博　士（環境科学）　モハメド　レザウル　カリム

学位論文題名

Climatic effects on seasonal rice yields in Bangladesh with implications for future projection

（バングラデッシュのコメ生産に及ぼす気候の影響と生産量の将来予測）

学位論文内容の要旨

Expecting that agricultural yield is highly dependent on climatic conditions, particularly water availability and suitable temperature, an agro climatic study was carried out on rice crops during three different seasons in four regions of Bangladesh. Data on climate (surface air temperature and precipitation) and seasonal rice production were examined for the period 1986–2006 from 18 rice growth observatories.

The relationship between climate and rice production was statistically analyzed by removing long-term trends so that the effects of improved irrigation, good quality production inputs which results in a general increase in crop production, were removed. The analysis using both single and multiple regressions suggested that, during monsoon and summer, higher temperatures had negative effects on rice production, especially in the northwestern (NW) region. In winter, positive effects were observed throughout Bangladesh. Since the annual mean temperature was positively correlated with those in the three seasons individually, the annual temperature had negative effects on the annual rice production only in the NW region, while it had positive effects in the central and southern regions. With the exception of the NW region, which was basically dry, excessive rainfall both in summer and monsoon yielded floods and reduced rice yield. In winter, more rainfall showed positive effects on crop production only in the central region, which was least irrigated.

Since the crop does not show clear statistical results probably due to irrigation, a model study has been done to explore the water demand. Soil moisture storage that affects the plant growth is strongly influenced by prevailing weather. Projected climate thereby could have a significant influence on future moisture balance and thus affecting rice production. Water deficiency is considered as one of the major climatic restraints for crop production in Bangladesh, especially in the dry season. To better understand the crop responses to moisture variation, a quantitative analysis is done for major water balance components named, potential evapotranspiration (PET), actual evapotranspiration (AET), soil moisture storage (ST), water deficiency (WD) and water surplus (WS) with the use of Thornthwaite monthly water balance program. Analyses were carried out for three different seasons, together with interannual variability for 12 major rice growing districts. Monthly average surface air temperature and precipitation data were collected from Bangladesh Meteorological Department during 1986 to 2006. Results suggested, Khulna, the coastal station had the highest PET of 1369 mm yr^{-1} ; while the lowest value of AET as 1108 mm yr^{-1} was estimated

for Teknaf. ST was found almost at field capacity from July to September and, the northern station Bogra experienced the lowest ST of 1392 mm yr^{-1}. The assessment of average WD of 178 mm yr^{-1} in northern Bangladesh reflected the worst situation among all regions, besides focusing the winter as the most critical season. Least amount of WS (642 mm yr^{-1}) was noticed for the central region. Significant positive relationship ($p<0.05$) between soil moisture and current rice yields proved the importance of surplus water conservation for the drought prone zone of Bangladesh.

Although the highest production was achieved in winter, but the lowest soil moisture reserve and the marginal temperature rise during for the observed period would be more crucial in future. Hence to clarify the effects of the future climate change on the yield of a popular winter rice variety BRRI dhan29 in Bangladesh were assessed using a bio-physical simulation model ORYZA2000. The model was first validated for 2000-2008 using the field experimental data from Bangladesh (Bangladesh Rice Research Institute, Soil Resources Development Institute), with a careful test of climate data on daily basis for station-wise and reanalysis datasets (Bangladesh Meteorological Department, National Center for Environmental Prediction, Asian Precipitation Highly Resolved Observational Data Integration Towards Evaluation of Water Resources). The model performance was found to be acceptable and satisfactory enough to represent the productions in nine major rice-growing districts. Then, simulation experiments were carried out for the two time periods in future, 2046-2065 and 2081-2100. Significant reductions in average rice yields relative to 2000-2008 were 33% over the two time periods, for three selected locations with a fixed planting date of January 18. An increase in daily maximum temperature would be the main reason for yield decreases in the future, while higher carbon dioxide might partially cancel the yield decrease. Projected future rainfall pattern and distribution would also have a significant negative impact on the yields, by increasing water demands by 14%. Model analyses showed that the later transplanting would receive less damage under the projected climate and declined production appeared due to a shorter growing season. Overall the findings suggested that accelerated atmospheric warming would result in serious damage to rice of all three seasons in Bangladesh. To boost up the rice production and cooping with climate change consequences, integrated adaptation measures should be recommended.ORYZA2000 can be a useful research tool to investigate the possible impacts of climate change in prior to finding the way out. However reliable prediction of future crop production will rely on the accurate projection of climate parameters in individual seasons.

学位論文審査の要旨

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(バングラデッシュのコメ生産に及ぼす気候の影響と生産量の将来予測)

Agriculture is the single most and largest sector of Bangladesh's economy, currently which contributes to 24% of the country's GDP. Among the agricultural crops, rice is the staple food for 147 million people of Bangladesh, where an area of 12 million hectare is used for the cultivation of rice. Agriculture is always vulnerable to unfavorable weather events, and despite technological advances, climate is still the key factor in agricultural productivity. Bangladesh is one of the most 'susceptible countries' to the negative impacts of climate change, where agricultural production is already under pressure from increasing demands for food and reduced cultivable land. Projected climate change is expected to aggravate the situation further by causing more frequent and intense droughts and increasing temperatures.

Expecting that agricultural yield is highly dependent on climatic conditions, particularly water availability and suitable temperature, an agro-climatic study was carried out to clarify the climatic dependence of rice crops, during three different seasons in four regions of Bangladesh. Data on climate (surface air temperature and precipitation) and seasonal rice production were examined for the period 1986–2006 from 18 rice growth observatories. The relationship between climate and rice production was statistically analyzed by removing long-term trends so that the effects of improved irrigation, good quality production inputs which results in a general increase in crop production, were removed. The analysis using both single and multiple regressions suggested that, during monsoon and summer, higher temperatures had negative effects on rice production, especially in the northwestern (NW) region. In winter, positive effects were observed throughout Bangladesh. Since the annual mean temperature was positively correlated with those in the three seasons individually, the annual temperature had negative effects on the annual rice production only in the NW region, while it had positive effects in the central and southern regions. With the exception of the NW region, which was basically dry, excessive rainfall both in summer and monsoon yielded floods and reduced rice yield. In winter, more rainfall showed positive effects on crop production only in the central region, which was least irrigated.

Since the crop did not show clear statistical results probably due to irrigation, a model study was carried out to explore the water demand. Soil moisture storage, which affects the plant growth, is strongly influenced by prevailing weather: i.e., rainfall and

temperature as well. Projected climate thereby could have a significant influence on a future moisture balance and thus affecting agricultural activities. Water deficiency is considered as one of the major climatic restraints for crop production in Bangladesh, especially in the dry season. To understand the crop responses to moisture variation, a quantitative analysis is done for the water balance using Thornthwaite monthly water balance program. Analyses were carried out for three different cropping seasons, together with interannual variability for 12 major rice growing districts along monthly average surface air temperature and precipitation data during 1986 to 2006. Results suggested that average water deficiency of 178 mm yr-1 in northern Bangladesh reflected the worst situation among all regions, besides the winter as the most critical season. Significant positive relationship ($p<0.05$) between soil moisture and current rice yields proved the importance of surplus water conservation for the drought-prone zone of Bangladesh.

Although the highest production was currently achieved in winter, the lowest soil moisture reserve and the marginal temperature rise during the observed winter period would be more crucial in future. Hence the effects of the future climate change were assessed on the yield of a popular winter rice variety BRRI dhan29 in Bangladesh using a bio-physical simulation model ORYZA2000. The model was first validated for 2000-2008 using the field experimental data from Bangladesh, with a test of climate data on daily basis for station-wise and reanalysis datasets. The model performance was found to be acceptable and satisfactory enough to represent the productions in nine major rice-growing districts. Then, simulation experiments were carried out for the two time periods in future, 2046-2065 and 2081-2100. Significant reductions in average rice yields relative to 2000-2008 were 33% over the two time periods, for three selected locations with a fixed planting date of January 18. An increase in daily maximum temperature would be the main reason for yield decreases in the future, while higher carbon dioxide might partially cancel the yield decrease. Projected future rainfall pattern and distribution would also have a significant negative impact on the yields, by increasing water demands by 14%.

Overall the findings suggested that accelerated atmospheric warming results in serious damage on rice production of all three seasons in Bangladesh. Furthermore, when rainfall increase is projected mostly in monsoon season, there will be a significant negative impact on rice, beside the winter production losses from less soil moisture reserve in future. To boost up the rice production cooping with climate change consequences, integrated adaptation measures should be recommended. ORYZA2000 can be a useful tool to investigate the possible impacts of climate change in prior to finding the way out. However reliable prediction of future crop production relies on the accurately projected climate parameters.

The examination committee of this paper recognized that these results provide essential information for the planning of management of rice production in Bangladesh. The committee also evaluated the great effort of the applicant in intensive data analysis work and skillful modeling work in management of ecosystem services, thereby concluded that the applicant is eligible for the degree of Doctor of Philosophy (Environmental Science).