AGRICULTURAL VULNERABILITY AND ADAPTATION TO GLOBAL WARMING IN CHINA

LIN ERDA

Agrometeorology Institute, Chinese Academy of Agricultural Sciences, Beijing 100081, China

Abstract. This paper discusses the vulnerability and adaptation of the agricultural sector of China to global warming. Based on a summarization of Chinese agricultural and general circulation model trends, adverse impacts on China's agriculture caused by a warming and drying climate were identified. Because of limited irrigation potential, the sustainable development of Chinese agriculture will be difficult. Six sensitive agricultural areas located on the edges of different agroecological zones, and seven provinces with high vulnerability to the impacts on agriculture, were identified. On the basis of an estimation of the potential supply of agricultural products and demand for food, the annual incremental costs for adaptation to climate change would be US$0.8-3.48 billion; without adaptation, the annual agricultural loss due to global warming would be US$1.37-79.98 billion from 2000 to 2050. Adaptive measures discussed include intensive management and the possibility of a tripartite structure of planting that would entail coordinated development of grain crops, feed crops, and cash crops.

Key words: China, agriculture, maize, rice, wheat, GFDL, MPI, UKMO

1. Introduction

Climate change would affect agriculture through effects on crops; soils; insects, weeds, and diseases; and livestock. Over the past nearly 40 years, most of China, especially in the north, has experienced a general warming trend. There has been a substantial decrease in precipitation over eastern China's farming regions, except for part of the northeast and the middle and lower Yangtze River. Irrigation, already important, has become even more vital, with two thirds of the country's grain, (60% of its economic crops), and 80% of its vegetables produced on the 45×10^6 ha (49.6% of farmland in 1990) equipped with effective irrigation facilities. If these climate trends continue, much of Chinese agriculture is likely to face shorter growing periods and increased water deficits, requiring even more irrigation. Yet the maximum irrigable potential of China's farmland under "normal" conditions is estimated at only 64×10^6 ha, or 60% of the total cultivated lands. Because China is already approaching the maximum irrigation of farmland, potential future water shortages may threaten the sustainability of China's agriculture development.

Agriculture is a very important sector for China's development. The overall objective of this paper is to forecast changes in crop production potential, and resulting economic impacts, for wheat and maize throughout the country and rice in some areas, given alternative general circulation model (GCM) scenarios. This paper also identifies sensitive agriculture areas and regions with high vulnerability. This paper describes the methodologies used for crop simulation, identification of sensitive regions, and identification of regions with high vulnerability as well as the limitations of these methodologies. The results and discussion section of this paper includes the output of crop simulations, analysis of sensitive areas, and a description of relative vulnerability. The final sections of the paper discuss potential agricultural supply and demand and potential adaptation to climate change.

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2. Methodology

2.1 CROP SIMULATION METHOD

In China's Country Study analyses, the results of three equilibrium GCMs are being used as the scenarios of climate change: Geophysical Fluid Dynamics Laboratory (GFDL) (Mitchell *et al.*, 1990), Max Planck Institute for Meteorology (MPI) (Cubasch *et al.*, 1992) in Hamburg, Federal Republic of Germany, and United Kingdom Meteorological Office (UK89) (Mitchell *et al.*, 1990). Depending on the scenarios, temperatures are estimated to increase 0.4-1.9°C and rainfall will change by -12.9 to +24.6% in China across different GCMs, sites, and seasons.

Three crop models were adjusted where necessary to ensure that they could be applied to China (e.g., how soil and genetic characteristics are incorporated into the models). The three models are a rice model (IRRI, 1993), a wheat model (Ritchie, 1985), and a maize model (Jones and Kinir, 1986).

A simulation was conducted using monthly GCM scenarios and daily data for present (1955 to 1985) and changed climate from the Chinese Weather Generator developed by Agrometeorology Institute, Chinese Academy of Agricultural Sciences (CAAS). Two hundred sample years were simulated for each crop to allow probability distributions to be derived for the production potential of each crop. Because of the GCMs' geographic resolution, an economic impacts assessment is feasible at a provincial level, but the physical impacts assessment may be possible at a finer geographic resolution.

2.2 IDENTIFICATION OF SENSITIVE REGIONS

Global warming is estimated to cause a general northward movement of agroclimatic regions, with certain exceptions in the south of China where moisture deficits may increase even more than in the north. Because climate change could cause both warming and drying, the agroecosystems of the extreme southern portions of current regions would have to be modified. Using a moisture deficit of 50 mm (precipitation minus evapotranspiration) as a critical value, several sensitive regions in China were identified. Additionally, areas affected by too much moisture were identified.

2.3 IDENTIFICATION OF REGIONS WITH HIGH VULNERABILITY

Five nonclimatic indicators of agricultural vulnerabilities were used to identify areas of high vulnerability. These indicators are based on readily accessible Chinese data at the provincial level for 1990 (irrigated area, cultivated area, agricultural land, available land, crop yield, cropping index, area suffering from disasters, and farmer income), and are subject to the strengths and limitations thereof (*Chinese Agricultural Yearbook 1990*). The indicators chosen were the following:

- Ratio of irrigated area to cultivated area (IC, also referred to as the irrigation coefficient). A ratio below 0.50 may be particularly vulnerable to extreme drought.

- Ratio of land used in agriculture and animal husbandry to total available land (A/L). The national average of 0.5925 is a critical value for A/L.

- Yield and cropping index (I.Y.). An I.Y. less than average in both areas should be considered to have less recoverability, hence a higher vulnerability to climate change.

- Disaster index (D/S). The D/S is calculated as the area suffering from meteorological disaster/cultivated land. The national average (0.295) of the past 10 years is used as an indicator.

- Farmer income (FI). Farmer income (average farmer income per year) reflects the ability of farmers to adapt to climate change the national average of 571 yuan in 1990 was used as the critical value.

3. Limitations

Despite the limitations of current models, understanding, and data, the need for information about broader scale responses to climate change has led to many attempts to estimate agricultural production effects. As might be expected, the variation of agricultural and climatic conditions across the world leads to very different climate impacts in different countries and regions of countries. Because regional climate predictions and agricultural impacts are highly uncertain, estimating vulnerability to potential climate change provides an approach for considering regions at relatively greater risk should climate change adversely. The economic effects of future climate change for particular localities, regions, and the world depend on how future agricultural production meets the demands of a growing population and on how climatic effects on production are transmitted among regions through international trade. Historically, agriculture has proved to be highly adaptive to changing technology, resource conditions, and increasing demand, providing evidence of the potential for agriculture to adapt to changing climate.

Variations in agriculture systems, climates, resources, and economic characteristics across and within countries may be more important in determining the effect of climate change than differences in climate scenarios themselves. Agricultural policies are an important consideration in most regions, and these policies have had many and changing goals. Climate change is generally not among top policy priorities for agricultural policy makers, but climate change could affect the cost and likelihood of achieving other policy priorities such as food adequacy and reduction in chronic hunger, improving export competitiveness, assuring regional and national economic and social development, increasing farm income and the viability of rural communities, assuring water availability and quality, reducing or reversing land degradation and soil loss through erosion, and attaining other conservation and environmental objectives.

Given the uncertainties in both magnitude and direction of impact, a key issue is vulnerability to possible climate change. Vulnerability is used here to mean the potential for negative consequences that are difficult to ameliorate through adaptive measures given the range of possible climate changes that might reasonably occur. Defining an area as vulnerable is, thus, not a prediction of negative consequences of climate change; it is an indication that across the range of possible climate changes, there are some climate outcomes that would lead to relatively more serious consequences for a region than for other regions. Improvements in the spatial and temporal resolution of GCM predictions will allow better estimates of the likelihood of detrimental climate change.

Given this information, it would seem a trivial exercise to consider the dual side of the problem that agricultural scientists and farmers have faced since cultivation began. Rather than asking "How do we limit the negative impacts of climate and weather on production?" we should be asking instead, "If climate changes, what effects would the change have on production?"

4. Results/Discussion

4.1 CROP SIMULATION RESULTS

Based on the method described above, the ranges of simulated changes in crop production under $2\times CO_2$ and across GCM climate change scenarios, sites, and two types of water use (rainfed and irrigated) are given in Table I. Table I shows three crops with two or three patterns each (e.g., spring and summer maize; early, late, and single rice). A preliminary conclusion is that there will be approximately a 10% decrease in production of the three main crops under climate change.

4.2 SENSITIVE AREAS

The following six areas appear to be the most sensitive to climate change (Figure 1), based on a critical value of 50 mm moisture deficit, except the last two, which would experience increased rainfall and its effects.

1. *The area along the Great Wall* lies southeast of a transition belt between agriculture and animal husbandry. The transition belt's climatic division is determined mainly by the degree to which dryland crops suffer from the rainfall deficit and from soil erosion and desertization caused by wind. The transition belt has large rainfall variability, greatly affecting the stability of arid-land agriculture, which produces bumper harvests in a limited number of water-rich years but poor harvests and greatly reduced herbage in water-deficient ones. The northwestern edge of the transition belt will become arid grassland with an expected moisture deficitof 55 mm. It will be difficult to maintain annual production of maize and millet because it is estimated that evapotranspiration will increase and rainfall may decrease.
2. *On the Hai River Plain and the Huang River Plain* the moisture deficit could increase by 70 mm, increasing dry conditions in spring (March to May) as well as hot and dry winds, which will damage wheat production and limit the extension of two crops a year. Crops that are traditionally planted three times in two years like wheat, cotton, maize, and fruit trees will suffer from drought.
3. *The area north of Huaihe River and east of Shandong* lies along the south edge of the southern temperate zone. Climatic warming could cause the northward movement of

TABLE I
Estimated changes in crop production under $2\times CO_2$ scenarios

Crop	Rainfed Wheat	Irrigated Wheat	Single Rice	Early Rice	Late Rice	Rainfed Spring Maize	Irrigated Spring Maize	Rainfed Summer Maize	Irrigated Summer Maize
Low[§]	-21%	-15.2%	-21.4%	-7.9%	-16.0%	-19.4%	-8.6%	-11.6%	-11.6%
High[§]	+42%	+54.7%	-3.8%	+0.1%	-4.3%	5.3%	3.6%	+0.7%	+0.7%

§ The range between low and high represents possible development scenarios for Chinese agriculture.

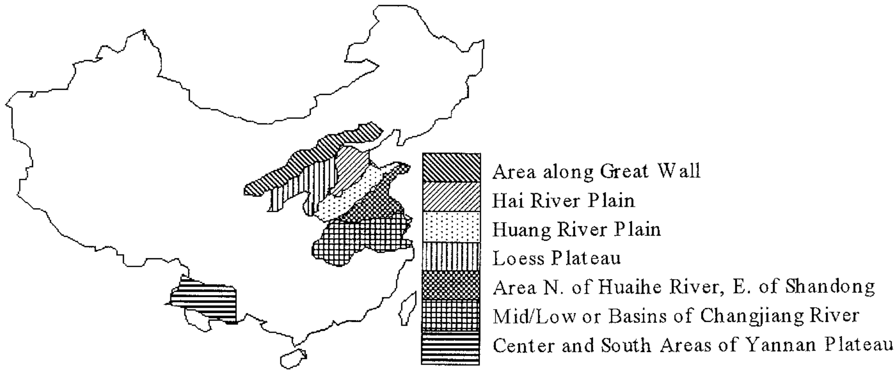

Fig. 1. Areas in China potentially sensitive to climate change.

subtropical crop areas. But frequent flooding in the south and spring dryness in the north because of growing water deficit mean that subtropical crops will not grow well in this area. The expected moisture deficit in this area is 65 mm.

4. *The central and southern areas of the Yunnan Plateau* contain regions apt to be affected by significant dryness in winter and spring under climate change. Climatic warming is estimated to increase the moisture deficit by 85 mm, and the rainfed farming system on poor red and yellow soil would be damaged. Rice and maize production, with higher water demand, would be seriously affected. The areas of trees and livestock raising might increase.
5. *The middle and lower basins of Changjiang River* are an area that would receive increasing rainfall and the largest summer variability; here alternate dog-season droughts (short droughts in the hottest season, July) and flooding often happen. Because the basins lie on the south edge of subtropical crop growth, crops planted two and three times a year like double-harvest rice, wheat, cotton, rape, bamboo, and mulberry would have higher productivity, as would fisheries and silkworm harvests. If climate change increases rainfall by 5%, and by more than 10% in summer, the agroecosystem with a high productivity will be damaged. This is because, depending on the historical data, increasing rainfall is often associated with large variability of rainfall in summer, which could cause flooding and damage the agroecosystem.
6. *The Loess Plateau* is a rainfed farming area with wheat as the main crop, which is planted as three crops in two years or two crops a year. Drought is the most damaging climate event for agriculture in this region. Because the rainfall in this region occurs mainly in summer (June to August), and is often heavy, and the spongy and fine loess is without vegetation, erosion is another damaging factor in this region. Some model results show the increase in rainfall might be 9-14% annually, and 16-32% in summer. Despite the uncertainties of GCM results, it is estimated that the agroecosystem of the area will not be able to tolerate the potential changes in rainfall.

The government and the farmer should pay attention to the sensitive areas mentioned above. Response strategies to increase adaptability, including introducing new species, using advanced technology, and increasing inputs, should be considered to reduce sensitivity to the impacts of climate change. The "anthropogenic sensitive areas" identified in this section may be sensitive to both increases and decreases in climate factors, and therefore both increases and decreases should be considered in management of the areas.

4.3 RELATIVE VULNERABILITY

Figure 2 provides a summary of "warning signals" for the vulnerabilities of the agricultural systems of China's 30 provinces to climate change. On Figure 2, "1" represents areas with one factor of higher vulnerability, "2" represents areas with two factors of higher vulnerability and continuing up to five factors of higher vulnerability. (Factors of higher vulnerability are identified in Section 2.3.) Shanxi and Inner Mongolia show vulnerabilities in all five dimensions. Nearby Gansu, Hebei, Shaanxi, Qinghai, and Ningxia are vulnerable in four indicators. These seven provinces produced 12% of China's total agricultural output value in 1990 (*Chinese Agricultural Yearbook 1990*, p. 165). In general, those provinces that are the most vulnerable are also in the areas of north and northwest China that, according to some models, are the most likely to be affected by global climate change.

5. Potential Agricultural Product Supply and Demand

5.1 DEMAND FOR AGRICULTURAL PRODUCTS

It is estimated that the population, grain production, and GNP from agriculture in China from 1990 to 2050 will increase as shown in Table II.

"The National Programme for the Reform and Development of Food Structure in China in the 1990s" set the following targets for food production in China in 2000: 500×10^6 t of grain, 39×10^6 t of meat, 14.3×10^6 t of eggs, 9.1×10^6 t of milks, 18×10^6 t of aquatic products, 32.5×10^6 t of fruits, 156×10^6 t of vegetables, 10.4×10^6 t of edible oil and 10.4×10^6 t of sugar. These targets represent estimates of China's food production needs in 2000. The estimated change in climate due to greenhouse gases will increase the difficulty in meeting these goals.

It is estimated that during the period from 2000 to 2050 the economy of China will attain the development of a medium-level developed country (Liangshu and Zhicheng, 1991a). In the first 20 years, the per capita consumption of agricultural products would have a small increase: grain by 12.5%, meat by 4%, edible oil by 20%, milks by 100%, and fruit by 100%. After 2020 the structure of food production is expected to stabilize. Apart from the increment of demand for agricultural products due to increases in population, total demand will reflect preferences for increased quality. The structure of food production is also expected

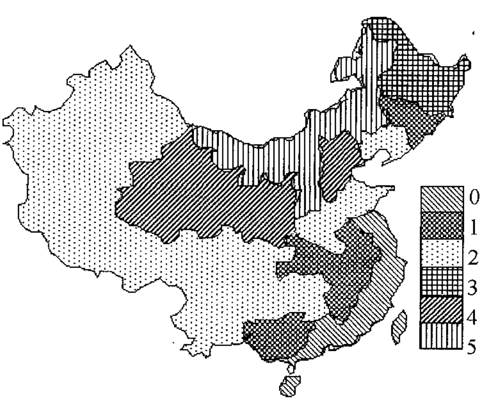

Fig. 2. Districts in China vulnerable to climate change based on nonclimatic factors.

TABLE II
Factors affecting agricultural product supply and demand

Year	Population (millions)	Grain Production (10^6 t)	GNP of Agriculture (US$ billion)	
			High	Low
1990	1,143	425	105.08	105.08
2000	1,300	500	158.84	151.81
2020	1,450	650	413.0	296.8
2050	1,500	675	993.6	463.05

Source: ADB, 1993.

to respond to the rationalization of the internal structure of agricultural production. Consequently, a total production of grain of 650 × 10^6 t in 2020 and 675 × 10^6 t in 2050 could basically meet the demand for the expected development of economy and society.

With no change in present climate and environmental conditions, but with full provision of material inputs, management, and other human factors, the maximum production of grain in China would be in the range of 840-1,040 × 10^6 t. During the past 40 years, natural disasters have brought about a 5% loss in production. It is possible that the variations and extreme events of climate would reduce the maximum grain production by 10% by 2050.

5.2 BENEFIT-COST ANALYSIS

The results of the current analysis and Tao Zhan (1993) show that with rises in temperature and changes in precipitation (mostly decreases, but some increases), the maximum production could probably drop by at most about 10%, because of the shortening of the growing period and the shortage of moisture. In 1990, the average unit yield of grain production of China was 3.975 ton ha^{-1}. To meet demand, it is estimated, considering farmland changes, that the average yield of grain production of China in the coming 50 years will change as expressed in Table III.

If the influence of climate variation on maximum production and the influence of production costs on the productive level are linear, maximum production will fall to 793-993 × 10^6 t in 2020 and 746-946 × 10^6 t in 2050. Thus in the coming 50 years, investment requirements for grain production of China would require incremental increases over 1990 investments as shown in Table IV.

The additional increments of investment for dealing with climate variation would be 4, 9, and 17% of the investment in agriculture in 1990 for each year, respectively. In the five years from 1986 to 1990, the state made a special investment of 5 billion yuan (US$1.06 billion) in the production of grain, and 20 billion yuan (US$4.26 billion) in ecological protection, technology popularization, and superior species breeding, together with some investments to support expenditures on rural production, providing disaster relief, and supporting impoverished areas, and the like. In 1990 the state invested over US$20 billion in agriculture. To adapt agricultural production to the effects of climate change in the coming 50 years, governments in China at all levels should increase the investment in agriculture every year, with the increments and their possible benefits as shown in Table V.

TABLE III
Estimated changes in the average yield of grain production to meet demand

Year	Yield (t ha^{-1})	Change
2000	4.55	1.14 times as much as that in 1990
2020	5.70	1.40 times as much as that in 1990
2050	6.14	1.54 times as much as that in 1990

Source: Erda, 1994.

TABLE IV
Incremental increase in investment for grain production required by climate change

Year	Without Climate Change	With Climate Change
2000	1.13	1.17 times as much
2020	1.42	1.51 times as much
2050	1.54	1.71 times as much

TABLE V
Potential benefits from adaptation of grain production to climate change

		Year		
		2000	2020	2050
Increased Investment		0.8	1.8	3.48
Benefit	High	1.44	16.00	79.98
or Loss§ (1990 US$ billion)	Low	1.37	11.47	32.27

§ If no newly increased investment.

6. Adaptation

Adaptation measures 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 any negative effects of climate change and in taking advantage of any beneficial effects. The extent of adaptation depends on the affordability of such measures, particularly in developing countries; access to knowledge and technology; the rate of climate change; and biophysical constraints such as water availability, soil characteristics, and crop genetics. The incremental costs of adaptation strategies could create a serious burden for China and other developing countries. Even though there are significant uncertainties about the capacity of different regions to adapt successfully to projected climate change, the possibility of adaptation should be considered in advance.

6.1 INCREASING INTENSIVE MANAGEMENT

It is important to maintain sown acreage and set up a system of zoning that will protect grain fields to maintain a response capacity for climate change. At present the cultivated land in China is declining by 66.6-166.6 × 10^3 ha per year (Liangshu and Zhicheng, 1991b). Also, at present, 13 million ha of arable land is held in reserve that can be opened up for agricultural use in the future. The present balance between the land acreage under cultivation and that being occupied by other uses should be maintained, and the cropping index should be increased steadily. In this way the sown acreage of all crops could reach 148.6 × 10^6 ha in 2000 and 152.7 × 10^6 ha in

2020 and thereafter, thereby allowing the sown acreage of grain to stabilize at 110×10^6 ha in order to attain the production target mentioned above. Except for Hebei Province, the provinces mentioned above where agricultural production is vulnerable to climate change have populations approaching or exceeding the carrying capacity of the existing cultivated land resources. In these areas, it is especially necessary to strictly control further occupation of farmland, and reserves should be opened up.

Strengthening irrigation capacity is one of the most beneficial means for maintaining agricultural production in the face of unfavorable climate change. The yield of grain per unit area is above the national average in one-third of the provinces and autonomous regions in China, where the irrigated farmland accounts for over 53% of the cultivated land. This ratio reaches 63% in the 6 provinces with the highest production and the 46 counties with the highest yield. The area that could be provided with irrigation facilities could probably increase by $5\text{-}6.7 \times 10^6$ ha, raising the irrigation coefficient by 5.5-6.8%. Where water resources and funding allow, increasing irrigation would be the most beneficial measure in the vulnerable areas (Liangshu and Zhicheng, 1991a).

China has 20 areas with medium or low yields that should be foci for land improvement. At least five of these are in locations vulnerable to climate change, such as the plains of the Yellow River, the Huai River, and the Hai River; the northwest area of Shandong Province; the Yellow River plain in the north Henan Province; and flood-prone clay soils in the middle and lower reaches of the Yangtze River. These medium or low-yield farmland should be provided improved irrigation and drainage capacity so that they are more adaptable to change.

Simulation exercises (see Ojima *et al.*, 1993; Duxbury *et al.*, 1993) have shown that a warming climate would have a major impact on the circulation of carbon and nitrogen in the soil. Even if precipitation were to increase, the content of organic matter in the soil would still fall by 10-30%. Therefore, to maintain the productivity of cultivated land, it is necessary to encourage the use of a more optimal fertilizer mix and to adopt the technique of subsoil application according to actual changes in soil conditions.

Other strategic intensive management measures that could reduce the vulnerability of China's agriculture sector and strengthen its adaptability are to encourage the use of superior species (e.g., those with greater drought resistance); to develop winter agriculture in southern China; to encourage the use of techniques for storing and applying water more economically; to disseminate techniques for the integrated control of pest and diseases; to improve the utilization of plastic sheeting and machinery; and to develop independent feed crop farming.

6.2 ADJUSTING THE STRUCTURE OF FARMING

The Programme for Food Development of the Chinese government stipulates that China will transform its traditional dual structure of farming (i.e., with grain crops and cash crops maintained on the majority of farm land) into a tripartite one that will entail the coordinated development of grain crops, feed crops, and cash crops, with the production of feed crops becoming relatively independent. Consequently, the proportion of farmland devoted to the three kinds of crops would change as shown in Table VI.

In time, the middle and lower reaches of the Yangtze River, north China, and southwest and northeast China would gradually supply more feed grain.

TABLE VI
Estimated proportion of crop acreage in a tripartite structure

	Year		
	1990	2000	2020
Total Sown Acreage (10^6 ha)	145	155	160
Grain Crops	76%	59%	46%
Cash Crops	20%	20%	25%
Feed Crops	4%	21%	29%

Source: Erda, 1994.

The middle and lower reaches of the Yangtze River, with 34.6% of the national production, are the major commodity grain areas in China. This area is vulnerable to probable increases in rain. Nevertheless, the increase in the production of feed maize, feed rice, and feed barley could make agricultural production less dependent on climate and probably reduce its vulnerability. But this adjustment could be sped up only if grain production increases in other areas to reduce of demand for the commodity grain of this area.

North China is vulnerable to possible droughts caused by a rise in temperature and decline in rainfall. Moreover, the social and economic resources used in agriculture are rather fragile in many places. Nevertheless, new species of wheat, maize, cotton, and pulse crops with short growing periods and high yields which are suitable for planting in this area, have been bred and put into production.

Except for the Sichuan Basin, most of southwest China has a low level of agricultural productivity. In particular, the Yunnan-Guizhou Plateau is vulnerable to drought. Adjustment in this area should rely on further improvement of the infrastructure for water conservation and transportation, in order to develop commodity production.

Northeast China has conditions that are estimated to respond positively to projected climate change with higher productivity, but we should be careful of proceeding incautiously.

6.3 USING TECHNOLOGY

While improving standardized cultural techniques, farmers should consider the possibility of climate variation so as to set up a more flexible cultivation system with stronger adaptability. Using plastic sheeting is a feasible technique to reduce the vulnerability of some arid areas and should be further encouraged.

Certain farming technologies can strengthen the adaptability of agricultural production which include techniques to save water in application and retention, and techniques for coordinated use of irrigation and fertilizer application. The technology of feed development can transform the use of land and the cropping structure in areas vulnerable to climate variation. Feed crops with low vulnerability to conditions of climate should be developed.

7. Conclusions

1. Possible climatic impacts span a wide range, depending on the climate scenario, geographic scope, and study in East Asia. For China, results show generally negative yield effects but range from less than -21% to more than +54%.

2. The general possibility of increased summer dryness in the continental midlatitudes suggests that six areas, including the area around the Great Wall, are most likely to be negatively affected by climate change in China.
3. Indices of vulnerability based on physical productivity and socioeconomic capability to adapt show that among China's 30 provinces, Shanxi, Inner Mongolia, Gansu, Hebei, Qinghai, and Ningxia are particularly vulnerable and less able to adapt to climate change.
4. The areas along the Great Wall and Huang-Huai-Hai Plains of North China are both socioeconomically and agronomically vulnerable to climate change and also are areas where climate projections suggest possible adverse changes in climate.
5. Climate change will occur against a steadily increasing demand for food in China over the next 55 years. The increased annual cost of government investment only (excluding farmers' additional costs) in agriculture due to climate change through 2050 was estimated at US$3.48 billion (17% of the cost of government investment in agriculture in 1990).

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