
Case Study 1: China Benefiting from Global Warming: Agricultural Production in Northeast China

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1 Introduction

Adaptation to climate change is crucial for China due to its huge population and various and vulnerable ecosystems. Water resources, forests and coastal zones will be the most likely affected sectors (IPCC 2001). Agriculture will, however, continue to be the most important sector to adapt to climate change: nearly 70 per cent of China's population depends directly on agriculture. Like other developing countries, China will need to develop adaptation strategies imposed by climate change against the background of existing poverty, resource and infrastructure constraints.

Northeast China was selected for this case study because it illustrates how anticipatory adaptation can lead to positive impacts from climate change in agriculture. This region is already one of the most important bases of commercial food grains (wheat, rice and maize) and economic crops (soybean, sugar beets) in China and possesses many state-owned agricultural ranchers that run field production like factories and realise adaptation measures quickly. Recent climate warming has on the one hand created favourable conditions for agricultural development in Northeast China through a prolonged growth period, northward movement of accumulated temperature belts and decreases of cold stress. On the other hand, environment and natural resource problems (e.g. water shortage, urbanisation) have placed enormous regional stress on agricultural production and ecosystems, illustrating the complex nature of the impacts of climate change. This case

study analyses the adaptation efforts of key actors active in agriculture production in Northeast China: farmers, non-government communities, country cooperation credit organisations, agricultural technology dissemination groups and the central and local governments. An examination of their adaptation actions demonstrates that the positive opportunities provided by climate change will not happen automatically but will require communities to be supported through resources such as extension services, new crop varieties and institutional frameworks that allow experimentation and reward entrepreneurship. Over the longer term and at higher temperatures, the negative impacts of climate change, such as increased water stress and extreme events, may decrease or reverse the benefits of climate change (IPCC 2001).

Section 2 of this study introduces the climate change status and the political-economic facts of Northeast China. Section 3 looks at agricultural production in the case study area in more detail and the role of different players in adaptation strategies and outcomes. Section 4 sets out the lessons learnt. Northeast China is demonstrated to be eager to adapt to climate change and benefits from the warming temperature, although different players have different requirements as far as adaptation support is concerned. A key factor in successful adaptation is the enthusiasm of farmers, activities of non-government communities to react to adverse conditions, support of agricultural technology dissemination groups and agricultural

Table 1: Key National Socio-economic Indicators in China

Criteria	1994	2000
Population (billion)	1.1985	1.26743
Natural growth rate of population (‰)	11.21	7.58
Ratio of population employed in 3 industries (%) [*]	54.3:22.7:23.0	50.0:22.5:27.5
Total GDP (trillion US\$)	0.5430	1.0808
<i>Per capita</i> GDP (US\$)	453	856
Ratio of 3 industries in GDP (%) [*]	20.2:47.9:31.9	16.4:50.2:33.4
Poverty population (million)	70	30

^{*}Agriculture, Industry, Service sector

Source: NBSC (2003).

policies and directions implemented by central and local governments. The concluding section provides valuable experiences that can be shared by stakeholders in other regions with similar circumstances.

2 Climate change and China

2.1 China's national circumstances

China's political system

China's fundamental political structures are organised around the People's Congress system. The National People's Congress (NPC) is the highest organ of state power. Local people's congresses are local organs of state power. The NPC and local people's congresses are established through democratic elections, responsible to and supervised by the people. State administrative, judicial and executive organs are created by, responsible to and supervised by the people's congresses. The multi-party cooperation and political consultation under the leadership of the Communist Party of China is the basic political system in China.

China's natural and socio-economic circumstances

China is situated in the Eastern hemisphere, in the east of Asia and to the west of the Pacific Ocean, with a land area of about 9.6 million sq km and an ocean area of about 4.73 million sq km. China is a vast populous, low-income developing country, supporting 22 per cent of the world's population on 7 per cent of global cropland. A low economic level results in a large poverty population¹ in rural areas. Since 1986, the Chinese government has been taking a series of measures to combat poverty, reducing the

poverty population from 125 million in 1986 to 30 million in 2000. Significantly for this case study, most of those in "poverty populations", i.e. who fail to resolve subsistence problems, live in 'Natural Obstacle Zones', which are unsuitable for human survival, or in the severely environmentally and ecologically overloaded areas. Consequently, poverty alleviation is a very difficult task.

China is one of the biggest developing countries in the world with a *per capita* gross domestic product (GDP) of US\$856 in 2000, which is only one-sixth of the world average and one-thirtieth of high-income countries. Its economy is characterised by imbalanced development between regions, with a *per capita* GDP ratio of 1:0.56:0.43 between the eastern coastal region, central region, and western region, respectively in 2000. The mainland population in 2000 was 1.26743 billion with the natural growth rate of 7.58‰ compared with over 25.0‰ in 1970. The key national socio-economic circumstances are listed in Table 1.

China's national development plan

The 13th National Congress of the Communist Party of China report noted that from 1978, a three-step strategy would be adopted in China's economic construction. First, doubling the 1980 GDP by the end of the 1980s (*per capita* GDP was US\$250 in 1980, doubling to US\$500 by 1990), thereby solving the problem of feeding and clothing the people; second, again doubling the GDP by the end of the twentieth century (*per capita* GDP reached US\$800–1000); and third, quadruple the twentieth century GDP by year 2050, thereby bringing China up to the level of a moderately developed country (*per capita* GDP US\$4000).

Table 2: Change of Surface Air Temperature and Precipitation in China Projected by 40 General Circulation Models (GCMs) Under Four Emission Scenarios (Change Relative to the Average of 1961–90)

	Scenario	2030	2050	2070	2100
Temperature (°C)	GG	2.8	3.3	4.4	6.0
	GS	2.0	2.3	3.4	5.1
	A2	1.5	2.3	3.8	5.6
	B2	1.5	2.4	2.9	3.9
	Average	1.9	2.7	3.6	5.2
Precipitation (%)	GG	9	14	22	17
	GS	-9	0	14	9
	A2	-6	7	8	16
	B2	10	9	7	12
	Average	1	8	13	14

GG: Equivalent CO₂ concentrate in the atmosphere increased continuously by 1% per year from 1990 onwards. GS: Equivalent CO₂ concentrate in the atmosphere increased continuously by 1% per year from 1990 onwards, and taking into account the interaction with aerosol. A2: IPCC-designed middle-high emission scenario. B2: IPCC-designed middle-low emission scenario.

China's vast population brings great challenges: the population will reach its peak of 1.5–1.6 billion in approximately 2030. If the population increase exceeds this estimate, the upper population limit will become uncertain and will bring increased pressure on the development plan.

China's climatic and land use status

China's climate is characterised predominantly by a continental monsoon climate and other complex climate types that bring complex and diversified natural features, different environment conditions and pose various natural disaster threats. Its climate differs greatly by region, but most areas are located in the subtropical zone, the warm temperate zone and the temperate zone. The average annual rainfall varies from 1,500 to 2,000 mm in southeastern areas, to less than 50 mm in the western arid basins. Rainfall is mainly concentrated in summer, resulting in frequent flooding and storms in the southeast and drought, desertification and land degradation in the northwest. For this case study, it is especially important to note that China's water resources are distributed unevenly in terms of time and place, with a perennial average ground surface water resource of 2.81 trillion m³ and one-quarter of the world average water resources *per capita* (NBSC 2003).

China has various land resources including (in 2000) 130.04 million ha of cropland, concentrated in the east of China and 400 million ha of grassland with a usable area of 313.33 million ha (NBSC 2003). Temperate grassland in northern China, affected by drought, ecological deterioration, overgrazing and reclamation, currently faces a crisis of degradation and desertification. The fifth national forest survey (1994–8) showed that the area of forest land was 158.941 million ha; a coverage of 16.55 per cent of the total land area of China, but a lower than world average tree volume accumulation, low stand quality and irregular forest age structure. Decreasing felling resources occur as woodland is converted to other land types and expropriated.

2.2 Expected climate impacts

Corresponding with the general global warming trend, the 1990s were one of the warmest decades in China's last 100 years. The most obvious warming occurred in north China while warming trends were not so obvious in the south. Seasonal warming in winter was significant.

About 40 general circulation models (GCMs) projected increased surface air temperature in China over the next 100 years under four emission scenarios. The air temperature would increase 2.3–3.3°C and 3.9–6.0°C, respectively by 2050 and

2100 (Table 2). Precipitation would generally increase by 9–17 per cent by 2100, though the detailed projected results between various GCMs are different (Table 2). The Ministry of Science and Technology, the Natural Science Foundation and the Administration of Meteorology all support the relevant climate change and impact assessment projects. Chinese Scientists also projected the same climate change trend using the RCM-PRECISE model and other Chinese regional circulation models (RCMs) based on nationally supported projects and other bilateral cooperative projects (China-UK, China-USA, China-Germany, China-Japan joint projects). The RCM simulated that the increment of temperature would be higher in winter and lower in spring, with an increase in temperature variability over the next 100 years (Xu *et al.* 2003). Precipitation would increase in southern China but decrease in the north, northwest and the south of the Northeast. Expected extreme cold disaster events would decrease, while extreme high temperature events would increase. Undoubtedly, future droughts in northern China and floods in southern China would increase.

Historical data shows that the runoff of six major rivers in China decreased in the past 40 years: the annual average runoff in the whole drainage area of the Haihe river and Luanhe river decreased by 46.2 per cent during 1980–9 against 1956–79. Continuous drought in north China and frequent floods in southern China occurred since 1980 as projected by Chinese scientists using hydrological models. The assessment showed that the future average annual runoff in some provinces (i.e. Ningxia, Gansu, Sha'anxi, Shanxi) of northern China would likely decrease by 2–10 per cent, while it would increase by 24 per cent in some provinces (i.e. Hubei, Hunan, Chongqing, Jiangxi, Fujian, Zhejiang, Guangxi, Guangdong, Yunnan) of southern China in the next 70–90 years (China's Initial National Communication 2004). RCM-PRECISE also projected the same trend (AMI 2004). Water shortage would deteriorate in north China in the next 50–100 years, consequently affecting regional sustainable development. The mountain glaciers also showed shrinking in China (Shi and Liu 2000), posing a threat to future glacier use.

Under the projected climate, the distribution of resources will spatiotemporally change, consequently affecting cropping systems. Some predictions showed that the area of multi-cropping

systems might increase in the future (Zhang 2000; Zhao 1995). However, climate warming, which could speed up crop growth and also shorten the crop growth period, would negatively impact the accumulation of dry matter and seed yield.

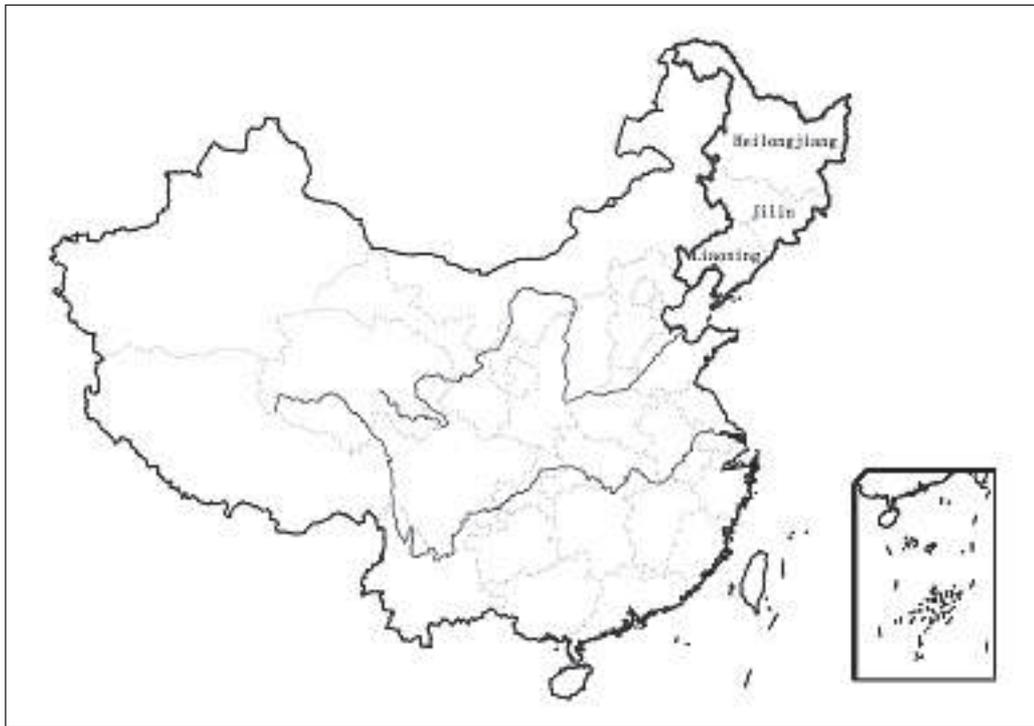
The yield of main crops would decrease under doubled CO₂ scenarios and climate warming in the twenty-first century (AMI 2004). Such decreases indicate potential food production decreases by 10 per cent by 2030–50 due to limitation of other factors such as unsuitable crop varieties, water shortage, extreme events and shortening crop growing period (see China's Initial National Communication 2004).

The projected dryness in northern China would result in the eastward movement of grassland (Zhao 1995). For forests, actual production might not increase as pest and disease problems would also likely increase, although some preliminary simulations did show increased production (Zhou and Zhang 1996; Xu *et al.* 1997; Peng *et al.* 2000). Climate warming would significantly impact on frozen earth, marsh, deserts, glacier and biodiversities in China (Ding 1998; Ci 1994; Wang and Liu *et al.* 2004).

Average sea level rise has been 1.4–2.6 mm/yr in recent years, with projected relative sea level rise of 31–65 cm in the five coastal areas up to 2100 (Du and Zhang 2000). Sea level rise has caused seashore erosion (Xia *et al.* 1993) and seawater invasion (Zhou 1998), potentially influencing fresh water supply and impacting upon socio-economic development of coastal areas, currently the most developed regions in China.

2.3 Key institutional and policy processes

China has begun to pay more and more attention to climate change issues. As early as 1990, the Coordination Committee on Climate Change was established. The up-to-date National Coordination Committee on Climate Change (NCCCC) was approved by the State Council in 2003. The NCCCC provides guidance both nationally and locally. The Office of the NCCCC is situated in the National Development and Reform Commission and hosts a diversity of other Ministry members responsible for deliberation and coordination on climate-related policy issues and activities. Major issues are submitted to the State Council for directions and guidance. China's Initial National Communication was submitted to the United Nations Framework

Figure 1: Map of China. The Location of the Case Study Region: Northeastern China

Convention on Climate Change (UNFCCC) in November 2004. This provides a detailed assessment of climate change impacts on China across all sectors as well as China's response in terms of mitigation and adaptation strategies.

Since 1990, a number of laws and regulations have been enacted in order to protect natural resources and adapt to climate change. In addition to specific measures taken, China also formulated long-term eco-environment development plans emphasising sustainable development including cultivating new stress, disease and pest-resistant crop varieties, converting some cropland to forest and grassland, improving agricultural infrastructure, stopping deforestation, expanding the area of natural reserves, strengthening the monitoring, forecasting, and early warning systems for control of fire, disease and pests of forest and pasture, raising the standard of embankments and strengthening the construction of coastal infrastructure against the tides.

Facing the double pressure of rapid economic development and environmental protection, China is in urgent need of assistance in funds, technologies

and capabilities to enhance its capacity to mitigate and adapt to climate change.

3 Adaptation and agriculture in Northeast China

3.1 Background

Northeast China experiences an eastern monsoon climate, entirely dominated by alternating continental and maritime monsoons featuring humid temperate climates, and comprises a total area of 790,000 km² with a population of about 107 million in 2002 (NBSC 2003). A high-latitude location (approximately 39°–53°N), makes it the coolest area in China with long and severe winters. Annual precipitation decreases from southeast (Tonghua: 900 mm) to northwest (about 400 mm) as the distance from the sea increases. Precipitation is generally concentrated in the summer and autumn, coinciding with the growing season, yet harvesting is sometimes at risk because of the flood hazard in the low plains. Spring drought is often a problem, and supplementary irrigation is necessary (Zhao 1994). The location of the region is shown in Figure 1.

Table 3: Key Economic Indicators in Northeastern China (2002)

Indicators	Liaoning	Jilin	Heilongjiang	Total	Share of China (%)
Population (million)	42.0	27.0	38.1	107.1	8.3
Area (x 10 ³ km ²)	150	190	450	790	8.2
GDP (x 10 ⁹ yuan)	5458	2243	3902	11603	11.0
Area of cultivated land (million ha)	130.0	4.2	5.6	11.8	16.6
GDP <i>per capita</i> (yuan)	13000	8322	10235	9390.4*	117.4**
Annual <i>per capita</i> disposable income of rural residents (yuan)	2751.3	2301.0	2405.2	2514.7*	101.6**
Total yield of wheat (x 10 ³ tons)	115	79	894	1088	1.2
Total yield of rice (x 10 ³ tons)	4062	3700	9210	16972	9.7
Total yield of maize (x 10 ³ tons)	8580	15400	10705	34685	28.6
Total yield of beans (x 10 ³ tons)	569	1850	6107	8526	38.0

*The average value in the region. **The equilibrium of regional average value to the national average value.
Source: NBSC (2003).

The region is physiographically diverse and ecologically rich in nature. The Northeast China Plain and the Sanjiang Plain, comprise the largest modern pioneer settlement belts in China, and the surrounding mountains form the largest timber-producing areas. Comparatively abundant precipitation and low evaporation rates in addition to densely forested mountains ensure relatively good water resources along with the Heilongjiang (Amur river) and its tributaries forming a river network second only to the Changjiang (Yangtz) in annual discharge.

Northeast China plays a vital role in China's economic development with its fertile land, developed industry and higher urbanisation. It is one of the most important bases of commercial food grains and economic crops (soybean, sugar beets) in China. It is also a hot-spot of land use because of its relatively high food production potential, and partly because of its rapid socio-economic change reliant on the land (Table 3). The northern part of this division uses one-crop/year farming systems, whereas in southern Liaoning Province, three crops in two years are possible. The region has the largest timber-producing area in China with the most important species including red pine, larch and some hardwoods.

Impacts of climate change on agriculture

Since the 1980s, Northeast China has experienced the most obvious national climate warming with an annual mean temperature rise of 1.0–2.5°C

compared with the 1960s–70s (Ye 1992). The growing period of crops increased and disasters reduced, creating favourable conditions for crop growth. Accordingly, in order for climate warming adaptation, adjustments of composition and structure of crops (including the alteration of crop species) in the region were conducted by governments and farmers. Due to northward movement of the accumulated temperature belt, the potential arable land greatly enlarged and total grain production in the region rapidly increased. The features of recent climate change and its impacts in Northeast China are summarised in Box 1.

While temperature increases create the potential for increased growing, the water system in the Northeast China is highly vulnerable to climate change. Even a minor change in the average climate indicators will cause significant change in runoff. Plains along the middle and lower reaches of its major rivers are more vulnerable to floods but also contain agricultural and industrial centres, and high population intensities. With climate warming, various weather systems are likely to become more active, and droughts, floods, heat waves and deep freezes are likely to happen more frequently (Zhang *et al.* 2003).

The semi-arid areas and areas with frequent drought damage in Northeast China are the most vulnerable to droughts. The irrigation systems and drought control measures in these areas are relatively weak, so the Songliao Plains exhibit poor adaptability. With the lowest water resources *per*

Box 1: Features of Recent Climate Change and its Impacts in Northeast China

Research indicates that Northeast China is one of the areas that has been experiencing warming over the last 100 years (Ding 1993). The annual precipitation has been decreasing since 1965, while average temperatures have risen by up to 1°C. Warming and drier trends are very significant in the recent decade. Temperature increase occurs mainly in winter, while due mainly to a decrease in summer precipitation, annual totals have decreased in Northeast China (Zhai *et al.* 2003). The temperature increases in the last 20 years might be mainly caused as a result of increased greenhouse effect. Moreover, as a result of the greenhouse effect, the lowest temperature is on the rise, while the difference between daytime temperature and night temperature has narrowed markedly (Zhang *et al.* 2003). There will be an overall increase in temperature, and either an increase or decrease in precipitation resulting in flooding or eventual water supply shortages, an increase in severity and frequency of extreme weather such as damaging floods and droughts, and crop production will be affected on remaining arable land. However, the predicted impacts to crop yields vary widely due to the uncertainty around water supply and the possibly positive effects of CO₂ on crop production. Large shifts in the remaining boreal forests, increased forest fire and wider distribution of many vector-borne diseases are likely related to climate change in this region. The climate change-induced trend of desertification has been controlled in varying degrees (RTCCCS 1999). Increased urbanisation and industrialisation also places environmental stress on surrounding areas which is likely to be exacerbated by climate change.

capita and poor ability to close the gap between the water supply and demand, the basins of the Liao will face the most serious water resource scarcity. The water levels of many lakes in Northeast China have been falling and some lakes are even disappearing.

3.2 The adaptation story

Main adaptation processes

Principal adaptation processes began with agriculture reform in China with cropping system adjustments that crosscut the adaptation processes. Each province is now diversifying its cropping systems trying to make the best use of land resources for crops suitable to local conditions. Climate change may lead to a general increase in heat resources in various farming regions in northern China. Based solely on this, we can predict that the cropping system will probably undergo two changes:

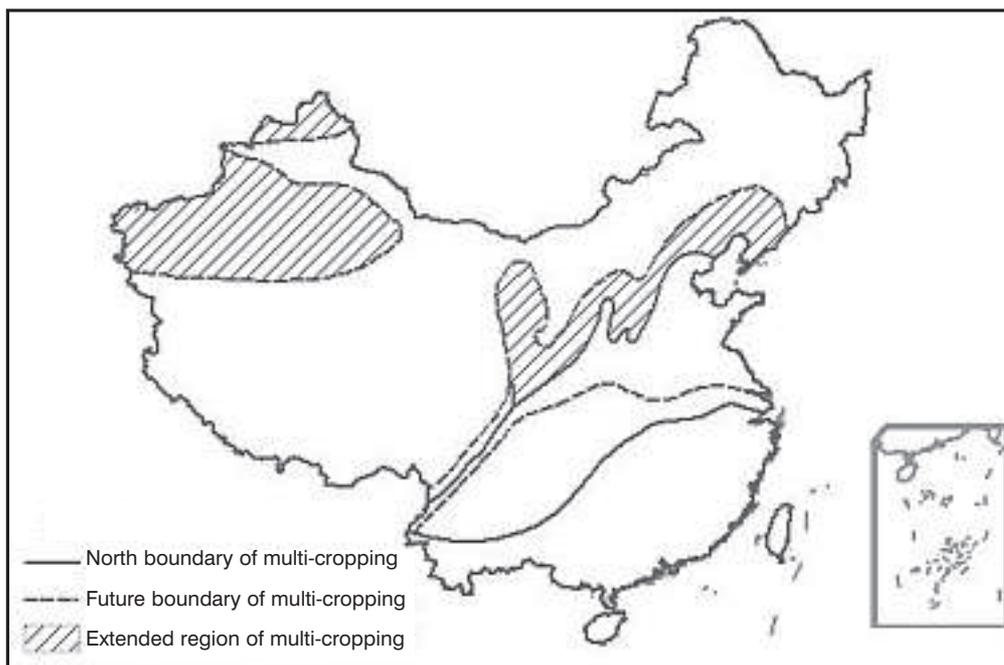
1. The northern boundary of areas currently under multiple-cropping system will move further north as well as west (see Figure 2; Zhang *et al.* 2003).
2. The timing of crop maturity will change from early to mid and late maturity. With global warming, various weather systems are likely to become more active. The unsteady climate

conditions alongside changing cropping systems will lead to more frequent hazards, such as droughts, floods and heat waves.

As an adaptive option, adjusting cropping systems was considered an effective measure to promote crop production and to increase farmers' income. Although cropping system changes are influenced by many factors such as policy, markets, natural resources and technical development, climate change as a whole, including temperature increase (winter warming and accumulated temperature increase) and frequent occurrence of droughts and floods, is one of the important factors leading to such system changes. In particular, taking water availability as a serious problem for crop production due to the region's increased drought frequency during the 1990s means adaptive options such as crop changing are urgently needed.

The largest problem facing all major maize-producing regions since the 1980s was water shortage caused by changing climate. The key solution to this problem was to improve water conservation and promote water-saving agriculture. After several years of continuous decline of food crop yields since 1999, food security issues emerged and led to new policy in promoting grain production in 2004. Therefore, enhancing food crop production

Figure 2: The Possible Changes in Cropping Systems in China Under Climate Change Scenarios



Source: Zhang (2001).

potential to ensure food security created a new round of changes for cropping systems in the region. The movement of winter wheat northwards and rapid expansion of rice planting areas, two adaptive options, played an important role during the changes of cropping systems in Northeast China, and could be partly considered as responses to climate change and increased temperature.

Winter wheat northwards

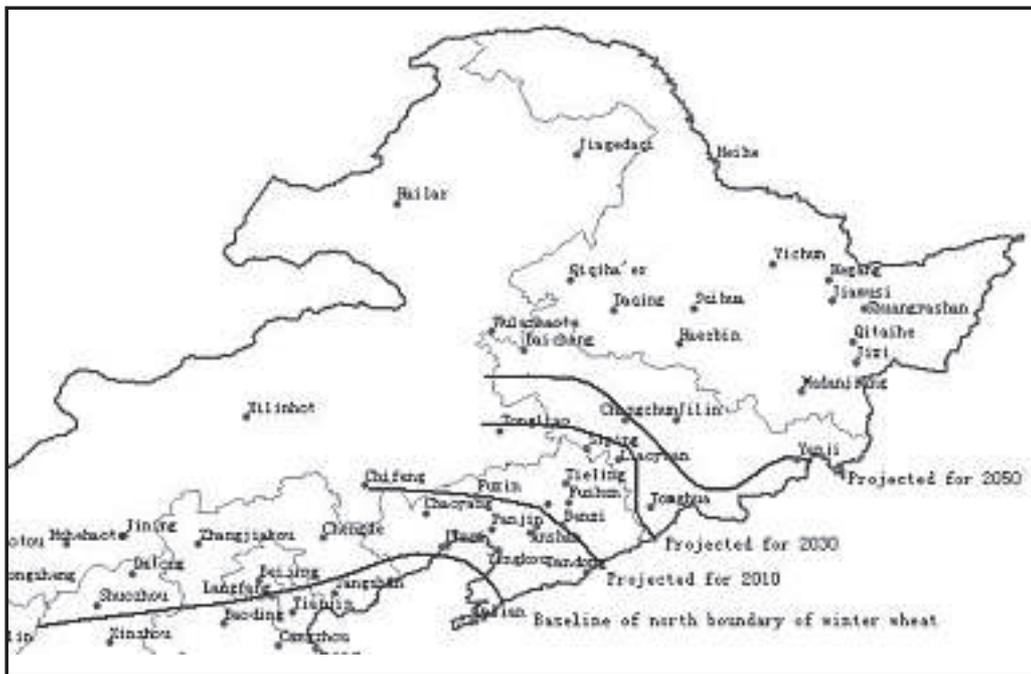
The large-scale experiments on winter wheat northwards in Northeast China began in the 1970s, as winter warming was identified. The research focused on new variety selection and their adaptive abilities in the target regions and made significant progress in the 1990s (Hou *et al.* 1996). Since the 1980s, farmers in Northeast China, as well as in north China, had systematically begun to plant winter wheat instead of spring wheat, in order to raise yields and improve the wheat-flour quality. This change led the northern boundary of areas to move further north and west. In the south part of Northeast China, two-crop/year systems replaced one-crop systems,

increasing crop yields. New varieties were adopted and the timing of crop maturity changed from early to mid and late maturity. The positive effects of winter wheat expansion in the south of the region had been achieved, in contrast to failures in other regions, such as the north and west parts of the region (Hou 1999; Hao *et al.* 2001). Figure 3 shows the projected movement trends of winter wheat.

As farmers practised winter wheat further northwards, supported by enhanced extension practices, the scientists began to study the problems emerging in this production (Box 3). It is expected winter wheat cropping in northern China will steadily develop in the future as a result of winter warming and as extension systems for cultivation techniques are strengthened (Sun 1997).

Rapid expansion of rice planting areas

Rapid expansion of rice planting areas in Northeast China held a similar process to the winter wheat northwards. Northeast China's favourable climate and fertile soil allows better quality rice to be grown, thus increased demand for 'Northeast Rice' and

Figure 3: Changes of Northern Boundary of Areas for Winter Wheat in Northeast China

Source: Jin *et al.* (1998).

favourable policies in promoting food grain crop production led to a continuous increase both for planting areas and yields in the last two decades. Increased temperatures and the new rice varieties, renewed several times during the last two decades, played an important role in the rapid expansion of rice planting areas and increasing yields.

With temperature increases, all the Three River Basins and the area to the south are able to grow rice: temperature is the key constraining factor for rice planting in Heilongjiang Province. Rice planting areas increased significantly since the 1990s with the increased temperature (following decreases during 1960s and 1970s with the decreased temperature during 1956 and 1969; Table 4).

Water availability is also a major constraint on rice production in the region. With frequent occurrence of droughts in recent years (e.g. the three years continuous drought in 1995–7 and extraordinarily serious drought in 2000), the water shortage for expanding rice cropping and eventually for the whole water use of agricultural irrigation,

is facing a tremendous challenge (Wang *et al.* 2002). The total rice cropping areas will decrease, in particular, where irrigation is not provided and planting risk may increase in adverse climate years. Controlling increased extreme weather events such as damaging floods and droughts, efficient water management and water-saving techniques must be adopted in order to use late maturity strains and multiple-cropping systems, adopted to increase output with temperature rise.

Key players in Northeast China

It should be first noted that climate change has both positive and negative effects on agriculture in Northeast China. Our introduction is mainly on what has been done to take advantage of the benefit, especially when adaptation was taken into account, however the adverse impacts, like drought and ecological degradation are also serious. These must be studied further and taken into account in adaptation responses to climate change.

This case study shows farmers are the frontline players in climate change response campaign.

Box 2: Principal Research Results on Winter Northwards in Northeast China

Objectives of research

To provide adaptive varieties, improved cropping practices to reduce the cropping risk and raise the wheat yields.

Importance of expanding winter wheat cropping in northern China

- Utilise the expanded growing period and raise cropping index
- Improve wheat quality, reduce production costs and make wheat production more effective; and
- Raise grain food crop production.

The existing problems for winter wheat northwards

- Poor grain quality of winter wheat in the expanded winter wheat cropping regions
- Cultivation practices such as water and nutrients management need to be improved
- The new adapted winter wheat variety needs cold and drought resistance to improve over-wintering rate.

Conclusion

To shift winter wheat northwards successfully requires new varieties and improved cultivation techniques based on regional cost-benefit-analysis.

Source: Hou and Chen (1996); Sun (1997); Zou et al. (2001).

Household Responsibility Systems, adopted in 1978, gave arable land use rights and autonomy for growing decisions to farmer households. This legal change allowed farmers the right to proactively experiment to take advantage of changing conditions based on their own understandings and judgements. Most options taken by local farmers are spontaneous adaptation and they learn through trial and error and knowledge from other farmers.

Changtu County in Liaoning Province is located in the south part of Northeast China. The spring wheat sowing date used to be at the beginning of May, but with climate warming, especially after 1990, some farmers could start their earliest sowing date at the end of March, and convert to longer growth period varieties providing increased production.

State-owned farms are well placed to take advantage of adverse conditions to improve performance. State-owned farms run field production like factories: communities have certain members working in the fields together and earning salaries like workers. To raise potential benefits and minimise disasters for farm groups, state-owned farms usually provide anticipatory advisers and a formulated annual planting agenda based on production markets and

weather conditions. If planting plans are approved by leaders or majority of the group, all members put them into action. As the communities usually easily get attention from government or technology assistance organisations, they quickly receive the latest techniques and information to deal with bad weather or extreme events. This enables them to respond quickly to take advantage of new climatic information and agricultural techniques.

In recent years, state-owned farms have adopted many modern techniques to use improved thermal conditions and take advantage of high machinery rates of field management (90 per cent in some farms) and the 'High Quality Grain Program', which will give techniques and capital assistance to target farms, including 32 state-owned farms in Heilongjiang Province.

Agricultural technology dissemination groups give substantial technical support to cope with climate change and extreme climate events. There exists an agricultural dissemination network in China; this system involves different level stations responsible for different government/municipal scales to give practical demonstrations for local farmers. Special attention has been paid to demonstrating techniques used for thermal accumulation increases on special

Table 4: Changes of Rice Cropping Area in Heilongjiang Province

	1949	1956	1963	1974	1984	1992	1997
Area (x 10 ⁹ ha)	112	294	123	165	278	778	1397

Source: Fang and Sheng (2000).

Table 5: Highlight of Key Issues of Each Player

Stakeholders	Key roles
Farmers	Minimise the loss and enlarge benefit through different crops or variety
State-owned farm	Cooperate with technique-assisting organisations and local governments to get latest information on climate change adaptation options and strategies; establish reactions promptly and maximise benefits
Capital organisations such as County Cooperation Credit Organisations or insurance companies	Provide proper loan approaches or insurance service for farmers and broader loan aspects regarding climate change
Agricultural technology dissemination group	Give better practical file management approaches related to climate change; tell farmers how to utilise warming to avoid negative impact; introduce new varieties and planting patterns according to climate change
Central and local government	Formulate relevant policies and development plans related to climate change; provide investments to deal with climate change

crops and livestock farming. For instance, as most regions in Heilongjiang Province become drier, insect pests and weeds appear earlier in spring and sustain longer in autumn, causing more crop loss and an increase in protection costs. The network has disseminated drought and disease resistance rice variety 'Longgeng 8' to cope with such problems and it has received good results. The dissemination network also gives advice on planting and cultivation according to local weather, and pest and disease conditions, and predicts production levels under certain weather conditions; all this information is useful to help farmers to cope with present day weather and longer term climate trends.

Climate warming makes it possible to optimise the agricultural structure and planting patterns in Tieling City of Liaoning Province. Following thermal accumulation increase after the 1980s, the dissemination group recognised a maize–wheat

interval planting pattern was becoming possible, subsequently giving demonstrations of this planting pattern in many sites. The pattern meant spring sowing of wheat in March and harvesting in early July, while simultaneously insetting maize in the same field. Early-maturing maize varieties were gradually replaced by medium- and late-maturing varieties, and increased production benefits were soon successfully adopted by local farmers. In these conditions, frost harm is reduced and agro-ecological zones move northwards, providing more options for seeding regimes. Thus technical demonstration bases have successfully conveyed experiences to farmers through practical demonstrations and now contribute to more than 70 per cent of agriculture in Heilongjiang Province.

Capital organisations such as County Cooperation Credit Organisations or insurance companies provide financial support. Farmers could borrow money from

Table 6: Effectiveness of Adapting Agriculture to Climate Change in Northeast China During the Period 1982–2002

Items		1982	2002	Increment ratio
The total crop sown area (million ha)		16.33	17.66	8.6%
Total grain output (million tons)		11.50	29.41	155.7%
Per unit area yield in Northeast China (tons/ha)	Rice	5.19	6.13	18.1%
	Wheat	1.42	3.45	143.0%
	Maize	3.64	5.63	54.7%
<i>Per capita</i> annual grain possession (kg)		361.6	627.9*	73.6%
Total grain output in China (million tons)		353.4	457.1	29.3%

*The current annual *per capita* grain consumption in China is 385 kg.

Sources: The Statistics Bureau of Heilongjiang Province (1992–2003); The Statistics Bureau of Jilin Province (1992–2003); The Statistics Bureau of Liaoning Province (1993–2003); NBSC (2003).

County Cooperation Credit Organisations to buy seeds and fertiliser, using money to start new agricultural activities following weather disasters. Therefore, credit organisations give some financial support for people to cope with climate change disasters. China has also planned to launch two specialised agricultural insurance companies in Northeast China in the next two years to better serve the local demands for agricultural insurance. Both agriculture and farmers need insurance to be better protected from risks and unexpected adverse climates.

Central and local government make adaptation strategies for climatic change. The Chinese government is strengthening efforts to address the consequences brought by global climate change. The NCCCC is serving as a guide for actions to address the potential impacts of climate change. The Ministry of Agriculture also organised actions to enhance adaptation. On local scales, local policy makers follow the regional integrated development blueprint promoting agricultural development or natural environmental construction, reducing negative impacts and taking advantage of climate benefits providing opportunities to establish adaptation strategies for agriculture under climate change or extreme events.

The central government has taken a series of measures to increase food production and farmers' incomes, such as offering better seeds to farmer, improving machinery application, and stabilising crop price. This year in Northeast China's Heilongjiang and Jilin Provinces, farmers have been exempt from paying agricultural tax on a trial basis.

Although these measures are not specifically for climate change adaptation, they are still providing win–win solutions and demonstrating ways in which institutional responses can serve to turn potential adverse impacts into positive climate benefits.

A farmer's climate adaptation story

Huang Xianguo, a local farmer in his 50s in Anshan City of Northeast China's Liaoning Province, is more confident with his crop production and selling. He made use of the arable land use rights of 1978 (see above) which gave autonomy for growing decisions to farmer households. In 2000, he contracted 87 ha of cultivated land for a term of 30 years. In the first year, he did not have a corn harvest due to problems with access to technology, the affects of drought and management challenges. In 2001, his per-hectare output of corn reached 11,250 kg, and his family annual income was nearly 300,000 yuan (about US\$37,000). Huang said his successful harvests are due to technologies that fully utilised the year's good climate and to government agricultural policies. As a farmer owning a large-scale planting field, he has superiority in operation scale and low costs in machine planting. He was able to utilise technology and scientific management efficiently through help or advice from the agricultural technology dissemination network. The network provided him with advice on seed selection and cultivation, seed packages, virus destruction and an increase in seed fertilisation, as well as the use of a potash fertiliser. As a result, Huang was able to take advantage of climate

warming and considerably improve his household income. Huang's experience shows some climatic change benefits could be explored through combination efforts between individual farmers, extension staff, technology institutes and governments alongside adequate financial support.

Financial support to key players

Dedicated financial support to reduce adverse climate change impacts is very rare at present in China. The capital to fund climate adaptation could possibly be retrieved from related development programmes illustrating that adaptation and poverty relief can be brought into sustainable development plans. The government normally distributes some capital for natural disaster relief programmes, and usually provides some money or subsistence donations to stricken people. However, all of this support is not enough for affected people needing to rebuild homes and resume production processes. Article 4 of UNFCCC, which mandates Annex II countries to provide resources to developing countries to help them adapt to climatic change, is therefore relevant. But thus far the amount of finances available from Convention funds have not been sufficient to meet adaptation needs.

As a result, most of China's financial support to farmers for coping with climate variability and change comes mainly from poverty relief programmes. An example includes the launch in 2001 of a large poverty-relief relocation programme in the Liaoning Province of Northeast China. This is relocating farmers and families from arid, inhospitable and poor areas into regions that are not as constrained in terms of their natural resource base and economic opportunities. The farmers are relocated on a voluntary basis and each of the farmer households willing to move will get 11,000 yuan (US\$1,300) of assistance. The migrants are resettled in the relatively developed regions with an abundance of farmland. Because jobs in industry or services are more readily available, this is an effective indirect approach to help vulnerable people to cope with climate change risk.

3.3 Adaptation benefits

Enhanced agricultural production

Northeast China experienced climate warming in the past two decades leading to favourable conditions for crop growth. Readjustments of crop composition and structure, enlargement of sown

areas and adoption of advanced technologies has successively increased the total grain output in Northeast China by 8.6 per cent in the period 1982–2002. Due to the northward movement of accumulated temperature belt, the growing belts of rice and maize moved 200–300 km northward. At the same time, total grain output in Northeast China increased 155.7 per cent (in comparison to the national output increase of 29.3 per cent; Table 6). Nowadays, the outputs of maize and soybean in Northeast China account for 30 per cent and 40 per cent of the nation's total, respectively (Bi and Li 2004). Agricultural development in Northeast China in recent years made it the biggest commercial food grain base in China and now accounts for one-third of China's total commercial output. The changes facilitated the adaptation of China's agriculture to climate change.

Improved regional well-being

Alongside the development of agriculture and other beneficial policies, *per capita* annual net income of rural households greatly increased. *Per capita* annual net income of rural households increased 222.6 per cent between 1987 and 2002, from 510.5 yuan (about US\$96.32) in 1987 to 2517.0 yuan (about US\$310.7) in 2002. The poverty ratio in Northeast China reduced as farmers' living situations greatly improved. The majority of households now have enough food and better living conditions, including rapid increases in rural telephone subscribers from 0.65 per cent rural households in 1985 to 37.41 per cent in 2002 (The Statistics Bureau of Heilongjiang Province 1992–2003). Highroads can now access most villages, educational conditions are much better than before and hospitals and clinics extend all over towns or villages. Every township has extension centres for agricultural technologies, providing timely service for farmers.

Improved natural resources management

Intense development has led to tremendous regional degradation of resources and environmental conditions. The current principal concerns for sustainable agricultural development is water shortage and land degradation. In recent years, different governmental levels have taken various measures to protect and manage natural resources in the region, including technologies for agricultural conservation, water and soil conservation, precision agriculture and degraded land restoration. Moreover,

local and national governments have strengthened natural forest protection projects, returning slope land to forests or grassland projects, reserve protection, infrastructure reconstruction and the development of eco-tourism. Simultaneously, rural public awareness and education was raised on natural resource and environmental protection, further improving regional natural resource use.

3.4 Adaptation potential

Adaptive techniques and gaps

Although much has been done to adapt to the changing situation, much remains to be done. Crop structure and composition, for example, have been readjusted to adapt to climate change. Sown areas with rice, maize, soybean and winter wheat have enlarged, whereas the areas of spring wheat, sorghum and some other crops have shrunk. Forage grass growing has become more popular. New varieties (e.g. longer growth period varieties with high yields), and new fertilisers and pesticides have been actively adopted. Some high-tech adaptation measures, however, are not being sufficiently applied. These include water-saving irrigation, biotechnologies (e.g. water-saving or drought-resistant varieties, disease- and pest-resistant varieties), precision agricultural technologies and disaster reduction technologies. This is due to shortage of finances and insufficient technology demonstration and training, dissemination, and public awareness. Scientific management of the land still needs improvement.

In Northeast China, sown areas of winter wheat could be further enlarged through introduction of maize and rice varieties with longer growth periods and higher yields and promotion of integrated management measures of agricultural resources. Precise management of soil nutrients and balanced fertilisation technology should be further studied and extended. The utilisation of organic manure (e.g. green manure, animal manure, biogas wastes) should be encouraged and integrated management of crop pests and diseases should be advocated and extended. These measures alongside the enhancement of natural resources (see above) which improve agricultural production and are central to adaptation, need to be considered by all stakeholders.

3.5 Individual and collaborative learning

Individual producers (farmers) are the main players of climate change adaptation. They learn through

experience and self-judgement but also, and importantly, from neighbours' practices and scientific demonstrations. In this case study, scientists played a supporting role by discerning long-term climate trends, predicting future scenarios and recommending development blueprints and technologies. Extension services tried to provide better means of production (new varieties, fertilisers, pesticides, high-efficiency irrigation equipment). Local governments conducted public awareness campaigns, training, practical demonstrations and loan provision, all of which were beneficial to the agricultural development in this region.

To further adaptation of agriculture in Northeast China under climate change, we suggest that key players should connect more with each other. Stakeholders should realise the advantageous or disadvantageous impacts of climate change on their agriculture and understand their "non-regret" options. Funding organisations should further support research and adaptation practices. We suggest that the national government and local governments reinforce the support to adaptation actions and strengthen training and public awareness on climate change, but all players should jointly participate in adaptation activities to drive forward agricultural development in the region.

4 Lessons learnt

4.1 For communities

With rising temperatures, it is possible and desirable to develop late maturity strains and adopt multiple-cropping systems to increase output. With rapid growth of animal farming and adjustment of cropping systems, the demand for maize and other feed grain crops will increase and exacerbate the existing water shortage problem (Zhang 2001), potentially hampering the benefits of increased grain production through warming. Climate models predict continuous temperature increase and may enhance drought in Northeast China. This will fuel the conflict over water resources, as will increasing demand from growing populations and industry. Improving water conservation and promoting water-saving agriculture is a necessary, but tough task in Northeast China.

Increased flooding in the north plain and more frequent droughts in the south of the region, means hydrological facilities are not meeting the needs of the irrigation systems. Therefore, water-saving irrigation, conservation tillage and integrated drainage systems should be improved.

Soil erosion and degradation has become a serious problem in the region, especially in arid and semi-arid areas. It is caused mainly by intensification of increased cropping, but also climate change-induced drought and flooding. The accelerated process of urbanisation and industrialisation will significantly lead to decline of arable land as land use changes and increased cropping areas for food grain crops pushes for more intensive agriculture. Ensuring food security and increases in farmers' income is likely to be more difficult.

The adjustment of cropping systems in Northeast China showed that the local experiences, such as adopting of new varieties of crops and planting methods against droughts, played an important role in selecting adaptation options. Thus, changing farm production practices to adapt new cropping systems needs input from both farmers and governments. Increasing crop yields do not always correspond neatly to a simultaneous increase in income, so extension services are badly needed to promote agriculture productivity and to emphasise the use of market mechanisms.

4.2 For regional/national policy makers

Both market and policy are the drivers for the application of adaptation options. It is important for the regional policy makers to develop market potential as a new task. Adaptation is a long process so it needs continuous policy support from all government levels and should be considered a long-term policy. Effective measures should be taken to prevent further reduction of farmland. These are:

- controlling the use of cultivated land by cities and industries
- encouraging opening up wasteland and multi-cultivation
- enhancing the comprehensive control of soil erosion, desertification and pollution of farmland
- optimising ecological environments for agriculture
- improving saline and alkaline land.

Institutional reform is needed to facilitate extension of new technologies. The non-governmental organisations (NGOs) have shown their strong vitality in developing local markets' potential and increasing farmers' income. During the past two decades, private enterprises have been deeply involved in research and have spread new agricultural technologies,

developing a kind of so-called contract-agriculture by contacting farmers and providing them with new varieties and agricultural techniques. Income diversification among farmers involved livestock ownership, but also off-farm activities such as trading home-produced goods, or providing services. Based on the voluntary acceptance of those involved, urban migration to trade and eco-tourism are also important income diversification strategies. Policies that provide the opportunities to pursue alternative livelihood options need to be encouraged. Institutional reform with key stakeholders' participation, is therefore essential to enhance adaptation to both short- and long-term climate impacts.

Incorporating adaptation options for climate change into sustainable development policies is one of the most effective strategies to reduce vulnerability with historic experience illustrating immediate benefits from the adoption of adaptation measures. China is one of the most vulnerable countries to climate change, thus anticipatory adaptation should be the country's priority for sustainable development. Therefore, both long-term and short-term adaptive options need to be developed including radical changes in public water supply and management, and investing substantially in order to cope with water problems in the twenty-first century. Food security and farmer income are also key concerns for local and central governments. In conclusion, enhancing adaptive capacity needs more support in all aspects and from all levels of government.

4.3 Financial interventions

In China, government institutions at all levels provide the most powerful investments in the agricultural sector. As shown by the case study, with policy and market support, private enterprises and farmers showed increased interest in agricultural programmes such as promoting food grain production, returning land to forest from agriculture, afforestation, natural forestry protection and desertification prevention. The government's investments played a very important role in enhancing agricultural research and extension, but investments in improving infrastructure and political sustainability of necessary reforms are also needed.

The NGOs and private enterprises hold the most investment potential in agriculture. However, facilitating the initiative to invest in adaptation

technology development and application requires a favourable policy environment. Thus farmers' initiatives need both financial and policy supports.

4.4 Future climate research needs identified

Vulnerability maps at the regional level are needed to identify vulnerable regions and people. There is a need for more integrated costing studies, which consider all potential impacts of climate change on the sector, as well as adaptation options. Such information is necessary not only for domestic issues, but also to assess comparative advantages within global markets. Enhanced research on extreme climate events (floods/droughts) will also improve understanding for climate change issues and possible adaptive options.

It is necessary to consider the full range of socio-economic impacts before promoting adaptation options. For example, although switching production to a new crop may increase overall agricultural production, it may not be economically viable due to marketing issues, higher capital and operating costs. Within this, regionally differential research for adaptation options should be undertaken.

Adaptive responses in agriculture should include efforts to breed drought-resistant crop varieties by utilising new varieties better adapted to warmer and drier conditions. Improvements in farming systems, fertiliser management and soil conservation also form major adaptation strategies (Zhang and Lin 1997). Research is needed to define current limits to heat resistance and the feasibility of manipulating such attributes with modern varieties. Crop architecture and physiology may be genetically altered to adapt to warmer environmental conditions by screening germplasm banks to find sources of resistance to diseases and insects, as well as tolerances to heat and water stress and better compatibility with new agricultural technologies. Genetic manipulation also may help to exploit the potentially beneficial effects of CO₂ enhancement on crop growth and water-use efficiency.

5 Conclusions

Climate change cannot be totally avoided and may be more pronounced than current estimates suggest, involving unexpected extreme events. Climate change brings opportunities as well as threats. Benefits can be maximised and impacts reduced, through planning. Anticipatory and precautionary adaptation is more effective and less costly than

forced, last-minute, emergency adaptation, disaster relief or retrofitting. Immediate benefits can be gained from better adaptation to existing climate variability and can be gained by removing current maladaptive policies and practices.

Despite considerable progress on evaluating the potential effects of climate change on China's agriculture, significant uncertainties remain, so "no-regret" agricultural policies that have immediate benefits are specifically appropriate for adaptation within more generic development. Adaptation options can be employed to increase the flexibility and adaptability of vulnerable systems, and reverse trends that increase vulnerability. Challenges to adaptation will be significantly affected by the manner in which climate change effects are experienced. A slow change in climate over decades, without a significant change in variation and weather extremes, will facilitate adaptation by farmers themselves, and may demand little new technology transfer. Conversely, if future effects include an increase in short-term weather extremes, the ability of farmers to adapt will be severely challenged, and improved technology transfer, such as more reliable long-term weather forecasting and drought-tolerant breeding, will become critical for adaptation.

As shown in this case study, advanced technologies and associated policy to foster their take-up and further dissemination have played a major role in bringing about a rapid increase in crop yields. The variation in the take-up and distribution of benefits among regions illustrate, however, that technologies alone are not equally adapted to all economic, cultural, or environmental conditions. Untapped potential for crop yield increase in other parts of China may be more difficult and may require the existence of a stable and conducive policy environment tailored to particular needs.

Adaptations, such as changes in crops and crop varieties, improved water management and irrigation systems and changes in planting schedules and tillage practices, will be important in limiting negative effects and taking advantage of beneficial changes in climate. The extent of adaptation depends on the affordability of such measures, access to know-how and technology, the rate of climate change and biophysical constraints such as water availability, soil characteristics and crop genetics. An effective adaptation policy must respond as soon as possible to a changing climate

and to a wide variety of economic, social, political and environmental circumstances both for future benefits and adverse impacts.

There are many barriers that may be encountered including the need for labour and capital investment and lack of knowledge. These may constrain the adoption of such technologies. In most cases, the profitability/success of technologies needs to be taken into account to ensure widespread adoption. Lack of financial incentives will be a major obstacle to the adoption of some of these practices. Otherwise, the system depends on potentially unsustainable subsidies to speed adoption and diffusion. Governments of developed countries should make contributions to these programmes and technology transfer should thus be a high priority. Domestic

and international farmer experiments and extension services to allow learning or sharing of new insights or experience are also important.

The development of a programme on vulnerability and adaptation should be included as part of long-term policy research and capacity-building activities under the UNFCCC. Drawing from the extensive research and experience of agricultural advisers, cooperation should seek to provide insight into the potential for improved or accelerated technology transfer to help agriculture meet the new challenges to developing countries identified in the UNFCCC. Case studies, such as this one, illustrating the role of government, industry and farmers in adaptation could generate further learning.

Note

1. Poverty population: the average annual income lower than 206 RMB (Renminbi, the Chinese money unit) in 1985 and 625 RMB in 2000 (~US\$75.6).

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