanghua) in the North China Plain (NCP), and analyzed adaptations of farming practices. Results indicated that the mean annual temperature followed a significant increasing trend during 1981–2011, with 0.57, 0.47, and 0.44 °C decade^{-1} for Luancheng, Huanghua, and Feixiang, respectively. A significant increase of 0.67, 0.53, and 0.38 °C decade^{-1} was observed for the winter-wheat (*Triticum aestivum* L.) season for Luancheng, Huanghua, and Feixiang, respectively ($P<0.05$), but no significant change for the summer-corn (*Zea mays* L.) season for the three sites. The annual accumulated temperature (≥10 °C) increased significantly during 1981–2011 ($P<0.01$), with 17.60, 10.49, and 14.09 °C yr^{-1} for Luancheng, Huanghua, and Feixiang, respectively. There was no significant increase of mean annual precipitation, which had large inter-annual fluctuations among the three sites. In addition, significant challenges lie ahead for the NCP due to climate change, e.g., increasing food grain demand, water shortages, high inputs, high carbon (C) emissions, and decreasing profits. Trade-offs between crop production, water resource conservation, and intensive agricultural inputs will inhibit sustainable agricultural development in the NCP. Farming practices have been adapted to the climate change in the NCP, e.g. late seeding for the winter-wheat, tillage conversion, and water saving irrigation.

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Therefore, innovative technologies, such as climate-smart agriculture, will play important roles in balancing food security and resources use, enhancing water use efficiency, reducing C emissions in the NCP. Coordinated efforts from the government, scientists, and farmers are also necessary, in response to climate change.

1 Introduction

Climate change, an important environmental issue, is a concern for both scientists and policy makers. Increases in atmospheric concentrations of greenhouse gases (GHGs, e.g., CO_2, CH_4, and N_2O), is the principal cause of global climate change (IPCC 2013). Agriculture, essential to human well-being, is strongly affected by the climate and weather (e.g., crop distribution, calendar of crops). In turn, agricultural activity, can strongly influence the environment and climate in various ways. Therefore, scientists and policy makers must objectively assess the complex relationship between agriculture and climate. Indeed, agricultural improvement is a continuously evolving process, and involves adaptation to a wide range of factors from within and outside of agro-ecosystems. For instance, the new crop varieties and cultivation practices have been adopted to adapt to the changing environmental conditions related to soil, water, vegetation, and climate (Howden et al. 2007). In addition, improved farming practices, including the use of organic fertilizers, conservation farming practices, etc., can increase crop yields, reduce GHGs emissions, and enhance soil organic carbon (SOC) storage (Branca et al. 2013).

Adaptation involves adjustments in ecological, social, and economic systems in response to actual or expected climatic stimuli and their effects or impacts (Smit et al. 2000). Indeed, adaptation is not only a natural process of evolution, but is also strongly affected by human activities (Smit and Pilifosova 2003). Therefore, understanding adaptations to climate change is essential to assess its impacts on agriculture and identify vulnerabilities and strategies for future development of agriculture. Numerous studies have focused on climate change and adaptation (Kelly and Adger 2000; Wise et al. 2014). Most studies have thus far focused on relationships and research framework for adaptation to climate change. Therefore, it is also necessary to assess how agriculture adapts to climate change, based on practical experiences.

Previous studies indicate that climate change has a moderate positive effect on food security, compared to the effects of changes in cropland area, population growth, socio-economic pathways, and technological development in China (Ye et al. 2013). However, bigger challenges to agricultural development lie ahead in the North China Plain (NCP), because of poor resource endowment, increase in food demand, and climate change. The NCP is the principal food grain base in China and the production of winter-wheat (*Triticum aestivum* L.) accounts for 71 % of wheat production in China (Sun et al. 2006). Because the NCP plays a key role in ensuring China's food security, these issues are of vital concern for the region. The NCP is facing unprecedented challenges from ecological and socio-economic sustainability (e.g., water scarcity, environmental pollution, and low profits from crop production). In the context of climate change and food security, these constraints are projected to worsen for sustaining agronomic production in the NCP. Therefore, it is critical to analyze climate change, assess challenges to adaptation, and identify pathways of future agricultural development in the NCP. Thus, the objective of this study is to assess the trends of climate change, identify challenges and opportunities, and outline adaptive farming practices for the NCP and similar regions.

2 Methods

2.1 Site description

The present study is conducted in the Hebei Province (36°05′~42°40′N, 113°27′~119°50′E) in the NCP as a typical case study. Hebei Province is located in the north of the NCP. The region has a temperate continental climate with an average annual temperature of ~4–13 °C and mean annual precipitation of ~300–800 mm, with most of the annual rainfall received during July and August. Winter-wheat and summer-corn (*Zea mays* L.) are the dominant crops in this region. Hebei Province is the most important wheat and corn producer, and provides almost 71 and 36 % of total wheat and corn, and accounts for more than 60 and 38 % of total land area under wheat and corn in the NCP (MAPRC 2014).

2.2 Data collection and analysis

Data regarding meteorology and cropping calendars were obtained from China agro-meteorological experiment stations of Chinese Meteorological Bureau (CMB 2013). The experimental stations are sited in Luancheng (38°16′ N, 116°03′ E), Huanghua (38°13′ N, 117°13′ E), and Feixiang (37°32′ N, 114°23′ E) (Fig. S1). Trends in climatic variables from 1981 to 2011 (i.e., mean temperature, mean accumulated temperature, and mean precipitation) were established using linear regression analyses.

Data for crop yields and agricultural inputs were obtained from the available statistics (HBPBS 1995–2013). Estimations of carbon (C) emissions from agricultural inputs (kg CO_2-eq. kg^{-1}) were calculated by the amount of each individual agricultural input and multiplied by the corresponding emission rate to GHGs emission including manufactured and/or application (Lal 2004). The specific CO_2 equivalent emission rates of fertilizer, electricity, and diesel were obtained from Chinese Life Cycle Database (CLCD 2012); of pesticides, and mulch film were procured from Ecoinvent database (Swiss Centre for Life Cycle Inventories 2010). Energy from human labor was not computed, because human respire CO_2 regardless of whether they are working or not (West and Marland 2002).

3 Challenges of crop production in the NCP

3.1 Climate change

Despite fluctuations in the data for nearly 30 years (1981–2011), air temperature showed a definitive increasing trend (Fig. 1). The mean annual temperature (MAT) were ~13.94, 12.94, and 14.39 °C for Luancheng, Huanghua, and Feixiang, respectively, with a significant average increase of 0.57, 0.47, and 0.44 °C decade^{-1} ($P<0.01$). Regardless of an accumulated temperature of either ≥0 or ≥10 °C, the annual accumulated temperature followed a significant increasing trend over the years for the three sites (Fig. 1a2, b2, c2, $P<0.01$). The average increase of annual accumulated temperature ranged from 12.91 to 17.97 °C yr^{-1} for ≥0 °C, from 10.49 to 17.60 °C yr^{-1} for ≥10 °C, respectively.

Despite large fluctuations, the MAT showed an increasing trend for both the winter-wheat and summer-corn season (Fig. 2a1, b1, c1). The significant increase of temperature in the winter-wheat season was observed in the three sites ($P<0.05$), while non-significant trends were observed in the summer-corn season. The MATs for the winter-wheat season were 8.91, 9.30, and 7.00 °C in Luancheng, Feixiang, and Huanghua, respectively, with a significant increase of 0.67, 0.53, and 0.38 °C decade^{-1} ($P<0.05$). The accumulated temperature (≥10 °C) for the winter-wheat also followed an increasing trend (Fig. 2a2, b2, c2).

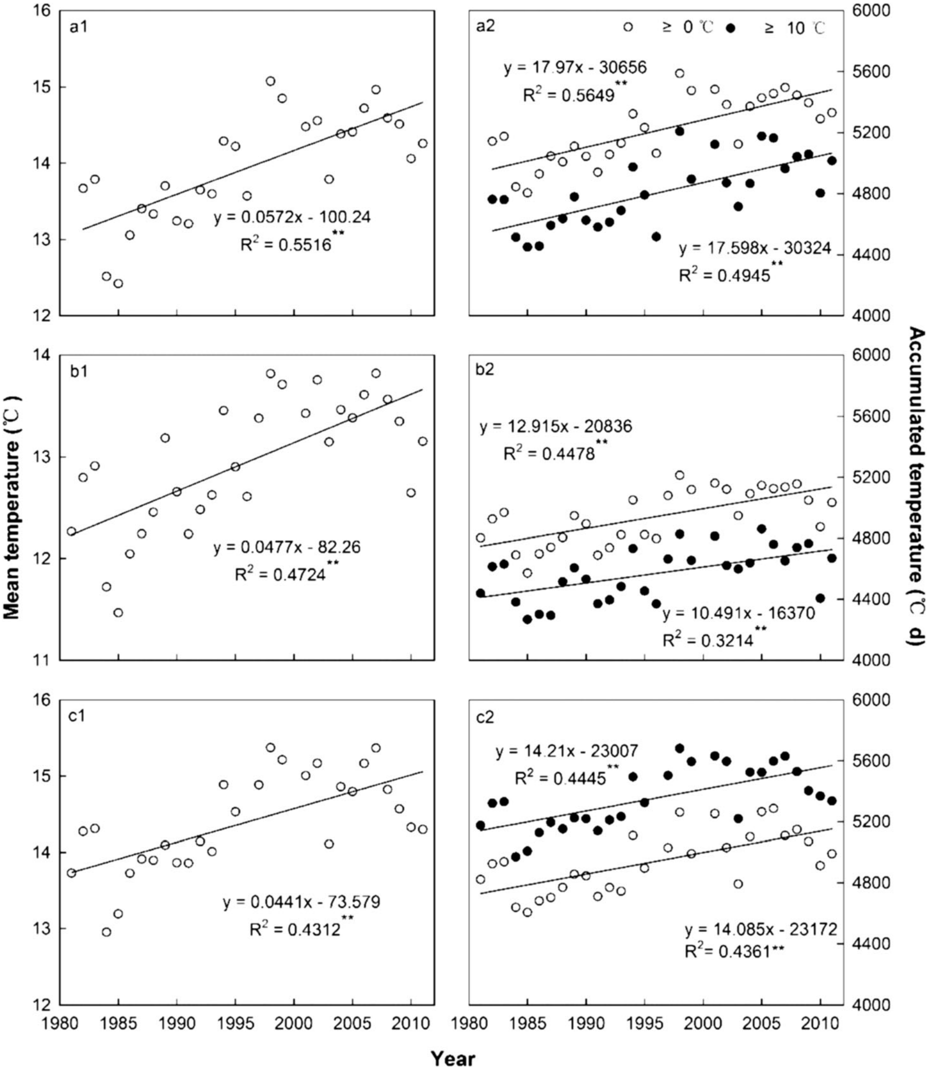

Fig. 1 Trends of mean annual temperature and accumulated temperature in Luancheng (**a**), Huanghua (**b**), and Feixiang (**c**) during 1981–2011. **Significant at $P<0.01$, *Significant at $P<0.05$

Compared with the winter-wheat season, the temperature changes during the summer-corn season exhibited larger variations over the years, but no significant increase were observed (Fig. 2a1, b1, c1). The MATs were 25.60, 25.24, and 25.83 °C in Luancheng, Huanghua, and Feixiang, respectively. While the accumulated temperature (≥10 °C) were 2676.50, 2627.55, and 2390.27 °C d^{-1} in Lucheng, Huanghua, and Feixiang, respectively. The large temperature variation between the summer-corn seasons over these years represents an increase in uncertainty and risks associated with corn production.

Along with temperature, climate change also affects the amount and distribution of precipitation. Precipitation followed an increasing trend for the year as a whole, the summer-corn and winter-wheat season in the three sites (except for the winter-wheat season in Luancheng) (Fig. 3). The mean annual precipitation (MAP) ranged from 228.2 to 1097.1 mm in the three

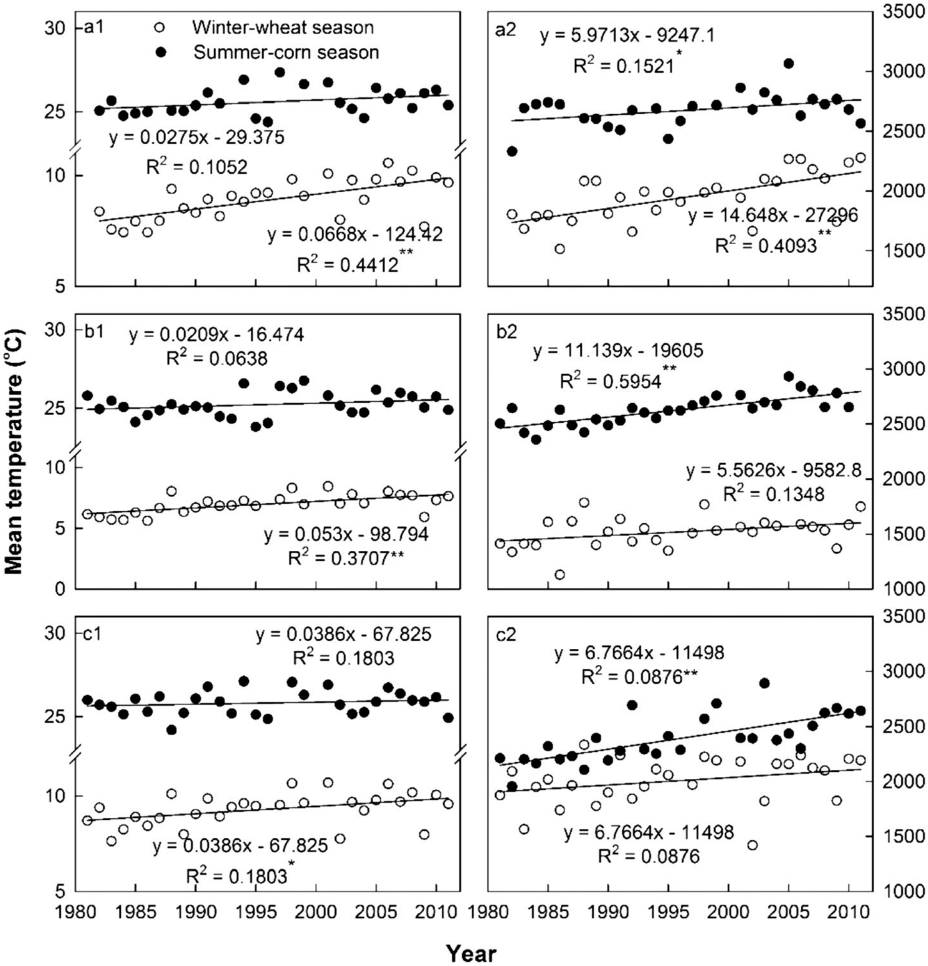

Fig. 2 Trends of mean temperature and accumulated temperature (≥10 °C) for the winter-wheat and summer-corn in Luancheng (**a**), Huanghua (**b**), and Feixiang (**c**) during 1981–2011. **Significant at $P<0.01$, *Significant at $P<0.05$

sites during 1981–2011, with an average of 530.5, 545.2, and 479.8 mm in Luancheng, Huanghua, and Feixiang, respectively. However, averages below 500 mm occurred for almost half of the years studied. The inconspicuous and fluctuating trend of MAP may exasperate the existing problems of water shortage in the NCP. The MAP for both winter-wheat and summer-corn seasons exhibited large variations among years (Fig. 3). Along with the notable fluctuations, no significant trends of precipitation in the winter-wheat and summer-corn season were observed for the three sites. The increasing trend in MAP for most of the winter-wheat and summer-corn season is too limited to meet the crop demands, and even a small decline in MAP during the winter-wheat season may adversely affect corn growth and production.

3.2 Shortage of water resources

Water shortage presents a serious threat to sustainable agriculture development and social stability in the NCP. The overexploitation of groundwater has fully depleted some wells and

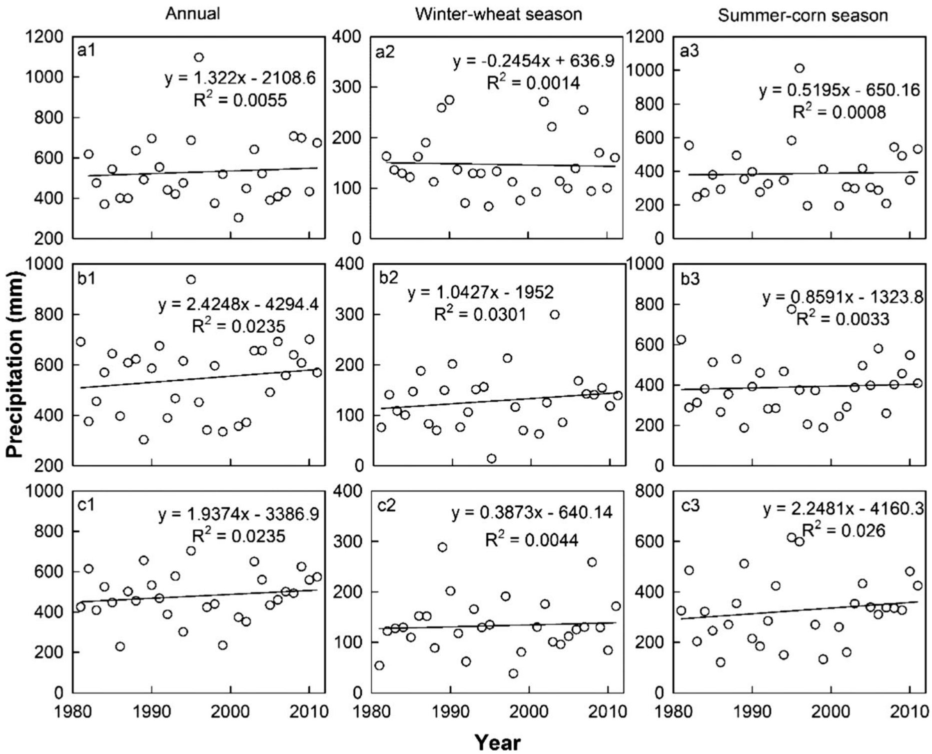

Fig. 3 Trends of mean annual precipitation, mean precipitation for the winter wheat, and summer corn season in Luancheng (**a**), Huanghua (**b**), and Feixiang (**c**) during 1981–2011

left little water flow to replenish reservoirs. The rate of drop of the ground water table in some areas of the NCP is ~1 m yr^{-1} with a total cumulative drop of over 100 m thus far (Qiu 2010; Zhang 2011). Yet, higher yields to meet growing food demands in the NCP will consume even more water. For example, based on the water estimation of supply and demand, there will be shortfall in irrigation water by about 18.2 km^3 in the Huang-Huai-Hai Plain in 2050 (Berkhoff 2003). Therefore, the trade-off between water shortage and crop production will be a long-term issue for this region. In the long-term, climate change may aggravate water scarcity and jeopardize agricultural sustainability in the NCP due to the large fluctuations of precipitation. The projected increases in ambient temperatures would also accelerate soil evaporation. Coupled with variations in MAP, these climate changes would further tax scarce water resources and increase the severity of agronomic droughts. In addition, due to the low profits realized with field crops, some farmers prefer to produce greenhouse vegetables requiring higher water consumption. These changes increase the severity of the existing water resource crisis in the NCP.

3.3 Input intensification and carbon emission

According to statistical data, the yields of winter-wheat and summer-corn in Hebei Province increased ~1.5-fold from 1985 to 2012, from 3.16 to 5.55 Mg ha^{-1} for winter-wheat and 3.88 to 5.41 Mg ha^{-1} for summer-corn, respectively (Table S1). Except for technological improvements, these increases can be attributed to input intensification.

Consequently, intensive farming leads to excessive consumption of resources, especially water. In addition, input intensification leads to increased C emissions. We computed C emissions and agricultural input proportions for winter-wheat and summer-corn in Hebei province from 1990 to 2012 (Table S2). Most agricultural inputs showed an increasing trend, which resulted in significantly positive C emissions with years ($P<0.01$) and the average yields of winter-wheat and summer-corn ($P<0.01$, Fig. S2). Among these inputs, emissions resulting from fertilizer applications, diesel and electricity consumption for irrigation and mechanical operations accounted for approximately 95 % of the total emissions. These agricultural practices not only relate to food security, but also impact GHGs emissions and environmental degradation. Therefore, there is a strong need to improve resource use efficiencies in respect to climate change and sustainable development.

3.4 Access and perceptions of improved technology by farmers

Farmers have to adapt to climate changes, because of its impacts on productivity. However, the adaptive efficiency for famers is always uncertain due to the limitation of the knowledge. Although farmers have some knowledge concerning climate change and the potential ecological risks (e.g., ground water depletion), economic benefit is always the primary consideration when adopting agricultural innovations. With the increasing costs of agricultural inputs, economic efficiency has become an urgent priority for farmers in the NCP. Thus, there is a need for policies promoting the adoption of new technologies by farmers, e.g., incentives, rewards, or subsidies. The refinement and simplicity of improved technologies are critical factors that influence the adoption process. In spite of ecological benefits, some technologies cannot be widely adopted by farmers if they result in even minor yield decreases, as in the case of no-till (NT) for winter-wheat in the NCP. Meanwhile, industrialization has led to increased migration of the younger population from rural areas to urban centers, leaving an aging farming population. Therefore, adopted technologies should provide savings in labor, time, and energy to alleviate the impacts of labor shortages.

4 Changes in farming practices

Climate change has strong impacts on agriculture, and in turn, agriculture practices can be adapted to the climate changes. For example, choosing suitable crop variety plays important an role in adaptations to climate change (i.e., high-temperature sensitive varieties) in the NCP (Tao and Zhang 2010). While an important aspect, crop breeding is not the only strategy towards adaptation to climate change. Indeed, farming practices (e.g., seeding, tillage and irrigation) have already evolved with agricultural development in response to growing food demands, climate change, and environmental conditions (Olesen et al. 2011).

4.1 Seeding

According to the cropping calendar in these sites, the appropriate seeding time for winter-wheat is from 10–20 October in the NCP. The average seeding dates of winter-wheat during 1981–2011 were 4 October, 24 October, and 30 September at Luancheng, Feixiang, and Huanghua, respectively (Table S3). Traditionally, most farmers have been used to seeding immediately after the summer-corn harvest because of the time-consuming tillage practices and seeding. Some scientists have hypothesized that appropriate seeding late in the winter-wheat season and extending the growing season of summer-corn in the NCP would optimize the use of climate and water resources (Sun et al. 2007). More than half of the annual precipitation in these regions occurs during the summer season (i.e., July and August). In addition, the critical water requirement period for summer-corn is during July and August. Therefore, extending the growing season of summer-corn is an adaptation strategy in response to the climate change. The increase in historic MAT and accumulated temperatures (Figs. 1 and 2) suggests that delaying the seeding date for winter-wheat is a feasible and practical option for the region. The supporting data regarding accumulated temperature indicate that delayed seeding of winter-wheat can prolong the growing season of summer-corn by 10–15 days in the NCP (Xiao and Tao 2012). Fu et al. (2009) indicated that delayed sowing of winter-wheat and delayed harvests of summer-corn, each by 10–15 days, increased the total yield of corn and wheat by 442–2575 kg ha^{-1}. Changes in these farming practices have been possible partly due to the increase in temperature during the winter-wheat season.

4.2 Tillage system

Conventional plow tillage (PT), plowing followed by secondary tillage (e.g., harrowing, levelling, and compacting), have traditionally been used in the NCP. Prior to the 1970s, the accumulated temperature was not adequate to ensure physiological maturity of both crops in a double cropping system in some regions of the NCP. With some adverse impacts on soil and time-consuming processes, PT also decreased the cropping duration. Consequently, some farmers burned crop residues in order to save time for seeding the next crop, which became a serious problem during the late 1990s. The conversion to a NT corn system, since the late 1970s, has been a revolutionary adaptation in the NCP. The time-consuming and energy–intensive PT system required ~20 days from harvesting winter-wheat to sowing summer-corn (Table S4). Conversion to a NT summer-corn strategy can save ~10–15 days by eliminating all primary and secondary tillage operations. The time saved is beneficial to summer-corn growth and yields. Compared to PT, NT for corn can reduce soil evaporation by ~40 %, and enhance water use efficiency (WUE) ~10–15 % (Zhang et al. 2002), which can alleviate water crisis in some extent in the NCP. Lower soil temperature under NT has been also reported, which is beneficial to corn growth in hot summer (Wang et al. 2012).

Winter-wheat farmers adopted rotary tillage (RT) due to its convenience and time-saving benefits. RT can chop crop residue, mix it in the soil, and also level the soil surface in one operation, saving approximately 5 days. Currently, RT is the principal tillage practice for winter-wheat in the NCP. A NT strategy for winter-wheat was used in 2000 for the first time, but was not widely adopted because of the poor seeding quality and low agronomic yield. Yet, conversion to NT extends the cropping duration, increases retention of rainfall in the soil, enhances SOC sequestration, and mitigates climate change. If the yield under NT is similar to that under CT, it also saves irrigation water by 40–60 mm, which can effectively alleviate the problems of groundwater depletion. Therefore, additional research is needed to improve the NT system for enhancing yield, particularly that of the winter-wheat.

4.3 Irrigation

It is important to develop and adopt water-saving technologies to decrease water consumption and increase WUE of crop production due to the severe water shortage in the NCP. Winter-wheat is a poorly suited crop for NCP due to the low precipitation during the growing season, which further aggravates water scarcity. For example, precipitation during the winter-wheat growing season in Luancheng is ~100–150 mm, far less than the water requirement (~450 mm) of this crop (Liu et al. 2002), and thus, irrigation for winter-wheat has also severely depleted the ground water (Liu et al. 2001). Nonetheless, winter-wheat is the principal grain crop in the NCP since time immemorial. Traditionally, farmers irrigated the winter-wheat for four to six times during the season, with the total water use of 300 to 400 mm, which severely jeopardized the groundwater reserves. Some long-term studies at China Agricultural University have indicated the need for only three irrigation regimens for the winter-wheat: (1) pre-sowing irrigation only, (2) pre-sowing irrigation + irrigation at jointing or booting stage, and (3) pre-sowing irrigation + irrigation at jointing and flowering stages. Grain yields of 5250–6000, 6000–6750, and 6750–7500 kg ha^{-1}, respectively, have been obtained using these irrigation regimens (Wang et al. 2006). Based on these regimens, a comprehensive crop production system for NCP includes irrigating three times to 150 mm (pre-sowing irrigation + irrigation at jointing and flowering stages), reducing N fertilizer inputs (15–30 kg ha^{-1} manure and 150–225 kg ha^{-1} N), and moderately delaying seeding dates (Wang et al. 2006). Results thus far indicate that it is possible to maintain relatively high yields and optimal WUE by refining irrigation schedules in respect to climate change.

5 Strategic responses and adaptations to climate change in the NCP

The problems posed by climate change in the NCP are more complex than elsewhere. Adaptations to climate change involve consideration of environmental, cultural, institutional, and economic factors and their interactions.

5.1 Policy options and coordinated actions

The strategies for adapting to climate change require innovations in policy and institutions. The latter encompass several levels, including support of technological innovation, extension and adoption of relevant technology, incentive plans, and education. To achieve the balanced use of water resources, the government of Hebei Province has initiated some projects that support innovations in water-saving technologies, improve agricultural infrastructure, promote the use of improved technologies, and adjust the cropping system.

Moreover, climate change and adaption is a complex issue, which needs a coordinated multidisciplinary response. Therefore, a coordinated effort is essential to improve research, extension, and education related to climate change and adaptation. While the government plays an important role in policy-making and implementation, it should also support research to develop innovative technologies, encourage farmers to adopt climate-smart technologies. Research must be focused on knowledge-based crop production systems for adaption to climate change. Farmers must be aware of climate change, and be willing to adopt innovative, adaptive, and climate-smart technologies. In 2014, universities and institutes in Beijing, Tianjin, and Hebei Province established an alliance to conduct research focused on the issues of climate change and water conservation. These actions will help bring adaptive technologies into practice and alleviate the water crises facing the NCP. Specifically, it is critical that small stakeholders can access, accept, and adopt the innovative technologies.

5.2 Adjustment of cropping systems and farming practices

Double cropping (i.e., winter-wheat and summer-corn) is the typical cropping system in the NCP. However, just as is analyzed above, limited water resources have become a bottleneck to sustainable agriculture development in the NCP. It would be nice to give up the winter-wheat to achieve water security, but this is not feasible because of the high food demand, and farmers' perceptions. Conversion to appropriate cropping system may be an effective strategy to cope with the severe water resource scarcity in the NCP. Rather than two crops per year, growing three crops in two years (spring-corn, winter-wheat, summer-corn) may be more appropriate for the NCP. The double cropping system of winter-wheat and summer-corn requires 470–850 mm of water under irrigated conditions (Mo et al. 2005) and an additional 300 mm for supplemental irrigation. However, changing double cropping every year to triple cropping every two years can reduce water consumption by approximately 400 mm (Guo et al. 2013). Another option is of planting alternative crops. For example, replacing rain fed for irrigated wheat can substantially reduce water consumption. Additionally, conservation agriculture is appropriate in the NCP because of multiple benefits (time, fuel, water, and labor saving).

5.3 Innovations in climate-smart agriculture technologies

Climate-smart agriculture has been widely accepted by policy makers and researchers due to the benefits of food security and climate change adaptation and mitigation. Innovations in climate-smart technology include the breeding of varieties tolerant to drought, and diseases and appropriate to holistic approaches of soil and crop management, and integrated pest and weed control. Small-size land holding in the NCP results in substantial losses of energy and resources. Currently, some large planter or cooperative organizations are consolidating land rented from farmers in the NCP, which will improve resource use efficiency and increase farmers' profits. Accordingly, the corresponding technologies associated with transition to climate smart agriculture should be strengthened in favor of resource-efficient and environment-friendly production systems as integral to climate-smart agriculture.

6 Conclusions

Climate change has strong impacts on environment, agriculture, and farming practices. During the past 30 years (1981–2011), the mean temperature has increased significantly for the winter-wheat season and the whole year in the three typical sites of the NCP, but no significant increase for the summer-corn seasons. The mean annual precipitation has large inter-annual fluctuations. Currently, serious challenges (e.g. water scarcity, high input, low economic profit, and labor shortage) are threatening the agriculture sustainability of the NCP. Meanwhile, the climatic changes may aggravate the already worse agricultural situations in the NCP. Changes of farming practices, such as adjusting the sowing date, converting tillage system, adopting water-saving technologies, can adapt or mitigate climate change to some degree. Climate-smart agriculture technologies may play important roles in adapting climate change by enhancing the management of soil and water resources, ensuring food security, improving resources use efficiency, and reducing C emissions. In addition, it needs a concerted and coordinated involvement and action of all stakeholders in the NCP to adapt or alleviate the challenges.

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