Environmental Changes and Food Production in Asia

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ABSTRACT

As a result of climate change, the air temperature and precipitation may become unsuitable for the cultivation of major cereals in Asia. This paper will describe the impacts of climate change on major cereal crops in Asia such as rice, wheat and maize. Moreover, the impacts of agriculture on the environment will also be presented. The air temperature and precipitation data from the 1961-90 mean monthly terrestrial climatology and the results from simulation studies based on the Global Climate Model (GCM) constructed by the Center for Climate System Research at the University of Tokyo (CCSR) were used to predict the impacts of climate change on sustainable cropping and agricultural development. Changes in the mean air temperature and precipitation in the major cereal-producing regions in different cropping seasons were predicted from the present through the 2090s. Climate change will generally increase both the air temperature and precipitation in Asia. The impacts of climate change could be either beneficial or harmful. The increase in air temperature and precipitation will be disadvantageous to wheat cropping in Asia, while those will be advantageous to rice-cropping during the cooler or dry season. In contrast, some regions in subtropical Asia will have excess water resources during the rainy season. Precautionary measures against flooding will be needed in these areas. Major river basins with rice-cropping zones from East to South Asia were also investigated. Possible changes in water quality in the future were evaluated. The data used included those on the course of a river, land-use/land-cover classification, population, climate, nitrous oxide (NOX) emission, and country boundary. Statistical data on rice yield, harvested area, fertilizer consumption, food production, food consumption and food trade were also used to construct nitrogen load maps. The nitrogen load changes seasonally depending on the cropping systems used and precipitation. In the future, nitrogen discharge from humans and fertilization will increase along with the increase in the population and cultivation intensity. Fertilization and deposition of NOX will also increase along with economic growth. Therefore, it is likely that the nitrogen concentration in river water will increase. Excessive irrigation and fertilization in the dry season will result in further deterioration of the water quality, leading to the development of nonsustainable ecosystems in river basins.

IMPACTS OF CLIMATE CHANGE ON AGRICULTURE

Asians now make up 55% percent of the world population, and this figure is rising (Fig. 1). Farmers are increasing rice production in Asia to feed this growing population (Fig. 2) and expanding the area of irrigated farmlands to cultivate more rice (Fig. 3).

The effect of climate change on agriculture remains an open question. Will the changes in air temperatures and precipitation in Asia benefit major cereal cultivation, or will they make conditions unsuitable for cultivation? To investigate this question, we assessed the air temperature and precipitation in

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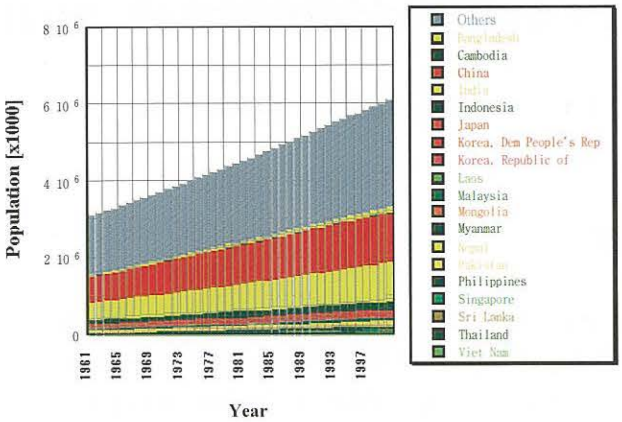

Fig. 1. Population in Asia and the world

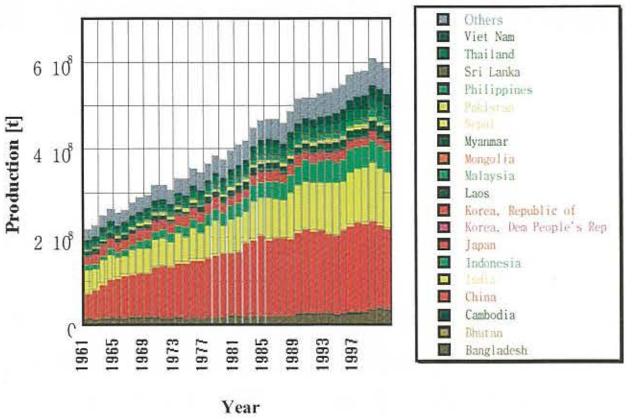

Fig. 2. Rice production in Asia and the world

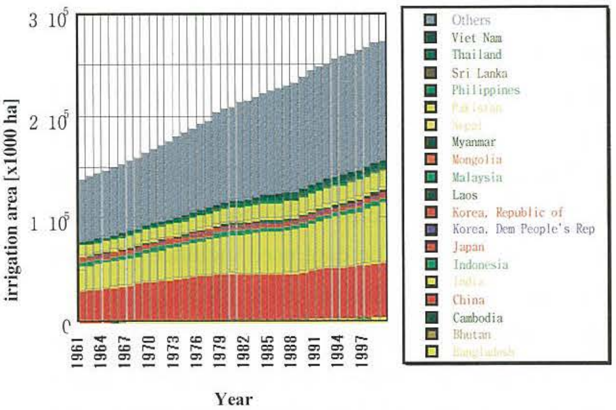

Fig. 3. Area of irrigated fields in Asia and the world

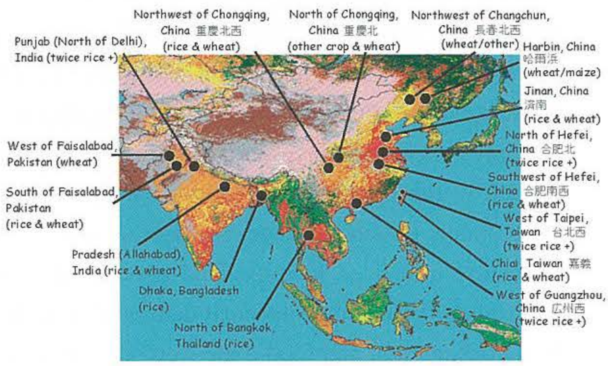

Fig. 4. Test sites for assessing climate change

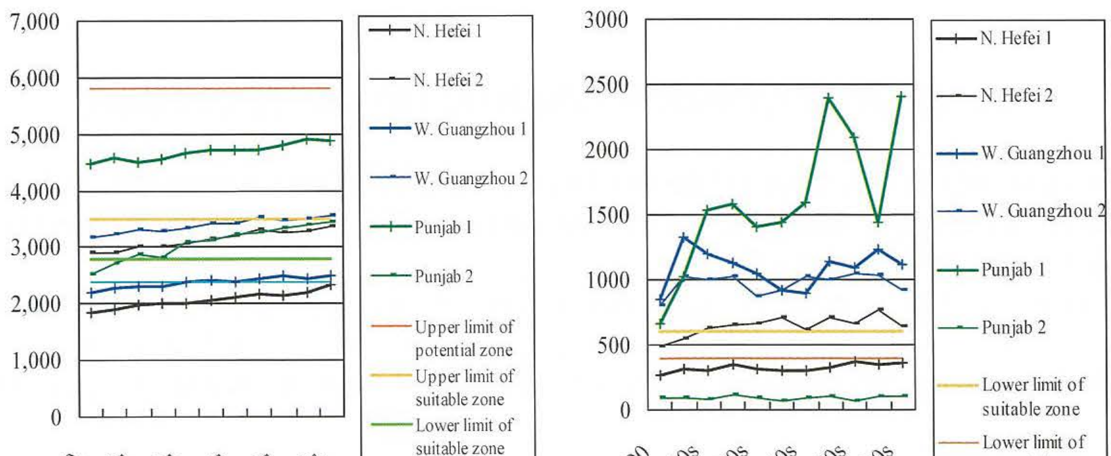

Fig. 5. Climate change of Punjab, Hefei and Guangzhou: (a) Air temperature and (b) precipitation

present-day croplands in Eastern through Southern Asia during the major cropping seasons (Okamoto *et al.* 2001).

DATA AND METHODS

The major cereals covered in the study were rice, wheat, and maize. Two crop calendars were employed to determine the cropping seasons: The "Country Rice Facts" (Crop and Grassland Service 2000) issued by the Food and Agriculture Organization of the United Nations (FAO), and the "Major World Crop Areas and Climactic Profiles" (World Agricultural Outlook Board 1994) for wheat and maize cropping areas.

The Basins and courses of rivers were determined on the basis of "Total Runoff Integrating Pathways (TRIP) data (0.5-degree grid cell version)" (Oki and Agata 1997).

The changes in the air temperature and precipitation were forecasted from the present to the final decade in this century (2090s), assuming that the cropping season was to remain unchanged.

Data on agroclimactic zones (Bachelet and Kropff, 1995) and crop climates (Cui 1994) were used to determine the potential and suitable zone for cultivating major cereal. The mean monthly temperature and precipitation from 1961 to 1990 were taken from data on monthly terrestrial climatology (New et al. 1999). Decadal mean values from the 2000s to 2090s were taken from a simulation study by the Center for Climate System Research (CCSR) of the University of Tokyo.

Test sites were distributed all throughout Asia and used for the cultivation of different types and combinations of crops, namely, for double-crop rice-cropping, single-crop rice-cropping, rice- and wheat-cropping, and spring wheat- or maize-cropping (Fig. 4).

IMPACTS OF CLIMATE CHANGE TO MAJOR CROPPING AREAS

In Punjab, Hefei, and Guangzhou, the double-crop rice-cropping areas, the air temperature is predicted to increase and the precipitation is predicted to oscillate (Fig. 5). The air temperature will rise above the upper limit of the suitable range for rice cultivation. No upper limits have been established for precipitation, though Punjab faces the threat of flooding from the months of June to October.

In Dhaka and Bangkok, the single-crop rice-cropping areas, the conditions will vary (Fig. 6). The air

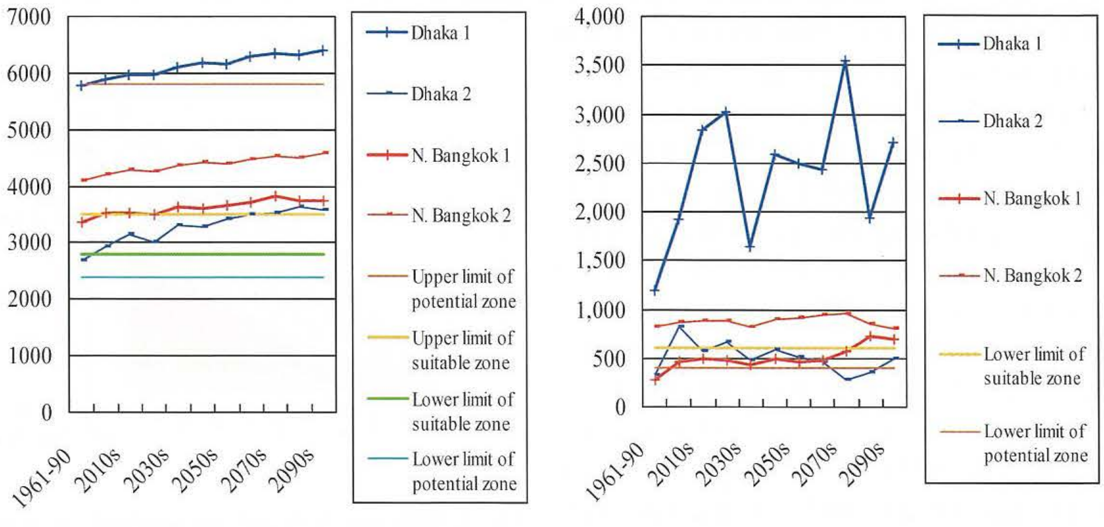

Fig. 6. Climate change of Dhaka and Bangkok: (a) Air temperature and (b) precipitation

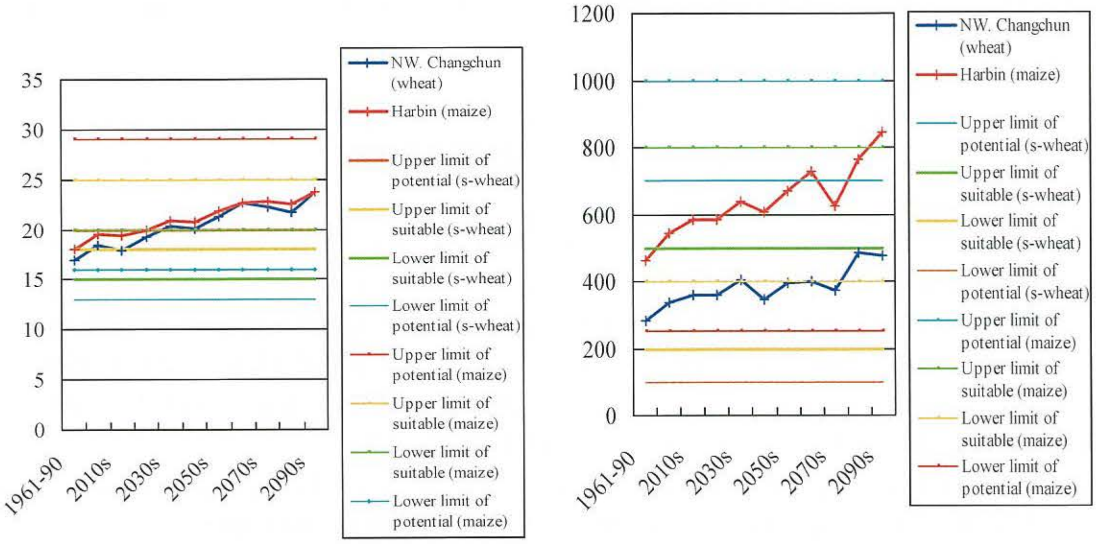

Fig. 7. Climate change of Changchun and Harbin: (a) Air temperature and (b) precipitation

temperature in Dhaka will be slightly too cold for rice cultivation during the second season, Boro (January to April), but it will rise to the suitable zone during the first season, Aman (June to October).

The precipitation in Bangkok will stay within the potential zone in the dry season (February to May), but rise into the suitable zone during the main season (June to October).

In the spring wheat- and maize-cropping areas, the air temperature will be unsuitably high for cultivating spring wheat, but suitable for cultivating maize (Fig. 7). The precipitation will be suitable for spring wheat and maize at these test sites from the present to the 2090s.

Rising temperatures in the decades to come will have benefits for the rice-cropping areas in the cooler seasons, and drawbacks for the wheat cropping areas. The rises in precipitation due to climate change will also have benefits and drawbacks.

IMPACTS OF AGRICULTURE ON THE ENVIRONMENT

The total area of arable cropland has steadily increased throughout the world over the past 300 years (Ramankutty and Foley 1999).

The population in Asia has steadily expanded, as mentioned earlier, and both irrigated croplands and agricultural production have been increased to feed the growing numbers of people (Figs. 1, 2 and 3). The effects on the environment are considerable.

The consumption of nitrogen (N) fertilizer, for example, has risen more than eightfold since 1961 (Fig. 8), posing considerable problems for water supplies. Japan now consumes an average of 100 kg of N equivalent per hectare (ha) of farmland, while farms in China and Western Europe consume more than 100 kg ha-1. The average yield per unit area in Western Europe is 10 t ha-1, while that in China is only about half of that level, i.e., 5 t ha-1. This means that the nitrogen fertilizer used in China discharges into the environment at a higher rate than that in

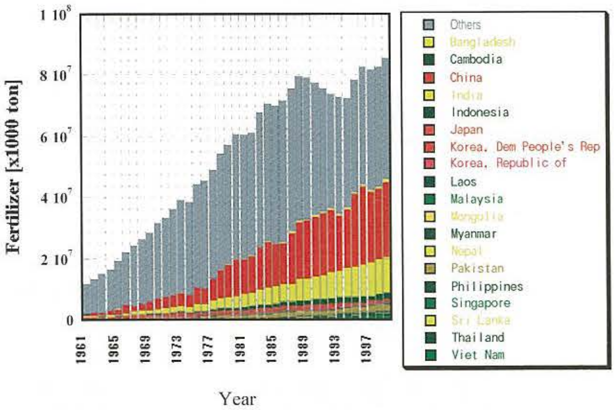

Fig. 8. Nitrogen fertilizer consumption in Asia and the world

Western Europe (Kawashima and Okamoto 1999).

The average value in Southeast Asia is reported to be 70 kg N ha-1 (Kaewthip et al. 2003). In some areas in China, 500 to 1900 kg N ha-1 is consumed (Zhang et al. 1996). The consumption level in Japan stands at 400-1560 kg N ha-1 (Tokuda and Hayatsu 2001).

As mentioned previously, the nitrogen load from fertilizer has a considerable impact on the quality of water and may even compromise the safety of water supplies for irrigation and drinking (Okamoto et al. 2003). Our group constructed a nitrogen load map based on measurements of nitrogen concentrations in major river basins in continental Asia (Fig. 9).

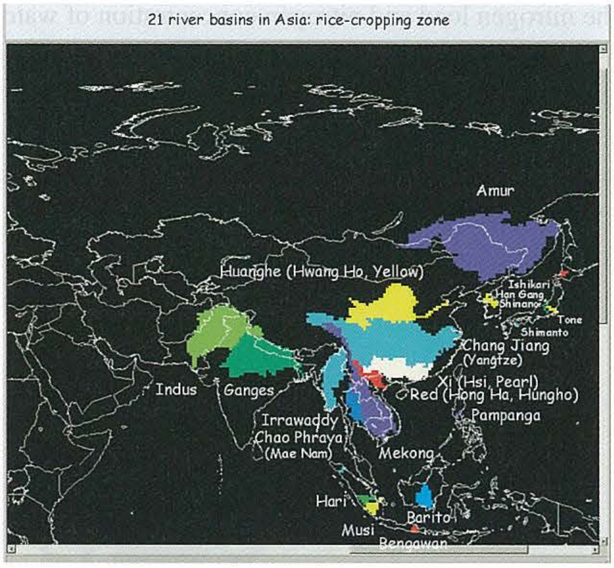

Fig. 9. Major river basins in continental Asia

Nitrogen levels in water are regulated quite strictly in Japan. The upper limit of quality for drinking water in Japan is 10 ppm. Within the river basins tested in our research, nitrogen concentrations were very low at lower altitudes, but high at higher altitudes (Table). The concentrations were very low in all the test sites measured in Thailand, Vietnam, and Laos, and in some test sites measured in China. In many other points in China, however, the nitrogen levels were very high (Shindo et al. 2003). At a vegetable farm in Laixi, for example, the concentration in groundwater reached 273 ppm, and a nearby supply of groundwater for drinking had a very high concentration as well.

Humans and farmlands occupy very important positions within the nitrogen flow, both outputting nitrogen load directly to the environment. Humans take nitrogen inputs from crops and output it back to agricultural land and the environment. Farmlands receive nitrogen inputs through biofixation and fertilization, and output nitrogen in crops.

Based on this model of nitrogen flow and environmental load in food production, our group simulated

Table. NO_3-N concentrations (ppm) of river water and groundwater in Asia

Location	conc.
Can Tho, Vietnam (Mekong Delta)	0.13
Vientiane, Laos (Mekong River)	0.12
Vientiane, Laos (groundwater)	0.13
Khon Kaen, Thailand (Ubon Rat Dam Reservoir)	0.03
Khon Kaen, Thailand (Chi River)	0.55
Nakhon Ratchasima, Thailand (Ton Sawar River)	0.68
Jinan, China (Yellow River)	3.36
Jinan, China (groundwater, hotel)	11.5
Laixi, China (vegetable farm)	273.0
Laixi, China (Sanxi Reservoir)	0.46-0.65
Laixi, China (groundwater, farmhouse)	89.3-120.6
Qingdao, China (groundwater, farmhouse)	22.9
Qingdao, China (Laoshan, mineral water)	12.1
Qingdao, China (groundwater, farmhouse)	3.81-3.96
Qufu, China (river water)	43.4

the nitrogen load and nitrogen concentration of water at test sites from 1970 to 2050 (Fig. 10).

The nitrogen load increased rapidly in the northern part of China between the years 1970 to 2000. Over the next half century, the nitrogen load will continue to rise in China, Vietnam, and the Philippines.

The nitrogen concentration in river water has also increased in Northern China, and it will continue to do so. Increases in other parts of the world will probably be minimal. The increases in Northern China are the expected result of climactic conditions, namely, poor precipitation and a low rate of denitrification due to the low temperature in this river basin.

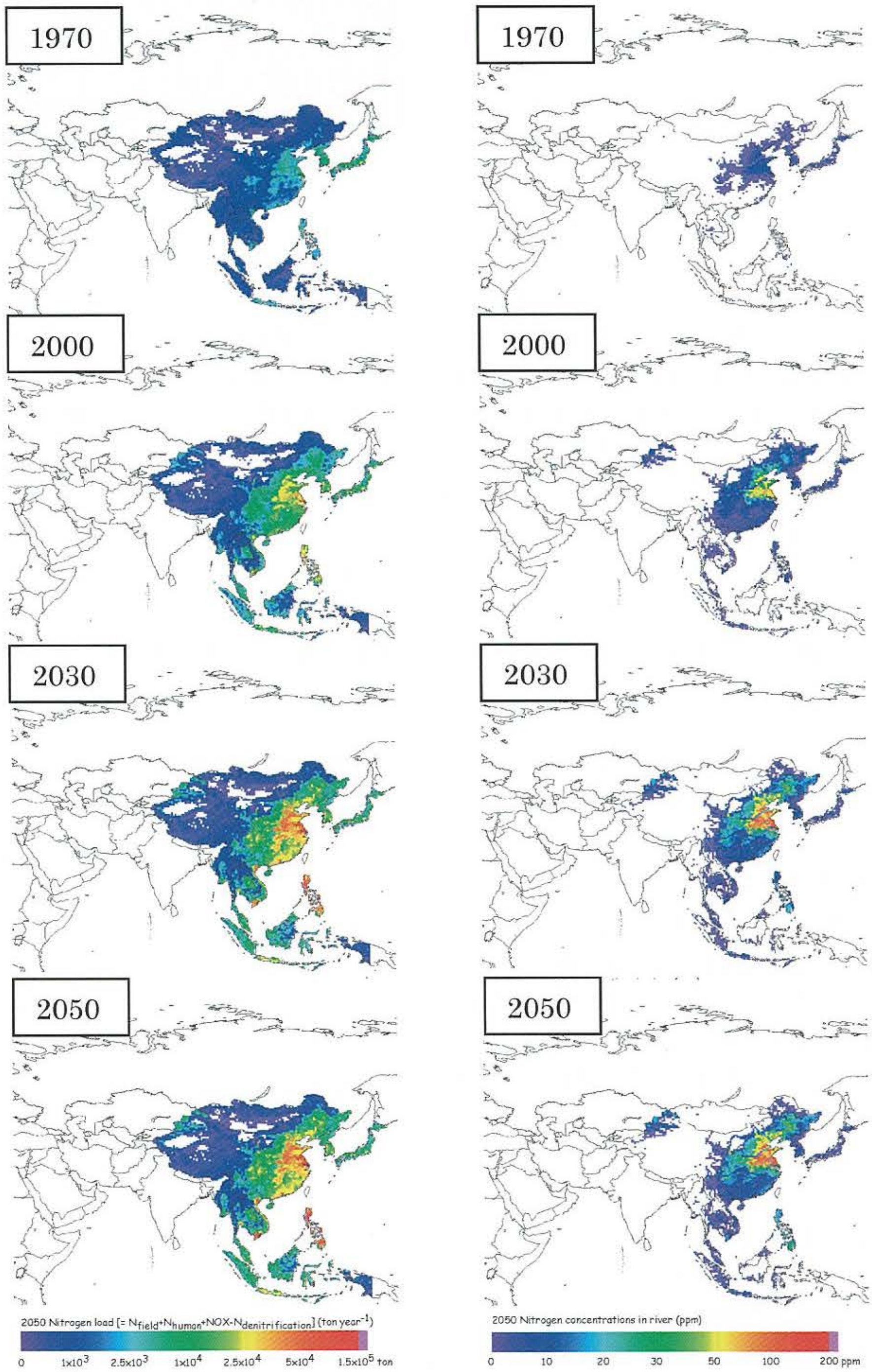

Fig. 10. Impacts of food production to water in Asia: (a) Nitrogen load (t year^{-1}) and (b) nitrogen concentrations (NO_3-N ppm)

CONCLUSIONS

It was predicted that climate change will cause a gradual increase in the air temperature. Changes in the air temperature are advantageous to rice-cropping areas in the cooler season. That is, the air temperature of Hefei and Guangzhou in the second season will reach the potential zone and the air temperature of Dhaka in the second season will reach the suitable zone. For wheat-cropping areas, changes in the air temperature are disadvantageous. That is, the air temperature of Faisalabad, Pradesh and Changchun will be above the potential zone. Consequently, crops cultivated in Changchun may have to be changed from spring-wheat to maize.

It was also predicted that climate change will cause an increase in precipitation. Changes in precipitation are advantageous to rice-cropping areas in the dry season. That is, precipitation of Bangkok and Faisalabad in the dry season will in the suitable zone. However, for subtropical rice-cropping areas, changes in precipitation are disadvantageous. That is, Punjab, Pradesh and Dhaka in the main season will be threatened by flooding. Taking the precaution of enriching infrastructures, such as embankments and the installment of drainage pumps, will be necessary.

The amount of nitrogen load was predicted to increase from 1970 through 2050. This trend is clear in the eastern part of China, Vietnam and the Philippines. The reason is that the amount of nitrogen fertilizer consumption is increasing.

The concentrations of nitrogen (NO_3-N) was also predicted to increase from 1970 through 2050. This trend is clear in the northern part of China. The rises will be due to the increasing usage of nitrogen fertilizer and the low precipitation in the region. The nitrogen load from farmlands will be far larger than that from humans (settlements), due both to the increase in nitrogen fertilizer consumption and economic growth.

REFERENCES

Bachelet, D., and Kropff, M. J., 1995, The impact of climatic change on agroclimatic zones in Asia, *Modeling the Impact of Climate Change on Rice Production in Asia*, edited by R. B. Matthews, M. J. Kropff, D. Bachelet and H. H. van Laar, CAB International, Wallingford (ISBN 0-85198-959-4), 85-94.

Crop and Grassland Service, 2000, Country Rice Facts. In *http://www.fao.org/WAICENT/FAOINFO/GRICULT/AGPC/doc/riceinfo/Corifa.htm*, International Rice Commission, The Food and Agriculture Organization (FAO), Rome.

Cui, D., 1994, *World Agroclimate and Crop Climate*, Zhejiang Science and Technology Publishing: Hangzhou (ISBN 7-5341-0656-7) (in Chinese).

Kaewthip, J., Kawashima, H., and Ohga, K., 2003, Projection of nitrogen load from food consumption and production in Thailand. *J. Japanese Agricultural Systems Society*, 19, 151-159.

Kawashima, H., and Okamoto, K., 1999, Global distribution of arable land, cereal yield and nitrogenous fertilizer use. *Journal of the Japanese Agricultural Systems Society*, 15(1), 73-76.

New, M., Hulme, M., and Jones, P., 1999, Representing twentieth-century space-time climate variability. Part I: Development of a 1961-90 mean monthly terrestrial climatology. *Journal of Climate*, 12(3), 829-856.

Okamoto, K., Yokozawa, M., and Kawashima, H., 2001, Pluses and minuses of climate change on major cereal cultivation in Asia. In *Advances in Ecological Sciences 10: Ecosystems and Sustainable Development III, edited by Y. Villacampa, C. A. Brebbia and J-L. Usó*, (Alicante: University of Alicante, Spain, and Southampton: Wessex Institute of Technology, U.K., ISBN: 1-85312-871-6), 79-88.

Okamoto, K., Shindo, J., and Kawashima, H., 2003, Land-use, water resources and nitrogen load in major river basins in Asia. In *River Basin Management II, edited by C. A. Brebbia*, (Southampton: WIT Press, U.K., ISBN: 1-85312-966-6), 423-429.

Ramankutty, N., and Foley, J. A., 1999, Estimating historical changes in global land cover: Croplands from 1700 to 1992. *Global Biogeochemical Cycles*, 13(4), 997-1027.

Shindo, J., Okamoto, K., and Kawashima, H., 2003, A model based estimation of nitrogen flow in the food production-supply system and its environmental effects in East Asia. *Ecological Modelling*, 169, 197-212.

Tokuda and Hayatsu, 2001, Nitrous oxide emission potential of 21 acidic tea field soils in Japan. *Soil Sci. Plant Nutr.*, 47, 637-642.

World Agricultural Outlook Board, 1994, *Major World Crop Areas and Climatic Profiles. Agricultural Handbook No. 664*, U.S. Department of Agriculture (USDA), Washington.

Zhang et al., 1996, Nitrate pollution of groundwater in northern China. *Agriculture Ecosystems and Environment*, 59, 223-231.