A Modeling Study of Climate Change and Its Implication for Agriculture in China Part II: The Implication of Climate Change for Agriculture in China

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ABSTRACT

The potential CO_2–induced impacts on the geographical shifts of wheat growth zones in China were studied from seven GCMs outputs. The wheat growth regions may move northward and westward under the condition of a doubling CO_2 climate. The wheat cultivation features and variety types may also assume significant changes. Climatic warming would have a positive influence in Northeast China, but high temperature stress may be produced in some regions of central and southern China. Higher mean air temperatures during wheat growth, particularly during the reproductive stages, may increase the need for earlier–maturing and more heat–tolerant cultivars.

Key words: Climate change, Carbon dioxide concentration, Climate impact, Agricultural crop zonation distribution

I. INTRODUCTION

The climate resources is one of indispensable conditions of agricultural production. Climate change would directly influence not only on the process of growth, development and yield formation of crops, but also on farming patterns, cropping systems, quality of agricultural products and agricultural technological measures. The implication of climate change for agriculture is one of the important parts and a central issue of the climate impact study. In particular, because of China being an agricultural country, which national economy is strongly dependent on agriculture, it is necessary to study the possible effect of future climate change on agricultural production.

The general circulation model (GCM) has been an important tool for simulating the global climate change at present. The outputs from GCM simulation are of significant value to the assessment of the implication of climate change for agriculture and ecosystem because of their completeness, consistency and experimental possibilities. Many scientists have extensively studied the relationship between the climate and agriculture by applying GCM outputs (Santer,1985; Rosenzweig, 1985; Schuharadt et al., 1989; Hulme et al., 1992; Chen et al., 1990). Gates (1985) summarized the methodology of studying climate's impact on the ecosystem by applying GCM. The first problem is concerned with the determination of seasonal and geographical distribution of that portion of the climate change generated by a GCM which is both statistically and physically significant. The degree of uncertainty or likely error accompanying the distribution of the change of each climatic variable is also described. Secondly, the significant large–scale climate changes are transformed into the local scale on which climatic impacts occur (the climate "inversion" problem). Next, specific statistical parameters or functions relevant to local ecosystem impact assessment are designed to interpret the modeled climate change. Impact models are then developed for the estimation of the local ecosystem's response to local climate changes. Finally, on the basis of the determination of local impact, the large–scale or global impact (taking the appropriate economic, social and political factors into account) may be determined.

Wheat is one of the main food crops in China, which ranks next to rice in areas planted and quantity produced. Wheat crop is widely adaptive and can be planted under the condition of various climates. According to different sowing time, it can be classified into winter wheat and spring wheat. This paper will mainly address the potential CO_2–induced climate effects on the geographical distribution of wheat in China based on the results obtained by Part I of the present paper (Dai and Ding, 1994). The geographical distributions of other crops can be studied by applying the similar method developed here.

II. METHODS

First, the environmental requirements for growth of wheat are specified and compared to temperature and precipitation results obtained from the control run of GCM in order to generate simulated map of current wheat production regions. Results from the doubled CO_2 run of GCM are then used to generate wheat regions under the new climatic conditions. The comparison of wheat–growing regions generated by the control and doubled CO_2 runs not only predicts potential wheat zonation shifts due to climate change, but also identifies those areas, particularly sensitive to climate change. The data applied in the study are identical to those of Part I.

Table 1. Environmental Requirements for Wheat Used in Wheat–Growing Regions of China

Length of growing season (days)		
winter wheat		120
spring wheat		90
Active accumulated temperature above o°C during growth (℃)		
winter wheat		1800
spring wheat		1400
Mean temperature in January (℃)		
winter wheat		>−10
spring wheat		<−10
Vernalization requirement of winter wheat variety		
strong winterness	>60 days mean temperature	0–3℃
winterness	>45 days mean temperature	0–7℃
weak winterness	>30 days mean temperature	0–7℃
springness	>15 days mean temperature	0–12℃
Water needed during growth (mm)		
winter wheat	northern wheat regions	350–500
	southern wheat regions	250–350
spring wheat		250–300

It should be noted, however, that some agronomic simplifications are made except uncertainty inherent in GCM. For example, the direct CO_2–fertilizing effects on crops are neglected; climatic tolerance of varieties and agricultural technology are kept unchanged; the effects of light and daylength and the limitation of soil to crop production are neglected; the complicated relationship between temperature, precipitation and crop growth and development is greatly simplified.

1. *Environmental Requirements of Wheat Growth*

Wheat is grown in a wide range of environments. The different cultivars have their marked differences in their response to environmental conditions. This study defines environmental requirements of wheat for winter and spring classifications, not for individual cultivars within these types.

Climatic factors affecting wheat geographical distribution include temperature (such as accumulated temperature, mean air temperature in January) and water (such as precipitation, evaporation and soil moisture). Environmental requirements for wheat–growing regions (Cui et al., 1984; Qiu and Lu, 1990; Weather–Climate Division, 1981; Li et al., 1988) are summarized in Table 1.

2. *Environmental Parameters Generated by GCM Simulation*

Values of environmental parameters for each gridbox in China generated by GCM control and doubled CO_2 runs are seen in Figs.1 and 2. Because of considerable difference between simulated and observed precipitation, it is difficult to directly apply precipitation results from GCM to the impact study. Therefore, observed precipitation was used in the control run instead of model–generated precipitation. The percentage changes due to doubled CO_2 from the model were then applied to the actual precipitation amounts to estimate the

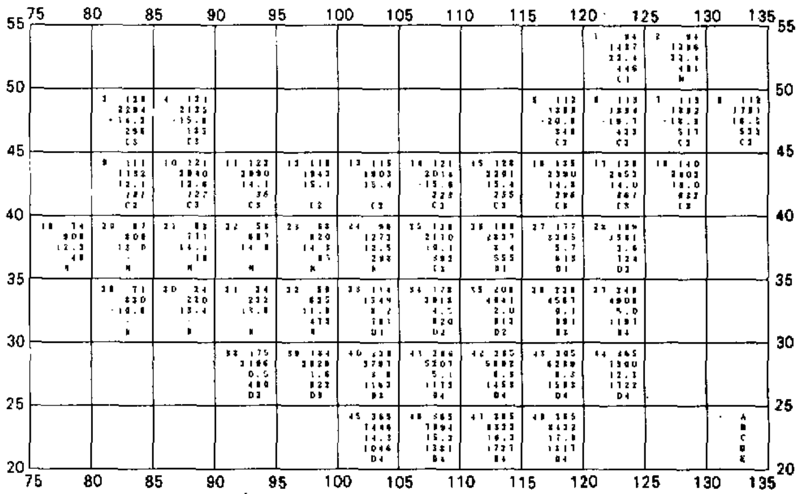

Fig. 1. Environmental parameters and wheat–growing regions of China generated by the control run of GCM. In the figure, * : gridbox #; A: length of growing season (days); B: active accumulated temperature during growth (℃); C: mean temperature in January (℃); D: annual precipitation; E: wheat cultivars including: C–spring wheat; C1–early maturing; C2–medium maturing; C3–late maturing; D–winter wheat; D1–strong winterness; D2–winterness; D3–weak winterness; D4–springness; N–no wheat.

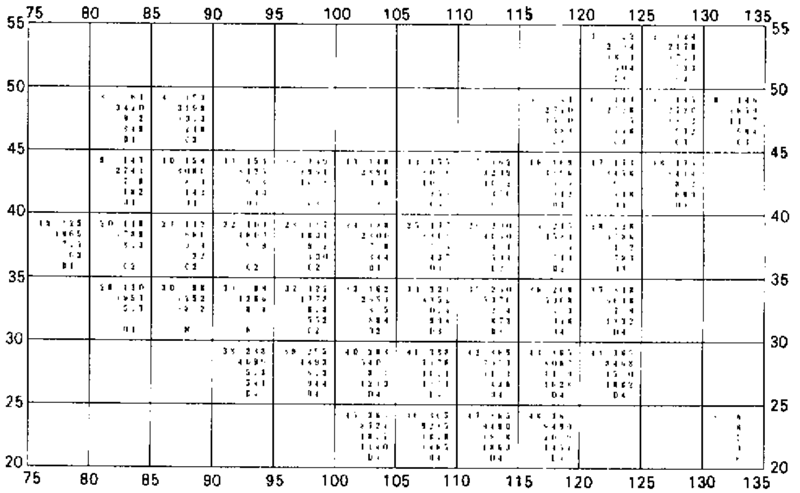

Fig. 2. Environmental parameters and wheat–growing regions of China generated by the doubled CO_2 run of GCM. The indications of the figure are identical to Fig. 1.

values of precipitation under the doubled CO_2 scenario. This procedure, although not precise, is able to systematically reflect the change of precipitation for any specific gridbox that might occur under increased CO_2 conditions.

III. RESULTS

1. *Comparison between Model–based Wheat Region Map and Actual Wheat Production Regions*

Wheat is grown extensively in China. Spring wheat is distributed mainly over the colder parts of northern China, winter wheat is distributed over the eastern Liaoning Peninsula, the North China Plain and the vast region in and to the south of the Loess Plateau, and winter / spring type is distributed over the transition belt from winter to spring wheat or where climate is bitterly cold. Both the acclimatization of the growth and development and the condition for yield formation of wheat are of regional properties. Fig. 3 shows the climatic regionalization of wheat growth in China (Cheng et al., 1993). Based on the climatic conditions of wheat growth (especially annual mean air temperature, absolute minimum temperature and precipitation), cropping systems, cultivar types and growth habit, the country is classified into 12 wheat regions. In the northern part there are three regions of spring wheat (regions I'_1, I_2 and I'_3 in Fig. 3) and nine of winter wheat in the other parts of the country (regions I, II, III, IV, V, VI, VII, VIII and IX). The winter / spring wheat regions are located in Xinjiang and the Tibetan Plateau (region IX).

The current wheat–growing regions of China simulated by the control runs of 7 GCMs are shown in Fig. 1. Each gridbox in the figure was assigned a wheat category or no wheat according to its values of environmental parameters. Predicted wheat–growing regions are seen to agree with actual regions in most gridboxes by comparing Fig. 3 with Fig. 1. Predicted

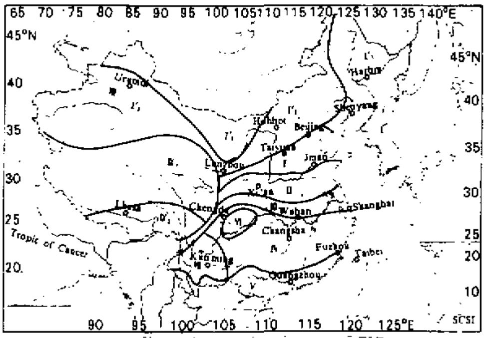

Fig. 3. Climatic regionalization of wheat growth in China.

dividing line between winter and spring wheat is almost coincident with actual line. There was consistency in areas and varieties of winter and spring wheat. Out of forty–eight gridboxes, nineteen were identified as winter wheat, eighteen identified as spring type, and eleven were identified as no wheat. The wheat–growing area not identified by the control run simulation is mainly found in Northwest China (gridboxes 19, 20, 21, 22, 23 and 24) in which no wheat growing was predicted due to inappropriate length of growing season and active accumulated temperature of these gridboxes. In reality, there are both spring and winter wheat planted in the above regions. Another error is found in the northern part of Xinjiang Province (gridboxes 3, 4, 9, 10 and 11) in which spring wheat was predicted but winter / spring wheat actually grows. The possible causes of errors above mentioned include: (1) as indicated in Part I, the difference between modeled and observed climate mainly occurring in Xinjiang and Northwest China. There, the model temperature was well below actual temperature so that simulated thermal conditions were inferior to actual values; (2) The simulated distribution is determined according to the environmental parameters averaged over each gridbox area. It only represents the general trend of a gridbox and can not resolve subregions in a region.

From the results presented above, the current wheat production regions generated by GCM simulation are basically similar to actual map (The regions where errors are found are not major wheat production regions). So, it can be justified using results from the doubled CO_2 run to study the effects of the predicted climate change on wheat regions.

2. *Wheat–growing Regions for Doubled* CO_2 *Run*

The major change in the wheat–growing regions due to the doubled CO_2 scenario is a great northward extension of the winter wheat belt and an increase of planted areas (Fig. 2). Under the doubled CO_2 climate, temperature variables become moderated so that growing season is lengthened, active accumulated temperature increased, and mean January temperature raised. The changes of these environmental parameters would lead to the changes of growth habit and cultivar type of wheat. The comparison of Fig. 2 to Fig. 1 indicates that the winter wheat belt extends northward to Liaoning and Jilin Provinces and part of Inner Mongolia. Winter wheat is grown extensively in the northern Xinjiang (gridboxes 3, 9, 10 and

11). Spring wheat regions (gridboxes 3, 9, 10, 11, 16, 17, 18 and 25) are replaced by winter wheat regions due to warmer winter temperature. Moderate winter temperatures also shift no wheat condition (gridboxes 2, 20, 21, 22, 23 and 32) to spring wheat condition, even to winter wheat (gridboxes 19, 24 and 29). In winter wheat regions, increases in winter temperatures allow greater changes in cultivar types such as winterness variety instead of strong winterness variety in gridbox 26, weak winterness variety instead of winterness variety in gridbox 34, and springness variety instead of weak winterness variety in gridbox 40. Out of forty-eight gridboxes, winter wheat is grown in thirty gridboxes, spring wheat sixteen gridboxes, and no wheat only two gridboxes (Table 2).

Table 2. The Number of Gridboxes in Wheat Classifications for the Control and Doubled CO_2 Run of GCM

Run	Winter wheat				Spring wheat			No wheat
	strong winterness	winterness	weak winterness	springness	early maturing	medium maturing	late maturing	
Control	3	3	4	9	1	7	10	11
$2 \times CO_2$	11	3	3	13	0	5	11	2

From the results presented above, it appears that the climate changes due to doubled CO_2 in the atmosphere as simulated by 7 GCMs would have general effect of extending the winter wheat region quite extensively and shifting growth habit and cultivar type of wheat. Above changes of wheat regions are mainly due to the change in thermal conditions. As shown in Part I, the annual precipitation of the whole country also increase by 10% except part of South China to the doubled CO_2. In particular, precipitation in winter and spring has a greater range of increase, which is favorable to wheat production. For example, in North China and Huanghuai Plain, precipitation during wheat growth is only 100 to 250 mm, not enough to meet the requirement of wheat growth and development. The increase in precipitation (especially in winter and spring) would mitigate drought condition, decrease artificial irrigation, and reduce production cost in these regions. But warmer temperature may increase evaporativity to offset the increase in precipitation. The result is the decreases of available water and yields of wheat. Moreover, the increase of precipitation in most wheat regions of southern China would aggravate existing wet damage and diseases. The impact of precipitation on wheat production is complex and estimated in terms of precipitation, evaporation, soil moisture, local climate characteristics and wheat growth situation.

Although there are some errors in the prediction of the change in Northwest China, it is certain that thermal and water conditions in this region would be moderated to some extent to be more adaptive to wheat production.

IV. DISCUSSION AND CONCLUSION

From analyzing the outputs from 7 GCMs, it was found that areas of wheat production may increase in China, particularly in Northeast and Northwest China. There were also considerable changes in growth habit and variety type of wheat. Winter wheat regions extended northward and westward. Warmer climate would have a positive influence in Northeast China, but negative in central and southern China. The increase of mean temperature during earring and maturing period would aggravate the damage of high temperature stress. In general, higher mean temperatures during periods of wheat growth and high temperatures before harvest may increase demand for earlier–maturing, more heat–tolerant cultivars. In South China, moderate winter temperatures would limit the growing of winter wheat. In other regions, stronger winterness cultivars may be replaced with stronger springness cultivars due to higher winter temperature.

To a certain extent, GCM provides a useful tool for analysis of potential agricultural crop zonation shifts due to climate change. The large grid size of the model prohibits any analysis of the considerable subgrid–scale variability. Reliability of impact study depends mainly on the reliability of GCM simulation. More advanced and perfect GCM will be suitable to the development of impact study. Further research is needed to include more detailed environmental factors which affect wheat production in the study, e.g., soil resources, daylength, snow depth and duration, and water status at different development stages.

The above research only estimates the indirect influence of increased carbon dioxide on agricultural production in conjunction with the predicted climate changes. Related research indicated that the direct influence of increased carbon dioxide on agricultural crops (so–called CO_2–fertilizing effect) may well be favorable. On the one hand, the effect of increased CO_2 in some species is an increase in stomatal resistance which leads to a decrease in transpiration and an increase in water–use efficiency. On the other hand, another effect of increased CO_2 is to increase photosynthetic rate and accumulation of carbohydrate. So, a rise in atmospheric CO_2 will increase the yield potential of wheat production of water–limited regions (such as North and Northwest China). The direct CO_2 effects of increased yield potential and decreased transpiration, combined with the expansion of wheat regions described above, may well mitigate the negative effects of high temperatures and moisture stress on wheat production in China.

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