The characteristics of time changes on rice production predicted by the MRI’s CGCM
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Abstract

We estimate the time change of the rice production for every 10 years for a period of 100 years by using the MRI’s CGCM containing the transient CO₂ experiment,¹² and the crop model named SIMRIW.³ On this estimation by these models, we choose the ‘Koshihikari’ as a representative cultivar and assume optimal cultivation technologies are adopted.

Annual and summer season's mean air temperature increase almost linearly, and become 2.0 to 3.0 degree C higher after 70 years, 3.0 to 4.0 degree C higher after 100 years, and these temperature changes are almost 1.0 to 2.0 degree C smaller than the predictions of previous studies.¹, ⁷, ¹⁴ As a result of this, the cultivated area of ‘Koshihikari’ is estimated to spread northward, and the yield in currently cultivated area is also simulated not to change toward a harsh condition for at least 100 years, under optimal cultivation technologies.

1. Introduction

Climate is the primary factor for determining the growing season and the yield of crops in various regions. Therefore, the currently increasing CO₂ concentration in the atmosphere and its accompanying global warming are predicted to have enormous effects on crop productions in the future. Moreover, these effects depend on the kinds of crop and their growing regions, so it is necessary to assess them on the production of major crops in each region to save the food security.

Many attempts have been made to predict the effects of global change on crops’ yield at various locations and these results were summarized in one report.¹³ According to this report, on the whole, global agricultural production could be maintained relative to baseline production in the face of climate
change modeled by general circulation models (GCMs) at doubled equivalent-CO2 equilibrium conditions. However, productivity is projected to increase in some areas and decrease in others, especially the tropics and subtropics. Moreover, regional effects would vary widely, so focusing on global agricultural production does not address the potentially serious consequences of large differences at local and regional scales, even at mid-latitudes.

Studies for Japan indicate that positive effects of CO2 on rice yields would generally be superior to negative climatic effects in the central and northern areas, leading to yield gains, but that in the southwest, particularly in Kyushu, the effects on rice yield were, on balance, estimated to be negative for several climate scenarios.\(^{10}\)

However, these studies predict and discuss on doubled equivalent-CO2 equilibrium conditions, not making clear the process to these conditions. In this report, we describe the prediction on the growth and the yield in Japan by the crop model using the results of transient CO2 experiment with the climate model, to make clear the changing patterns on its yield and growing season due to the process of the global warming.

2. Model description

To make clear the process of the global warming, we use the results of experimental numerical predictions of the global climate for 100 years with a coupled atmosphere-ocean general circulation model (CGCM) developed by the Meteorological Research Institute (MRI) of the Japan Meteorological Agency.\(^{12}\) This CGCM is characterized by two aspects; one is a relatively high resolution of the oceanic part in the low latitudes to simulate El Nino phenomena, and the other is to include an elaborate sea ice model to simulate seasonal variation of sea ice coverage and thickness, and these phenomena have considerable effects on the weather of rice growing season. Moreover, on the transient response experiment performed with MRI-CGCM, atmospheric CO2 concentration is gradually increased at a compound rate of 1 % / year. This increasing rate of CO2 roughly corresponds to the actual increase of radiative forcing due to the increase in several greenhouse gases, and has been used in other studies.\(^{6,9,12}\)

Impact assessments on regional rice yield in Japan are made by using the
rice growth simulation model named SIMRIW (Simulation Model for Rice-Weather relations). The ontogenetic development process of rice from emergence to heading is represented in this model by a continuous variable, the developmental index DVI, of which the value is defined to be zero at emergence, 1.0 at heading and 2.0 at maturity. The value of DVI at any given moment of crop development is given by integrating the developmental rate DVR with respect to time. The DVR is given by a nonlinear function of daily mean temperature and day length.

The dry matter accumulation process of rice crop is simulated based on the idea that a crop dry weight at any moment is proportional to the absorbed radiation accumulated up to that moment. This process of biomass accumulation is characterized by only one crop parameter, the radiation conversion efficiency Cs. The Cs is assumed to be constant up to the heading (DVI=1), and thereafter is given by a decreasing function with respect to DVI to simulate the maturation or senescence process. The growth rate in leaf area which governs the radiation absorption rate is modeled as a unique function of temperature, and independently of its weight growth.

The grains yield is simulated in SIMRIW from calculated total biomass by multiplying by a harvest index. The harvest index is given by a function of DVI and the sterility percentage of spikelets.

In order to make SIMRIW applicable to predictions of the effects of elevated CO2 and warming on rice yield, two important processes need to be incorporated into this model; the process for determining the CO2 effect on growth and yield, and the one to determine high temperature effect on the reproductive organs. The effects of CO2 concentrations on photosynthesis were incorporated into SIMRIW simply as the enhancement of radiation conversion efficiency by CO2. For simulating the effects of anticipated temperature rises on rice yield, the processes in which higher temperature brings to spikelet sterility were incorporated into this model.

3. Results and Discussions

Figure 1 shows the time evolution of annual and summer season's mean air temperatures in Chikugo located in south-west part, Tsukuba in central part and Asahikawa in north part of Japan for every 10 year until 100 years later,
Figure 1: Time evolutions of annual and summer season’s mean air temperature in Chikugo, Tsukuba and Asahikawa until 100 years later, predicted by the MRI-CGCM.
predicted by the MRI-CGCM. According to this prediction, in these three places, annual mean and summer season’s mean air temperature increase almost linearly, and become 2.0 to 3.0 degree C higher after 70 years later when the CO2 concentration in the atmosphere is doubled, 3.0 to 5.0 degree C higher after 100 years later than now. These temperature changes are almost 1.0 to 2.0 degree smaller than the predictions of previous studies.\textsuperscript{1,7,14} Taking notice of their trends, Asahikawa changes larger, and their magnitudes become smaller with advancing south-west ward though Japan Islands.

The grain yield simulated by using the SIMRIW is larger than actual yield, because this model gives a climatically potential yield under optimal cultivation technologies. Moreover, the yield depends on the cultivar, the day of transplanting and the growth period. In this study, ‘Koshihikari’ is selected as the representative cultivar in Japan, and the day of transplanting and the growth period are selected as give the maximum potential yield in the harvest season. Figure 2 shows the time changes of the potential yield, its transplanting day and growth period in three places mentioned above for every 10 year until 100 years later. The potential yields in Tsukuba and Chikugo fluctuate ranging from 600 to 800 kg/10a, and become 6 to 7 % more after 70 years later, but 2 to 4 % less after 100 years later than now. On the other hand, in Asahikawa, we may yield the Koshihikari after 40 years later, and the potential yield reach more than 750 kg/10a after 100 years later. The transplanting days, in Tsukuba and Chikugo, are estimated to be 18 and 20 days earlier, and the growth periods are to be 7 and 11 days shorter than now, respectively. These results mention that the change of crop production is greater with advance to northward.

Horie\textsuperscript{2} found generally negative effects on rice yield in Hokkaido under the GISS climate scenario when rice variety was not changed but found increased yields if longer maturing varieties were adopted. Horie\textsuperscript{3} also found that rice yields would fall in most areas of the country under the Oregon State University climate scenario, but that changes in rice variety and other management changes could recover most losses expect in the southwest, where the projected increase in temperature of 4.0 to 4.5 degree exceeded the temperature tolerances of japonica rice varieties. Our result with considering the optimal cultivation technologies is not so severe as these ones.

Figure 3 shows the spatial pattern of the potential yield of rice on the present time and Figure 4 shows after 100 years later simulated by using the
Figure 2: Time changes of the potential yield, its transplanting day and growth period in three places (Chikugo, Tsukuba, and Asahikawa) simulated by the SIMRIW, using the results of a transient CO2 experiment with the MRI-CGCM.
Figure 3: The spatial pattern of the potential yield of rice on the present time.
Figure 4: The spatial pattern of the potential yield of rice after 100 years later.
SIMRIW. The untillable area colored black distribute in the central mountainous area, north part of Tohoku district and Hokkaido currently, but do only in restricted area of Hokkaido after 100 years later. Moreover, the potential yield of currently cultivated area is estimated not to change toward a harsh condition.

**Conclusion and Remarks**

Using the result of the transient CO2 experiment by the MRI’s CGCM and the crop model named the SIMRIW, we estimate the time change of the rice production for every 10 years until 100 years later.

Annual and summer season’s mean air temperature increase almost linearly, and become 2.0 to 3.0 degree C higher after 70 years later, 3.0 to 4.0 degree C higher after 100 years later, and these air temperature changes are almost 1.0 to 2.0 degree smaller than the predictions of previous studies. As a result of this, cultivate area of a cultivar named ‘Koshihikari’ is estimated to spread northward, and the yield of currently cultivated area is also simulated not to change toward a harsh condition until 100 years later, under optimal cultivation technologies.

**References**

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