Global Warming and Agricultural Production in Asia

Motoki Nishimori

Abstract In Japan, a rise in temperature of up to 3 °C will reduce the risk of cold-weather damage and increase biomass due to the CO_2 fertilization effect, especially in the northern part of the country, which is the main rice production region. As a result, rice production in Japan would be increased. However, there is concern about the quality of rice if the rise in temperature is extremely high. Also, research in Southeast Asia has raised worries about the negative effects of climate change on rice cultivation in regions such as northeastern Thailand and the Mekong Delta of Vietnam, which strongly depend on the hydrological environment. In general, agriculture around the world depends on the amount of rainfall, and water is essential for agriculture. This resource is itself on the verge of crisis due to climate change, and numerous political and economic issues. It is said that "the twenty-first century is the century of water." The same can be said about agricultural and food issues around the world, especially in the Monsoon Asia region. In short, the twenty-first century is "the century of agriculture."

Keywords Global warming · Monsoon Asia · Paddy rice · Crop model · Water resource

1 Introduction

The regional effects of global warming, such as frequent occurrences of climate extremes and the resulting unstable food production and supplies, are becoming of increasingly greater concern. The IPCC (Intergovernmental Panel on Climate Change) Fifth Assessment Report (IPCC 2013) states that "warming of the climate system is unequivocal," based on their estimations that the global average surface temperature rose 0.85 °C over the period 1880–2012, and that an increase of

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0.3–4.8 °C from now until the end of this century is "likely." The 2014 report of the IPCC Working Group II (IPCC 2014), assessing the impact, adaptation, and vulnerability to climate change, also states that in addition to the risk of mortality and morbidity during periods of climate-change-wrought extreme heat, it believes with high confidence that food insecurity, and lack of reliable and safe drinking water due to drought, will also increase.

In addition to irrigated rice cultivation as practiced in a country like Japan, rice production in Asia also includes many regions that depend on rainfed paddy fields. In these areas, rice cultivation depends entirely on rainfall. Consequently, in contrast to Japan, China, and both Koreas—where the primary concern is on the effects of temperature on rice production—other parts of Monsoon Asia are focused on whether it is possible to ensure the crop water demand is met. While the increase in the concentration of CO_2, a major greenhouse gas, is the cause of the rise in global temperature, it also has the fertilization effect of stimulating photosynthesis, which increases crop production levels. Furthermore, to evaluate the effects of global warming on agriculture and food production, it is necessary to consider the meaning of "regionality" in its broadest sense, including not only the natural conditions of a region, but also local people's motives for production and changes in consumption preferences (consumer trends) based on economic circumstances.

When examining the relationships between global warming and regional food production in Asia, we must consider a variety of perspectives, not just the impact of changes in nature. While not meant to be exhaustive, here we introduce the findings of research in Japan and Southeast Asia, and discuss points that should also be considered besides natural conditions.

2 Effects of Global Warming on Rice Production in Japan

Three broad categories of techniques are used to estimate future rice production under global warming conditions.

(a) Use of statistical equations to estimate rice production developed from data on past production amounts and natural environmental conditions, such as temperature, to calculate the estimated rice production under future temperature change conditions.
(b) Cultivation of paddy rice under conditions of high temperature and concentrations of $CO_{2,}$ and measuring production amounts experimentally.
(c) Development of a numerical model that can simulate rice growth from planting to harvest to project changes due to high temperatures and concentrations of CO_2.

These methods have their advantages and drawbacks. As an example of (a), Nishimori and Yokozawa (2001) sought to determine the difference between the maximum yield temperature and the current temperature. In northern and inland

Honshu regions of Japan, the difference is positive: rice yield is expected to further increase even if the temperature rises from the present value. However, in southern Kanto and northwest Kyushu regions, a future rise in temperature is expected to reduce rice yield. This research, however, used statistical estimation, and did not consider the fertilizer effect and state policies such as reduction in crop size.

Rice growth experiments in category (b) include growing rice outdoors in a FACE (free atmosphere CO_2 enrichment) environment in which carbon dioxide is increased (Kobayashi 2001) to reproduce global warming conditions, in addition to growing rice in greenhouses with higher temperatures and CO_2 concentrations. However, it is not possible to carry out experiments for all combinations of rice breeds and soil conditions, and sufficient information about the complex effects of temperature and CO_2 concentration cannot be obtained. Therefore, changes in crop production as a result of climate change are basically estimated using method (c), developing models of crop production from research data on crop physiology and ecology obtained from experimental cultivated fields (or lab settings) as carried out in (b), together with the statistical calculations of (a); expected climate change scenarios are input into the models to estimate future yield.

Models in category (c) can be broadly divided into those that place weight on empirical statistical formulas like those developed by Yokozawa and Iizumi (e.g., Iizumi et al. 2009) and models that seek to faithfully reflect a crop's physiological and growth processes, as presented in Sect. 1. Yokozawa et al. (2009) estimated the annual rice yield in each region of Japan for current, near future, and century-end periods by inputting climate change scenarios into a model of the former category. According to the model, a rise in temperature of up to 3 ºC will result in a rice yield nationwide that is similar to or slightly above current yields. A large increase in yield in northern Japan would be due to a reduction in the probability of cold-weather damage. Also, the coefficient expressing the magnitude of yearly variation in rice yield in each region increases in all regions as the temperature rises (Fig. 1). The reason is that empirical knowledge about the sharp decrease in the conversion factor (harvest coefficient) from the crop biomass to yield, which occurs because of high-temperature stress effects during the rice crop's flowering season, is incorporated into the model. However, there are still great uncertainties about the response of rice yield to high temperatures, and research from the perspective of crop physiology is needed, as described in Sect. 4.1 below.

3 Effects of Global Warming on Rice Production in Southeast Asia

3.1 Water Resources and Rice Cultivation in Monsoon Asia

In this section, we present the effects of global warning on water resources based on the results of a continental-scale water circulation model developed by Ishigooka

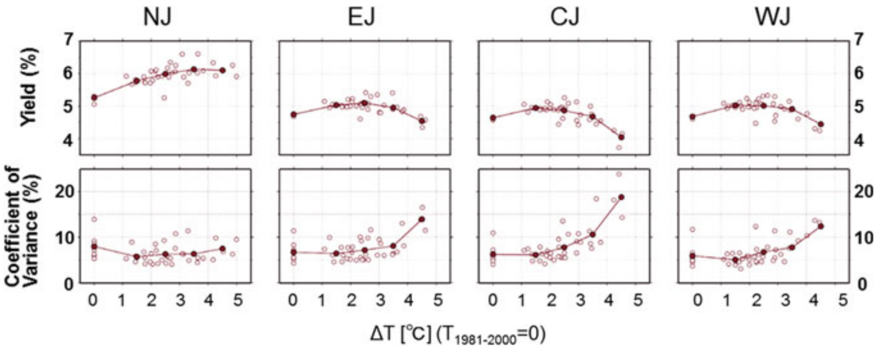

Fig. 1 Regional effects of climate change on rice yield in Japan (Reproduced from Yokozawa et al. 2009) *Note* The horizontal axis shows the degree of warm season averaged surface air temperature increasing from 1981 to 2000. The vertical axis shows the average yield (top) and the coefficient of variation (bottom). The regions considered here are composed of Japan's traditional regional divisions (from left): NJ (northern Japan); EJ (eastern Japan); CJ (central Japan); WJ (western Japan)

et al. (2005), which takes land use into account. This model calculates the amount of water demand for irrigation (the amount needed to grow crops without stress brought about by insufficient water) and the amount of water resources that can feed arable land.

Figure 2 shows the difference between the averages of the amount of water needed for irrigation and suppliable water resources over a 30-year period (1961–1990) obtained from long-term wide-region weather data. Regions with high values require considerable water to grow crops without water-related stress, but we have to note non-arable areas that are not colored. The greater the difference, the more the agricultural water supply was in danger. Regions with great disparities included Central Asia, Pakistan, and Northern China, with the amount of water that is insufficient to needs reaching more than 500 mm per year in the Indus River region. Thus, we see that water is the limiting factor of rice production in Monsoon Asia.

3.2 *Effects on Northeastern Thailand*

The northeast region of Thailand is one of the major rice production areas in Southeast Asia. Even now, 70 percent of rice paddies in that region are rainfed (Shimizu et al. 2004). It is therefore essential to consider water use when estimating rice production.

To evaluate the climate change effects on the surface water circulation process and its relation to rice production in rainfed regions, Ishigooka et al. (2010) first estimate the surface area of rice planting as the saturation surface area, an indicator that the ground surface is sufficiently moist. Fig. 3 shows a comparison between a

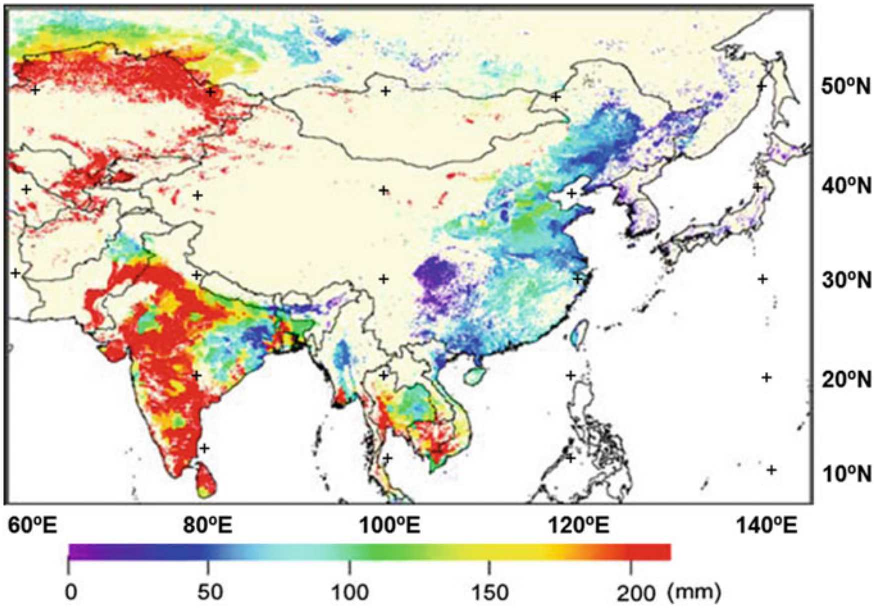

Fig. 2 Theoretical distribution of insufficient amounts of crop water (difference between amount needed for irrigation and suppliable water sources) during a 30-year period (averages from 1961 to 1990) in eastern Eurasia (Reproduced from Ishigooka et al. 2005)

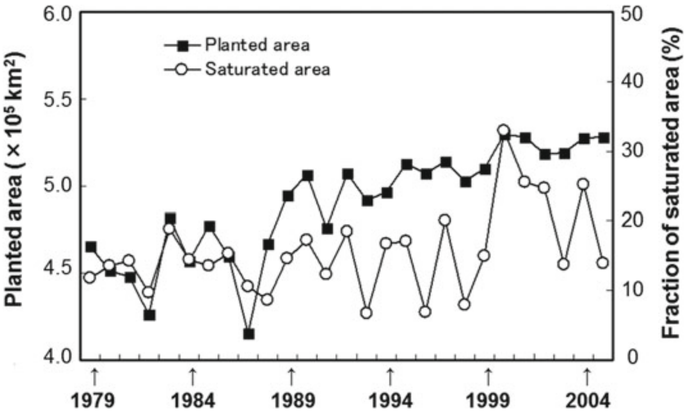

Fig. 3 Interannual variability of observed planted area obtained from statistics and simulated saturated area in mid-August. *Note* Saturated area is expressed as an area fraction to the maximum paddy area within Northeast Thailand (Ishigooka et al. 2010)

simulation of yearly variation in the rice-planting area in mid-August and values estimated from statistical data of the FAO Statistical Yearbook 2007–2008. While the model values in the latter half of the period are underestimations, the trend of yearly variations itself comparatively matches the statistically estimated values. Thus, it is possible to estimate the rice-planting area based on the projected supply and demand of agricultural water.

3.3 Effects on the Mekong Delta in Vietnam

The Mekong Delta in the southern region of Vietnam (Fig. 4) produces about half of the rice crop in Vietnam, one of the top rice-exporting countries after India and Thailand (Inoue et al. 2015). Nevertheless, much of this region is less than two meters above sea level, and saltwater intrusion is a problem.

To evaluate the change in rice production in this area, Khang et al. (2010) modeled a rice-planting style that seeks to maintain yield by focusing on intensive rice-planting periods when the saline concentration is low. The model was developed to estimate the periods in which rice planting and growth are possible from water resources in the paddy fields. The results reveal that the low salinity period

Fig. 4 Geographical location of the Mekong Delta region in Vietnam indicated by dark area surrounded by a rectangular box (Reproduced from Khang et al. 2010)

suitable for planting becomes shorter as saltwater intrusion expands because of global warming. It is expected that the number of possible plantings will decrease because of saltwater intrusion's seasonal cycles on the cultivation calendar. Furthermore, Kotera et al. (2014) sought to estimate changes in the rice-planting calendar, the surface area of harvest, and the yield for each small water area in the Mekong Delta by combining hydrological processes and a rice crop growth and yield prediction model that takes climate change scenarios as its input. The results showed a mutually opposing relationship whereby the harvestable surface areas in the upstream region during flood years and in coastal areas during low rainfall years experience large decreases, while at the same time the plantable and harvestable surface area in other regions experience increases. Meanwhile, ill effects on the rice yield as the temperature rises will be observed immediately; it is possible that the amount of rice produced in the Mekong Delta in the latter half of the 2020s will drop by 11 percent from current yields.

4 Prediction of Rice Production in Monsoon Asia and Various Issues

4.1 *Necessity of Perspective from Crop Physiology*

Determinants of the development, growth, and yield of rice, the major agricultural product in Monsoon Asia, are the rice's genotype (variety), environment, and the interaction between the two. As a result, models derived by incorporating various genetic traits obtained from theoretical equations expressing the development process of rice in accordance with physiological, ecological, and physical laws, which are tested empirically, are effective for understanding the interactions between the genetic characteristics of growth and yield formation, and the environment; they are also effective for identifying high-yield dominant traits under different environmental conditions.

Figure 5 shows the simulation results by Horie et al. (2005) that developed a crop model for Indica rice IR72 and Japonica rice Nipponbare at a CO_2 concentration of 700 ppm in Iwate (the northeastern part) and Kyoto (the central part) of Japan, Nanjing (the central part) and Yunnan (the southwestern part) of China, and Ubon, the northeastern part of Thailand. The figure also shows the relative additional yield (as a percent) at 360 ppm of CO_2 for each of the locales and rice varieties. Compared with Japonica rice varieties like Nipponbare, the yield of Indica rice varieties like IR72 responds well to CO_2. The yields in all surveyed regions increase in doubled CO_2 concentration and present temperatures. However, under global warming conditions with an increase in temperature of +2 °C, the beneficial effects of a high CO_2 concentration disappear in all stations, except for Iwate. At temperatures of +4 °C, the harvest is reduced excluding Iwate. In short, the effects

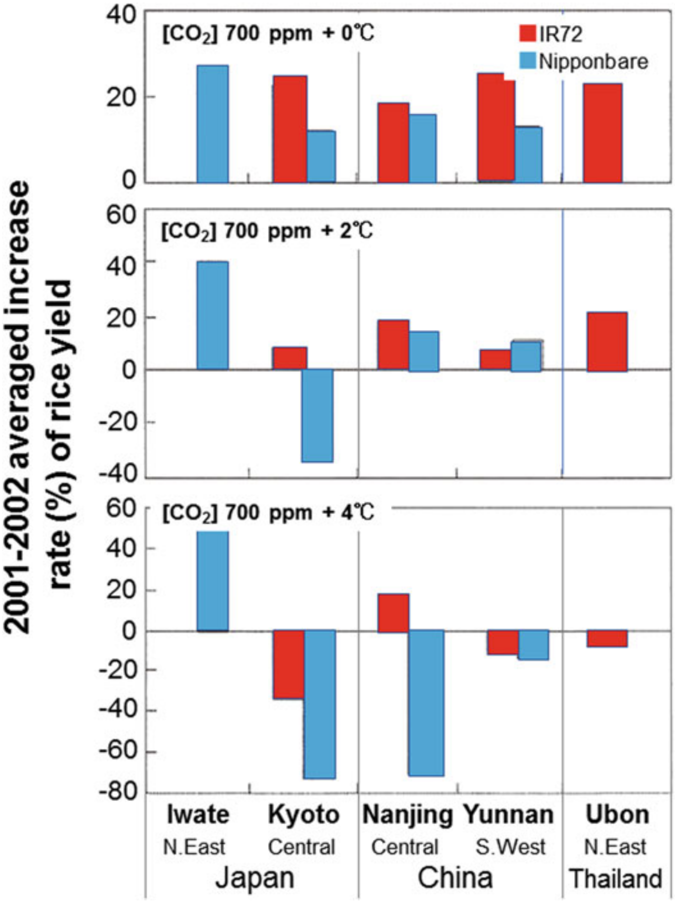

Fig. 5 Rate of increase in rice yield under increased CO_2 and temperature conditions in Iwate and Kyoto, Japan; Nanking and Yunnan, China; and Ubon, Thailand, for two rice varieties (IR72 and Nipponbare) (Reproduced from Horie et al. 2005) *Note* Three conditions (increase of 0 °C, +2 °C, +4 °C from present temperatures) are applied with CO_2 concentration of 700 ppm. The average increase rate is obtained by using the standard temperature and rice yield data at each location in 2001 and 2002

of high temperatures and high CO_2 concentrations are significant in the tropics during dry-season rice cultivation and in the temperate zone (which includes Kyoto and Nanjing), which is subject to high temperatures during the summer season. Even if adaptive measures are considered on the basis of the rice variety and cropping season, the predicted global warming will have major effects on rice cultivation in each part of Asia.

4.2 Necessity of Perspective Besides Agronomics and Climatology/Meteorology for Research

To project agricultural ecologies and food production in these Asian regions, it is necessary to consider not just hydro-meteorological conditions but also causes inhibiting the growth of crops. For example, rice production declines because of insect pests even if the natural (atmospheric) environment is sufficient. Rice blast, which occurs in Japan, is a representative example. Also, small brown planthoppers (*Laodelphax striatellus*) are known to carry a virus that causes rice plant sheath blight disease. Furthermore, much of the carbon-containing organic matter in soil in which rice is planted is decomposed by the activities of soil microorganisms, and a great portion of nitrogen found in soil is in ammonia form, which renders it inorganic through the removal of carbon. As a result, the amount of nitrogen in arable land has a critical effect on the yield and quality of rice crops. The rate of nitrogen's mineralizing activity is determined by temperature, pH, moisture, and the type of soil. It will be greatly affected by global warming (Nishimori 2007).

5 Conclusion

To summarize the discussion above, in Japan a rise in temperature of up to 3 °C will reduce the risk of cold-weather damage and increase biomass due to the CO_2 fertilization effect, especially in northern parts of the country, the main cultivated areas for rice. Thus, it is expected that the rice production of Japan would continuously increase. However, there is concern about the quality of rice and crop yield if the rise in temperature is extremely high. Also, research in Southeast Asia has raised worries about the negative effects of climate change on rice cultivation in regions such as northeastern Thailand and the Mekong Delta of Vietnam, which strongly depend on the water environment.

In general, agriculture around the world depends on the amount of rainfall, and water is essential for agriculture. Of course, water is necessary not just for agriculture but also for drinking and other wide-ranging aspects of human society, including industry. This resource is itself on the verge of crisis due to climate change and numerous political and economic issues. It is said that "the twenty-first century is the century of water." From our discussion above, the same can be said about agricultural and food issues around the world, especially in the Monsoon Asia region. In short, the twenty-first century is "the century of agriculture."

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