Impact of Global Climate Change on Agriculture and Food Security over Asia

Motoki NISHIMORI

Division of Agro-Meteorology,
National Institute for Agro-Environmental Sciences
3-1-3, Kan'nondai, Tsukuba, Ibaraki 305-8604, Japan
e-mail: mnishi@niaes.affrc.go.jp

Abstract

The current and latest works on the impacts of global climate change on agricultural production throughout the Asian region are introduced from the viewpoint not only of changes in natural environment (meteorological and water resources) but also of soil environment changes and increased insect pests. The results involve a model simulation of rice yields at different locations in Asia under increased CO_2 and temperature conditions. How the impact of global warming on the agro-ecosystem may influence food security in Japan and around the world is also discussed.

Key words: agriculture, global climate change, rice, soil water content

1. Introduction

According to the Third Assessment Report of Working Group I of the International Panel on Climate Change (IPCC, 2001a), the global averaged surface air temperature has increased by about 0.6°C over the last 100 years. Comparing this temperature increase among various parts of the globe shows that the greatest increase has occurred in northern and eastern Asia, where average temperature rose almost 1°C. If this trend continues, agriculture in East Asia may become the first to suffer the negative effects from global warming. In fact, there have been many cases of severe weather and natural disasters such as heavy rainfall in the rainy season, repeated landfalls of many typhoons and heavy snowfall in Japan in recent years. Variations in wet and dry environments in China have also been predominated such as the loss of water in the Yellow River, the remarkable drought of 2003 in the northeastern region and severe flooding in 1998 in the Yangtze River. Thus, the recent climate seems to be similar to that projected by the IPCC under future global warming or unusual weather scenarios.

Agriculture in China, which is one of the world's major food producing and consuming countries, has been affected not only by changes in the natural environmental change but also by rapid economic growth and explosive population increases. Production of major crops (wheat and maize) in most parts of China has depended on rain-fed water supplies, so it is vulnerable to year-to-year climate variation, especially to changes in precipitation. In addition, the amplitude of the variation in agricultural production has tended to increase. Elucidating the causal factors and evaluating the future impacts due to climate change are crucial tasks with regard to ensuring a stable food supply in East Asia, and hence, food security around the world.

The present paper will focus on risks to agricultural production related to temperature and CO_2 rises and changes in water resources in East Asia. It will examine a few of analytic studies on climate change impacts on natural environments and growth inhibition factors in relation to changes in Asian food production. It will also introduce a crop simulation model of the physiological and ecological effects of temperature and CO_2 rises and a statistical model study on changes in agricultural production taking trade and economics factors into consideration. Further, it discusses how such climatic impacts on Asian agro-ecology may affect world food security from the viewpoint of changes in precipitation and land productivity and the effects of trade and markets.

2. Vulnerability of Rice Production of Japan

Generally, there are three approaches to projecting future changes in rice production as follows:

1. To project them in terms of statistics, based on changes in previous production, and inputting future climate (temperature, etc.) change predictions,
2. To cultivate rice in environments with higher tem-

perature and CO_2 levels,

3. To project changes by using computer simulation models from seeding to harvesting.

These three methods have their own separate advantages and disadvantages. It is possible to consider the influence not only of high temperatures but also of insect pests and water resource shortages in spring due to earlier snowmelt, and to set up various other subjects in Method 1. Method 1, however, is based only on statistical calculation and cannot take socio-economical and political matters into consideration. Method 2 provides the possibility of estimating actual rice yields at projected future temperature and CO_2 concentrations. It is difficult, however, to run experiments applying these conditions to the various species of rice and soil conditions all around the world and it is insufficient for getting information on complicated effects of temperature and CO_2 concentrations, and their differences among rice species.

Paddy rice production in Japan is often affected by cool summers and high temperatures, which damage the crops. In order to project the future rice production of Japan under climate change or global warming, it is necessary to clarify quantitatively the influence of changes in climate factors such as air temperatures and solar radiation on rice yield. Therefore, a multiple regression analysis was conducted to examine changes in rice yields, using averaged air temperature and accumulated solar radiation during the heading period in each agricultural region (Nishimori & Yokozawa, 2001). In addition, obstructive factors such as pests and diseases or water resource shortages should be considered in estimating the vulnerability of rice production (Nishimori *et al*., 2007). In the northern part of Japan, the rice yield is generally increasing as the temperatures rise and the diurnal temperature range (DTR) decreases. In the western part of Japan, on the other hand, the rice yield is generally increasing as solar radiation increases. In the Hokuriku region and northwestern parts of Kyushu, the rice yield is relatively sensitive to high temperatures so the risk of high temperature injury is recognized. The above vulnerabilities to climate factors, as well as those to pests, diseases and water resource shortages were included. As a result, rice production in the Hokuriku region was found the most vulnerable to CO_2-induced high temperatures. Rice production in the Sea of Japan coastal part of the Tohoku region and the northwestern part of Kyushu is also vulnerable (Nishimori *et al*., 2007).

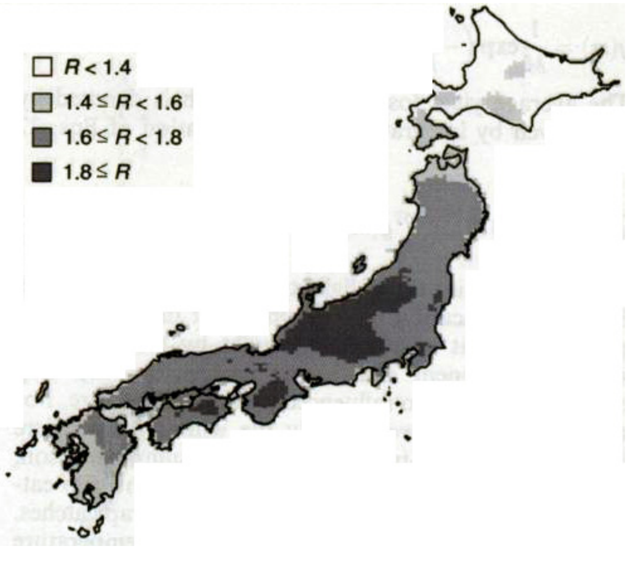

Fig.1 Estimated increase in the yield loss of rice caused by *C. suppressalis* under global warming.
R: predicted annual yield loss in the period from 2031 to 2050 divided by the corresponding loss in the period from 1981 to 2000. (Yamamura *et al*., 2006)

Considering the impact of insect pests on rice production, Yamamura *et al*. (2006) have calculated the future average yield loss due to insects relative to that expected in a normal year by substituting future projected temperatures. Figure 1 shows that the yield loss resulting from the insect pest species, rice stem borer *Chilo suppressalis* (Walker) (Lepidopotera: Pyralidae), in the period from 2031 to 2050 will exceed that in the period from 1981 to 2000 by a factor of about 1.6 in most areas of Japan and about 1.8 in the Hokuriku region. This result demonstrates that climate change impact research on rice production in Japan has made significant progress relative to the period when rice production change was discussed only from the viewpoint of high temperatures and increased CO_2.

3. Vulnerability of Rice Production throughout Asia

The IPCC Working Group II has pointed out that Asian agriculture and food security faced crises due to the increase in severe high temperatures, flooding, sea level rise and strengthened tropical storms (IPCC, 2001b). In this section, a moisture balance model for soil was introduced in order to evaluate the vulnerability of cereal production in China and a growth simulation model was introduced to explain crop growth processes under various Asian environmental conditions. The latter modeling analysis corresponds to the third method as described in Section 2.

Results of a spatial-temporal analysis of the soil moisture environment during the past 50 years throughout China are shown in Fig. 2. Figure 2(a) represents the ratio of normalized soil moisture changes during 1976-1995 to that during 1946-1975, and Fig. 2(b) shows the significance of the difference using a double-sided student-t test. The normalized soil moisture was found to have decreased maximally by 10 mm in the North China Plane involving Hebei, Henan and Shandong Provinces and a part of northeastern China (Fig. 2). The agricultural water demand in southern China is projected to decrease generally, and the cropland soil-moisture deficit to decrease due to climate change. However, in northern China, the agricultural water demand is expected to increase, and the soil-moisture deficit to increase generally. Such changes in the water resources would have consequent impacts on the yield index (Tao *et al*., 2003). Cropland surface runoff during the growing period is expected to increase on some sloping croplands in the southwestern mountainous areas and in some areas along the south coast. These changes would have important implications for agricultural production. Particularly the rain-fed crops in the North China Plain and northeastern China would face water-related challenges in the coming decades due to the expected increases in water demands and soil-moisture deficit, and decreases in precipitation. What should be of concern is that the rain-fed crops in the North China Plain and northeastern China could face water-related challenges in coming decades due to the expected increases in water demands and soil-moisture deficit, and decreases in precipitation. The effective adaptation options should include adjusting the inharmonious proportion between plantation, forestry and stockbreeding, improving greatly the water use efficiency in agriculture and increasing the water supply to northern China (Tao *et al*., 2003). The reason for the decreasing tendency is temperature rises and the related increase in evaporation. The range of year-to-year variation has decreased in regions affected by dryness, and the surface run-off rate over the Yellow River area has been decreasing. Furthermore, the future (2031-2065) projected soil moisture compared with the current one (1961-1995) shows that soil moisture could increase in South China and decrease in the northern upland area of China (Yokozawa *et al*., 2001).

Next, growth and yield simulations were introduced for different rice genotypes grown under 700 μmol/mol CO_2 (doubled CO_2) and different degrees of temperature rise at the respective sites of the Asian Rice Network Experiment (ARICENET: Horie *et al*., 2003). This crop growth and productivity prediction model for rice considers procedures for selecting species, changing crop calendars and applying mitigation techniques. This new rice model was also developed to simulate growth and yields of different genotypes under variously different environments. The model simulation makes it possible to project rice yields at different locations in Asia under increased CO_2 and temperature conditions, and to discuss the implications of the simulation results for future Asian rice production.

Figure 3 represents the simulation results for cultivars of IR72 (indica) and Nipponbare (japonica) in Iwate and Kyoto in Japan, Nanjing and Yunnan in

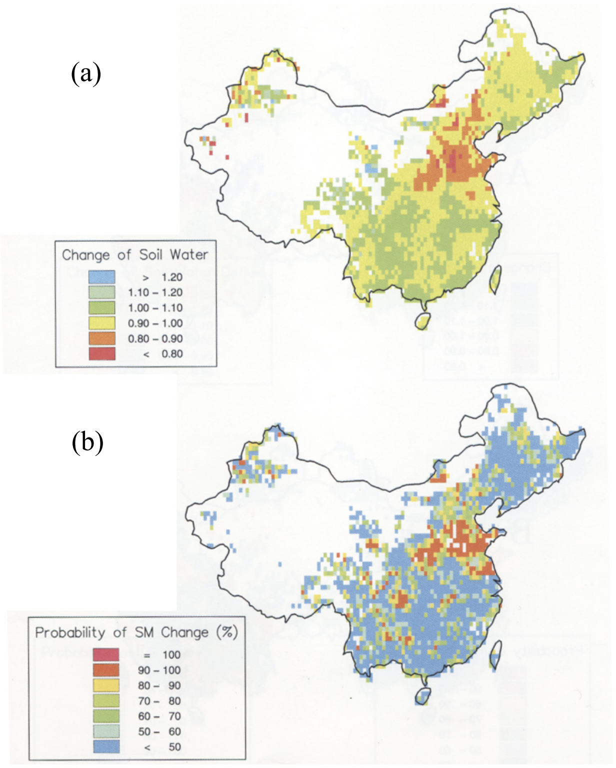

Fig. 2 (a) Geographical distribution of change in normalized soil moisture (ratio of annual mean soil water content to soil water capacity in crop root zone) in China during the period of 1976 - 1995 to that of 1946 - 1975 and (b) geographical distribution of the significant level of the difference of the soil moisture between above two periods. (Yokozawa *et al*., 2001)

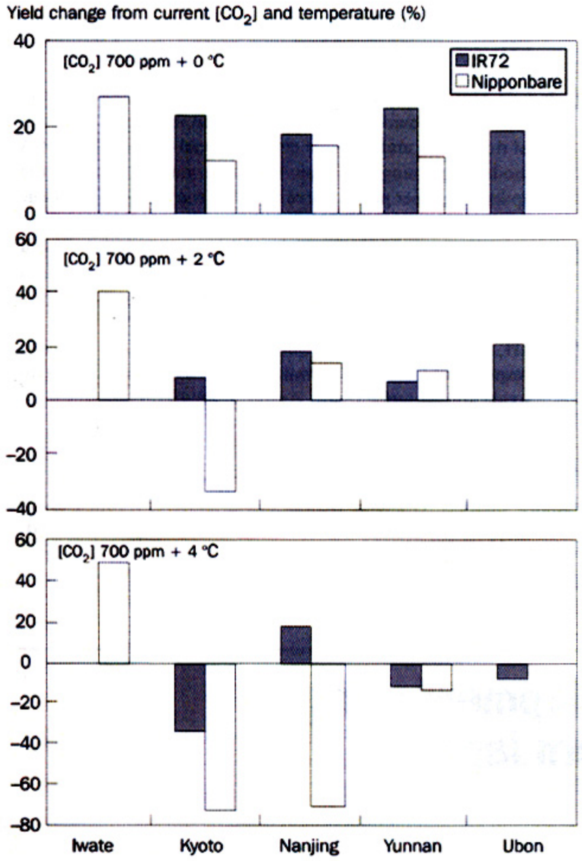

Fig. 3 Percentage yield change from the current conditions of less than 700 umol/mol (CO_2) with 0°C, 2°C and 4°C temperature rises, simulated for cultivars IR72 and Nipponbare in Iwate and Kyoto in Japan, Nanjing and Yunnan in China, and Ubon Ratchathani in Thailand. Climate data of 2001 and 2002 at each location were used as base climate. (Horie *et al*., 2005)

China, and Ubon in Thailand as a percentage yield change from the base conditions at each site (Horie *et al.*, 2005). The results on IR72 in Iwate and Nipponbare in Ubon are not shown in Fig. 3 because these cultivars showed very poor adaptability to the climates of those sites. The model projected higher yield responses to elevated CO_2 in IR72 (indica) than in Nipponbare (japonica) simulated at all the locations under the current temperature conditions, which agrees well with the observations. Since the model assumed the same leaf photosynthetic response to CO_2 for both genotypes, the higher yield response of IR72 to CO_2 was due to its larger sink forming ability and higher source limitation under ambient CO_2 than Nipponbare. The model projected that doubled CO_2 alone will increase the yields of the two genotypes by about 20%-30% at most locations simulated. This effect of CO_2, however, was drastically reduced by a 2°C temperature increase at all locations except Iwate in the northern part of Japan. In Kyoto, where summer temperatures are much higher, doubled CO_2 with a 2°C temperature rise would significantly reduce the yield of Nipponbare, reflecting the increased spikelet susceptibility to high temperature damage under conditions of elevated CO_2. It was projected that doubled CO_2 with a 4°C temperature rise would have severely negative effects on rice yields at most Asian locations except for northern areas like Iwate. The negative effects were more pronounced in warmer areas like Ubon. The results in Ubon in Fig. 3, however, were for wet-season rice, and severely negative effects on dry-season rice yields were projected there under conditions of doubled CO_2 with a temperature rise of more than 2°C (Horie *et al.*, 2005).

4. Food Security in Japan

There are many kinds of works projecting changes in future food production, but there is a strong need to consider the effects of markets and trade worldwide added to the three above-described methods, using techniques such as cultivation experiments, statistical analyses and crop modelings. The two representative examples are CERES-Wheat, a crop model, and an integrated model connected to the world food trade model, BLS (Parry *et al.*, 1999). In Japan, the same procedure (Furuya & Koyama, 2005) has been applied by the Japan International Research Center for Agricultural Sciences (JIRCAS). The Japanese model utilized a non-linear process that estimated crop yield as a function of time, temperature and precipitation. Figure 4 represents one example by using the Japanese model, a comparison of production in two cases of four major crops (wheat, maize, rice and soybeans) and other grains between the future (2025) and current (2005) situations, which consider only economical effect and together with the effects of rising temperature around the world. These results show that world grain production may tend to increase gradually. This means that demand could potentially be met in the world. Wheat, the biggest crop, may continue to show increased yields in the countries with highest productivity such as the United States, India and China.

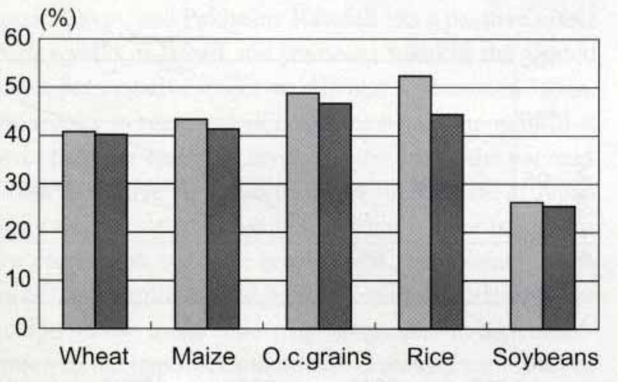

Fig. 4 Comparison of two cases of changes in production of four globally major crops (wheat, maize, rice and soybeans) and other grains between future (2025) and current (2005) situations, considering only economical effect (Left: Light) and together with the effects of rising temperatures around the world (Right: Dark). (Furuya & Koyama, 2005)

Considering the effects of climate change effect, major crops other than rice have not shown changes in the productivity because this model has a definition of active trade related to supply and demand. For rice production, however, a relative decrease in productivity was found as the result of higher temperatures. The reason is the world's rice production and consumption is clustered in the Asian region in comparison with wheat, which is in demand and traded throughout the world. Actually, in Japan, however, the consumption of rice has significantly decreased compared with the decreasing of production though rice imports from the U.S. or Australia have been increasing considerably. Therefore, a crisis in the supply and demand for rice in Japan is not expected in the near future. The other major grain in Japan, wheat, is dependent on imports from abroad. There is concern about how Japan could supply wheat demand if imports were stopped. Actually, wheat can be produced at lower temperatures and less precipitation areas compared with rice, and has been cultivated even areas of limited growth. According to the results in Fig. 4, the productivity of wheat is not expected to be affected by global warming, but the model analysis used in Fig.4 has a problem of not considering future changes in precipitation.

5. Summary and Discussion

Future vulnerability of rice production in Japan has been previously indicated only with regard to high temperature damage, but now there is a tendency to understand influences of insect pests and water resource shortages due to decreasing snow cover. For example, this paper points out that the decrease in rice production due to insects may occur by a factor of more than 1.8. From the viewpoint of previous variability and future projection of water resources, this paper also reports on significant dryness in China where the average soil moisture has decreased maximally by 10mm in the North China Plane, involving Hebei, Henan and Shandong Provinces and a part of the northeastern plane.

According to crop simulation model analyses, doubled CO_2 at current temperatures contributed by a factor of 1.2 to 1.3 to the current usual yield in all analyzed stations in Asia, but doubled CO_2 with 2°C of temperature rise eliminated the good effect. In addition, doubled CO_2 with 3°C or more of temperature rise caused a decrease in yields, except in Iwate. This effect was more prominent for tropical dry season cultivation or in Kyoto and Nanjing where summer temperatures are significantly higher. Thus it is found that, under conditions of increased CO_2, species which have large numbers of spikelets have generally an advantage for production, but a 2°C temperature rise denies the fertilization effect of CO_2 and a 4°C warming is connected to decreased rice yield. We have to pay attention to the fact that bad influence of rising temperatures and CO_2 levels are larger in temperate zone areas with hotter summers like Kyoto and Nanjing and in tropical areas with dry-season cultivation, therefore, the currently projected climate change could have a remarkable influence even with consideration of species of rice and crop calendar mitigation efforts.

Agriculture worldwide generally depends on precipitation, and water resources are absolutely necessary for agriculture. Actually, water resources are needed not only for agriculture and tap water but also for every situation of human life, but water resources face a crisis due to climate change or various political and economical issues. We often hear the phrase “the 21st century is an aqueous century”. In addition, we can say, “the 21st century is an agricultural century” for the above reasons.

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