Changes in Nitrogen Flow and its Effect on Environment Associated with Food Production and Consumption in East Asia

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Abstract: A numerical model was created to estimate the nitrogen flow associated with food production and consumption based on statistical data and nitrogen output to the environment and its effect on nitrogen concentration in river water were estimated for the 11 countries of East Asia from 1961 to 2003. Based on the recent trend of per capita food consumption and scenarios of population growth, future nitrogen load was predicted by 2030. Food consumption increased steadily from 1961 to the mid 1980s and has been almost stable since then in Japan. Nitrogen output to the environment and nitrogen concentration in river water estimated with a simple first-order reaction model both showed a decreasing trend recently. In other countries, food consumption has been increasing rapidly: there has been a notable increase in the consumption of livestock products in China and some other counties. Estimated river water quality showed that rivers close to the east coast of Northern and Central China were highly polluted with nitrogen in recent years. Because of the growing population and the increase of per capita consumption of food, especially of livestock products, nitrogen load to the environment was predicted to become about 1.5 times and more than 2 times the present load in China and Southeast Asia, respectively. The effect of additional production of sugarcane for biofuel on nitrogen load was also evaluated.
Keywords: East Asia, Nitrogen Cycle, Food Production and Consumption, Water Pollution, Numerical Model

1. Introduction

Intensive agricultural practices that depend on artificial nitrogen fertilizers have dramatically enhanced crop yield and contributed to providing sufficient food. East Asia having growing population has been benefited from such agriculture and is making remarkable economic progress. These practices have, however, altered global and local nitrogen cycles and have caused a variety of environmental problems [1, 2]. Excess reactive nitrogen in the environment causes nitrate pollution in groundwater, eutrophication of lakes and ponds, red tides in coastal areas, and enhanced emission of nitrous oxide. To quantify the effects of anthropogenic nitrogen, the nitrogen cycle and environmental load have been modeled at global and catchment scales [3, 4].

Water quality in Japan has largely improved due to the various measures. Groundwater monitoring of 4122 wells in Japan in 2005 showed, however, that the nitrate and nitrite concentrations exceeded the Japanese environmental standard of 10 mg N L^{-1} at 174 wells (4.2%). Concentration of total nitrogen in lakes and bays often exceeds its environmental standard. Water pollution is more serious in other countries in East Asia and it has become one of the most critical environmental problems recently; lakes and estuaries are widely overtaken by an algae bloom in China, which threaten the drinking water safety, for example.

In the present study we evaluated the nitrogen load to surface water caused by farming and livestock production, food trade and human waste to clarify nitrogen flow and its effects on water quality over the past several decades in 11 countries in East Asia. The future nitrogen load to the environment was also predicted for the study area where population is still growing and dietary transition is taking place due to its economic development.

2. Nitrogen Flow Model

We made a simple nitrogen flow model [5] to evaluate the yearly trend of food production, trade and consumption in terms of nitrogen flow in a country and estimated the nitrogen load to the environment and also the concentration of nitrogen in groundwater and river water. The scheme of the model is shown in Fig. 1.

Nitrogen inputs to the model are nitrogenous chemical fertilizer, biological nitrogen fixation due to crop production and net import of food and feed indicated with green arrows. Fish and seafood are also included as inputs. The input nitrogen circulates in the food supply and consumption system through direct consumption as human food and animal feed, production of livestock products and protein meals, and consumption of these products. It eventually outputs to the environment through farmland soil, and as human waste (brown arrows). Some portion of nitrogen is volatilized as ammonia and returns again to land as atmospheric deposition. In the current estimation crop byproducts and livestock waste are all assumed to be applied to farmland soil as compost. The flow rates for the nitrogen flows in Fig. 1 were estimated by using statistical data provided from FAO [6] and from statistic section in each country and existing literature data.

Nitrogen surplus (N_{sur}) in the farmland calculated as the balance of input and output by equation (1) was assumed to leach from farmland to the environment.

$$N_{sur}(Y) = N_{fert}(Y) + N_{fix}(Y) - N_{crop}(Y) - N_{byprod}(Y) - N_{NH3\_VF}(Y) + N_{min}(Y) \qquad (1)$$

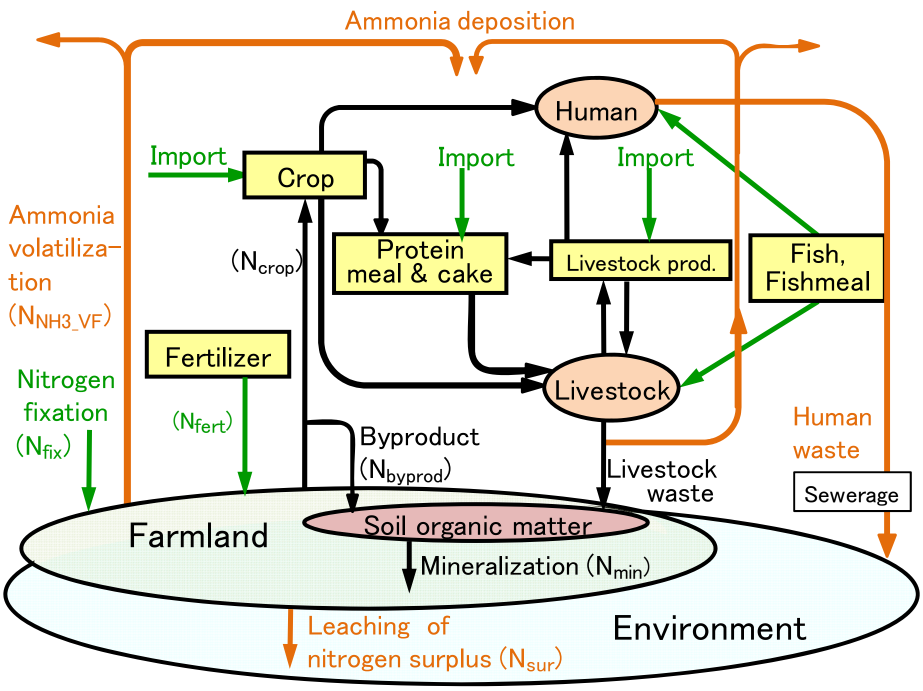

Fig. 1 Schematic diagram of the nitrogen flow model.

3. Changes in Nitrogen Input, Output and Internal Flow Associated with Food Production and Consumption in Each Country

Fig. 2a shows the estimated annual nitrogen flow associated with human food consumption and its composition from 1961 to 2003 in Japan. Total amount of nitrogen derived from food consumption increased more rapidly than the population growth until the mid 1980s mainly caused by the increased consumption of livestock products and it has slowed down after that. Nitrogen in total food consumption in 1990 and 2003 are about 1.6 and 1.7 times, respectively, of the value in 1961, while these ratios for livestock products consumption are 4.6 and 5.1, respectively. According to this figure, our per capita demand for food seems to have already reached a maximum. Fig. 2b shows the same for China. The amount of nitrogen in food consumption has been growing much more rapidly than for Japan. Increasing rate of livestock products consumption after mid 1980s is especially large: the amount of consumption of livestock products in 2003 is more than 20 times of that in 1961, while population has doubled

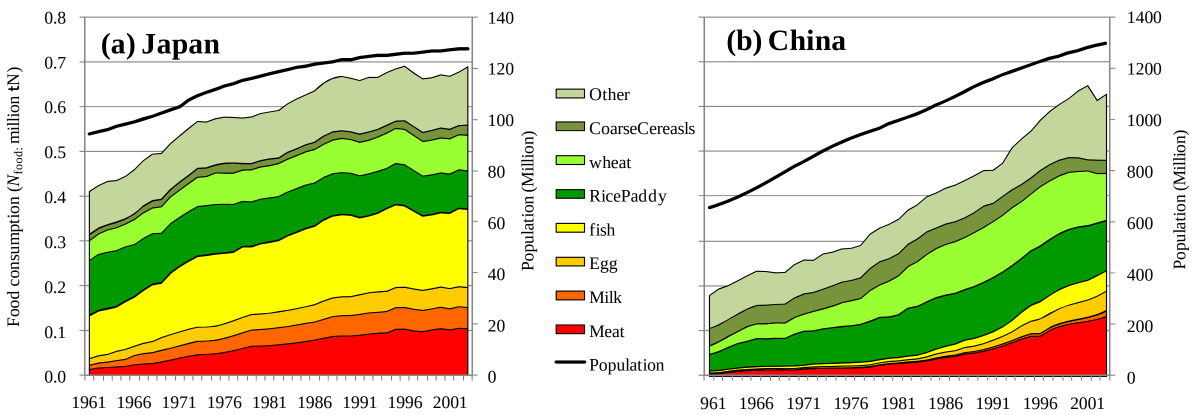

Fig. 2 Annual human food consumption in nitrogen equivalent and the population from 1961 to 2003.

during the same period. Consumption of livestock products showed the dramatic increase also in many other countries in East Asia.

Feed consumption also increased markedly until the mid 1980s in Japan and until now in China corresponding to changes in the production of livestock products. Although the relative contribution of various kinds of food to the feed supply are variable by country and year, the contribution of soybean cakes and other oil cakes has been increasing markedly in recent years both in Japan, China and some countries in Southeast Asia.

For providing these amounts of food and feed for domestic use, nitrogen input to each country and output to the environment have increased. Fig. 3a shows the changes in the annual amount of nitrogen input and the output from various sources in Japan. Nitrogen fertilizer was the largest contributor among the nitrogen sources until the mid 1980s, but it was replaced by crop import after that. Total nitrogen output to the environment increased gradually until end of 1980s, after which it tended to decrease. Among the components of nitrogen surplus in farmland, the relative contribution of nitrogen from mineralized livestock waste has increased and it occupies about 40% currently. In China and some countries in Southeast Asia, on a contrary, the relative contribution of nitrogen fertilizer increased over the years and has been about 75-85% of the total input since 1980s (Fig. 3b). Ratio of crop import to the total nitrogen input has been quite small though the amount of soybean import has started to increase recently.

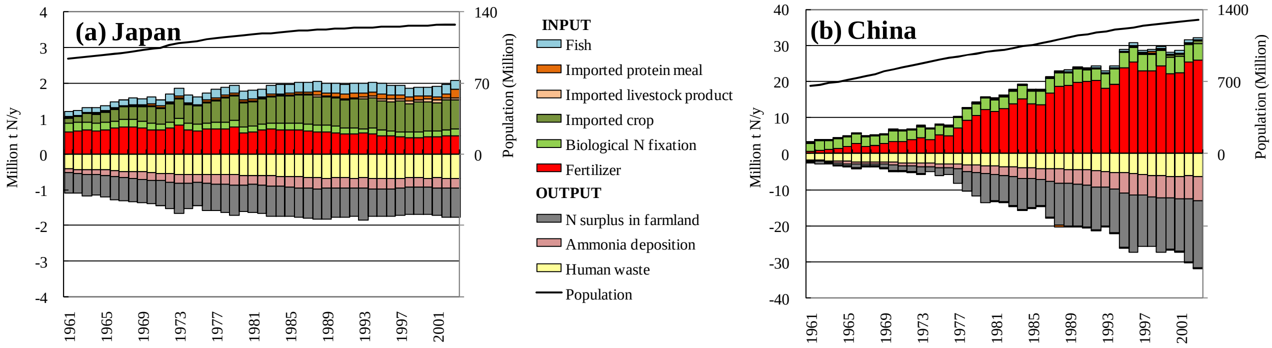

Fig. 3 Annual nitrogen input and output resulting from food production and consumption from 1961 to 2003.

Fig. 4 show the ratio of total nitrogen input to nitrogen in food consumption (N_{input}/N_{food}) in some countries. In Many countries in East Asia, the ratios have been increasing over the 40 years, and the larger portion of nitrogen input is causing the environment load recently. In Japan, to the contrary, this ratio is rather invariable despite the increase of the consumption of livestock products and demanded feed. The reasons for this constant ratio are considered to be the increase of net import of meat and feed crops and large contribution of fish to Japanese diet as well as the improvement of fertilizer efficiency. Japan has satisfied its demand for food with import. It prevented the increase of either nitrogen input or output to the environment, while it gave rise to a low food self-sufficiency rate.

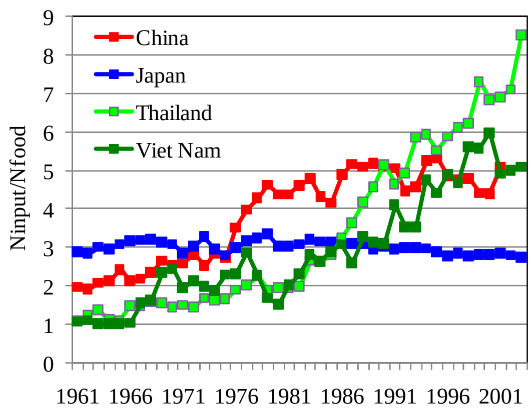

Fig. 4 Nitrogen ratios of total input to food consumption (N_{input}/N_{food}).

4. Estimation of Water Pollution

In order to evaluate the effects of nitrogen load to the water quality, outputs due to the nitrogen surplus in farmland (N_{sur}), human waste (after sewage treatment depending on the coverage of sanitation in each country) and atmospheric deposition of ammoniacal substances were assigned to grid cells based on the farmland areas, number of animals, human population etc. in each grid cell. Nitrogen oxide emission mainly from fossil fuel combustion from grid cells [7] was also taken into account. Nitrogen concentrations in groundwater and river water were then calculated by assuming that the nitrogen is removed from the water by denitrification and by immobilization during the leaching process in soil and groundwater layers and in rivers. These processes were assumed to proceed by a first-order reaction depending only on temperature and the residence time in the layers.

Fig. 5 shows the estimated spatial distribution of nitrogen concentration in river water in East Asia. Nitrogen concentrations were very low across the region in 1975 except for Japan and South Korea. High concentrations in Japan was primarily occurred near large cities due to high NOx deposition and concentrated nitrogen leaching from human waste and also in the areas where intensive livestock farming has been practiced. In other countries, the concentration have been getting higher rapidly after 1980s at eastern and northeastern part of China, some areas in Southeast Asia. Areas around the lower reaches of the Huang He and the Chang Jiang and also around the Liao River of northeastern China were estimated to be severely polluted in recent years and nitrogen pollution in river water and in groundwater has been becoming severer and widespread in East Asia.

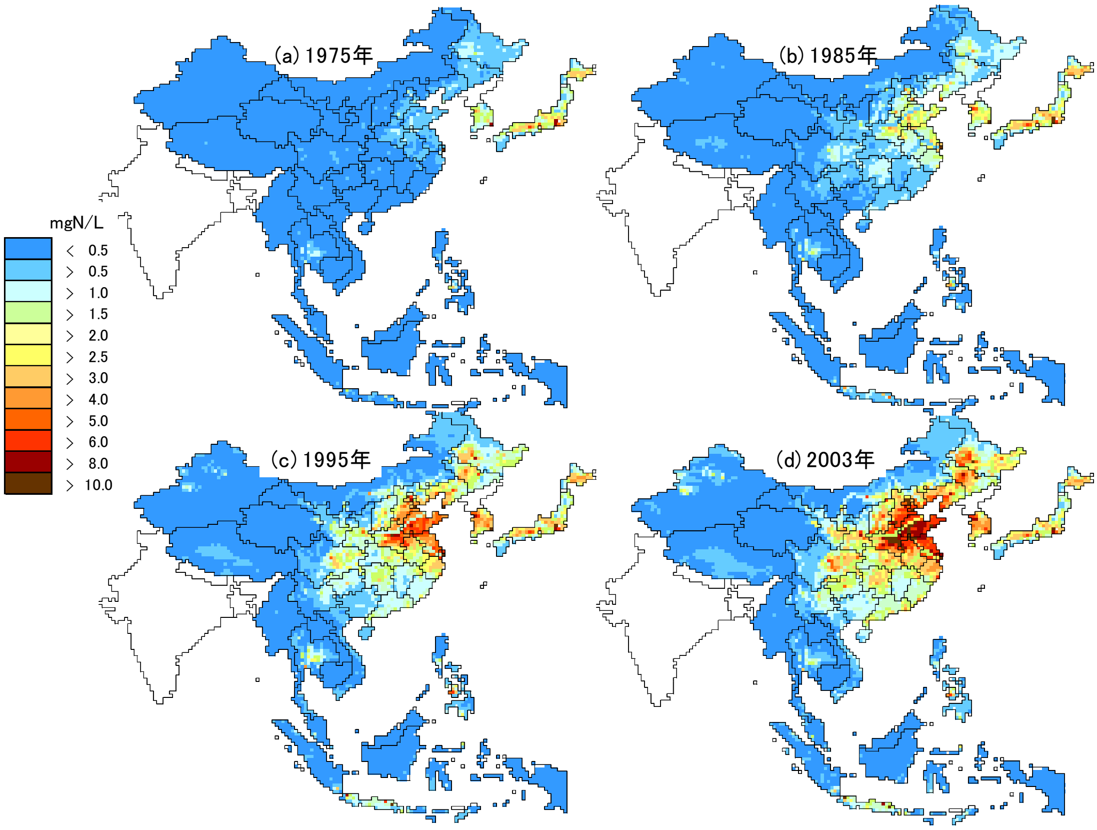

Fig. 5 Estimated spatial distribution of the nitrogen concentration (mg N L^{-1}) in river water.

5. Future Food Demand and Nitrogen Flow

1) Changes in food demand and nitrogen load in East Asian countries

Future food demand in each country is determined by population change and per capita food demand. Total population in the 11 countries in our study region has been almost doubled from 0.98 billion in 1961 to 1.92 billion in 2003. According to the projection by the United Nations, it will increase to 2.21 billion by 2030, about 15% increase in medium variant scenario [8]. Increasing rate is small in China and larger in Southeast Asia. Per capita food consumption has changed annually depending on economic growth in each country [9]. Fig. 6 shows the relationship between per capita meat consumption and logarithm of per capita GDP. They have a positive linear trend in most of the countries, but the slope and intercepts of regression line varied for different countries. As shown before, per capita meat consumption in Japan is not increasing recently. The consumption in Singapore and Malaysia is now decreasing after the rapid increase. Thus there must be a ceiling in per capita meat consumption at about 50 to 60 kg $capita^{-1}$ y^{-1} that is much lower than the current meat consumption in western countries.

The future demand for human food was predicted based simply on the trend of per capita consumption of various food and population changes. Table 1 shows the ratio of estimated food demand in 2030 to the values in 2003 in China and Southeast Asia based on the low and medium variant scenarios for population growth. Food demand was

Table 1 Ratios of population, food demand and N output in 2030 to those in 2003.

	China	Southeast Asia
Population	1.07 - 1.13	1.23 - 1.31
Meat	1.16 - 1.22	2.28 - 2.57
Cereals	0.95 - 1.00	1.55 - 1.75
Other crops	1.20 - 1.26	1.59 - 1.79
N output	1.46 - 1.60	1.99 - 2.24

The smaller and larger values correspond to the low and medium variant of population provided by the UN estimated to increase rapider than the population growth especially in Southeast Asia, where considerable numbers of people are still undernourished in some countries. Nitrogen outputs to the environment were predicted to increase to 1.4 to 1.6 times its 2003 value in China and 2 times or more in Southeast Asia, when it was assumed that various conditions such as farmland area, trade ratio, nitrogen use efficiency in cropping and in livestock feeding etc. do not change next 20 years..

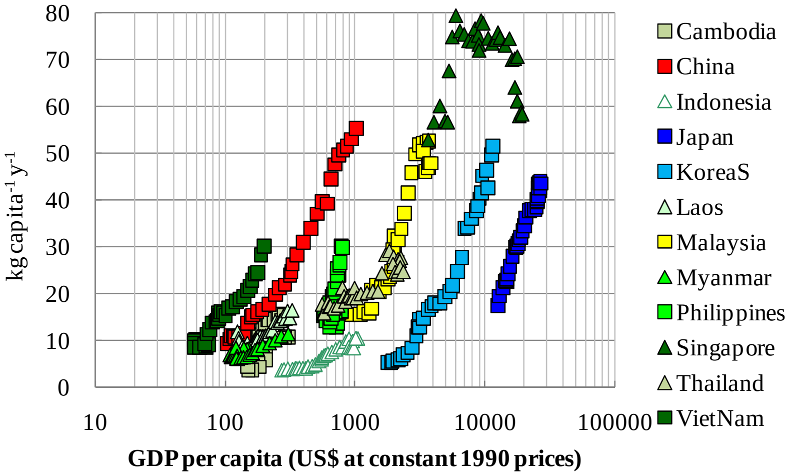

Fig. 6 Relationship between per capita meat consumption and GDP based on the data from 1980 to 2003

2) Potential biofuel production and its effects on nitrogen flow

Nitrogen fertilizer is used for production not only of food but also of energy recently. Oil crops, Sugarcane, and starch crops are raised as the feedstock of biofuel. Although the food demand in Southeast Asia will increase substantially, some countries such as Indonesia and Thailand will still have a reserve of productivity by enhancing the crop yield, while additional fertilizer use for producing the energy crop affects the nitrogen status as well. Thus, the possibility of production of sugarcane ethanol in these two countries was examined in terms of nitrogen flow.

Cereals yield is 4.2 t ha^{-1} in Indonesia and 2.7 t ha^{-1} in Thailand, which has been growing at the average rate of 0.072 t ha^{-1} y^{-1} and 0.025 t ha^{-1} y^{-1}, respectively, during the past 40 years. Assuming that the yield will continue to increase at the same rate, the potential yield in 2030 was estimated (Table 2). As the increase rate of cereal production exceeded the rate of demand, surplus farmland that is 10 to 20% of the original cereal harvested area, can be used for raising sugarcane. Base on the present yield of sugarcane (72 t ha^{-1} in Indonesia and 64 t ha^{-1} in Thailand) and a typical ethanol yield (0.057 kL ethanol/t sugarcane), it was estimated that 14 to 18 million kL of ethanol could be produced in these 2 countries in 2030. Producing sugarcane additionally would, however, increase the nitrogen output by 20% and lay the more load to the environment.

Table 2 Result of the prediction of sugarcane ethanol production and nitrogen load in 2030.

	Cereal yield (t/ha)		Surplus area in 2030		Ethanol productivity	Nitrogne load (10^6 tN)		
	2003	potential in 2030	10^6 ha	(%)	10^6 kL	2003	2030 Food only	2030 +Sugarcane
Indonesia	4.2	6.2	1.7 - 2.5	(11.4 - 16.6)	6.9 - 10.1	2.1	3.7 - 4.2	4.4 - 4.7
Thailand	2.7	3.7	2.0 - 2.3	(17.3 - 20.3)	7.2 - 8.4	1.2	1.5 - 1.7	1.9 - 2.0

6. Conclusions

By using the nitrogen balance model, nitrogen flow due to food production and consumption were evaluated. Nitrogen in food consumption and output to the environment have not changed after 1990s in Japan, while those have shown drastic increases in the last several decades in eastern Asian countries, and these increased loads have had a negative influence on water quality in recent years. River water appeared to be severely polluted, especially in the eastern part of China. According to the simple food supply-and demand model based on the current trends, total nitrogen output to the environment in the study region is predicted to become 1.5 to over 2 times that of the present output caused by the increasing population and more consumption of livestock products. These results highlight the importance of improving nitrogen use efficiencies in crop and livestock production, so that food demand can be met and economic development maintained while minimizing negative environmental impact from anthropogenic nitrogen.

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