## C-6 Assessment method for ecosystem acidification and eutrophication caused by acidic deposition on the basis of material cycles in catchments

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1. Introduction

Emission of $SO_2$ and NOx is considered to increase due to increasing energy demand caused by economic growth in East Asia. The predicted emission rates of $SO_2$ and NOx in 2030 are 1.34 and 1.51 times, respectively, of 1995[1]. Ammonium emission will also increase rapidly caused by population increase and intensive agriculture. Excess input of these substances to the terrestrial ecosystems may cause the acidification and eutrophication of soil, groundwater, stream water etc. Nitrogen and sulfur are bio-elements that circulate in ecosystems through metabolic mechanisms of plants and microbes. "Nitrogen saturation" in forest ecosystems has been intensively investigated in Europe and North America[2-7] recently but mechanism of nitrogen saturation has not been completely clarified yet. Nationwide nitrogen status of Japan and of East Asian countries is not well known, though it is known that there are some nitrogen-saturated ecosystems in Japan[8-10].

2. Research Objective

The objective of the research is to develop a method for estimating current status of regional acidification and eutrophication in Japan. In order to attain the objective, the continuous field surveys in some typical catchment areas, nationwide survey of stream water quality and research on internal cycle of nitrogen and sulfur are conducted. Based on the results of these researches, numerical models are created to evaluate the regional material cycle in forest ecosystems in Japan. Increase of nitrogen load and its ecological effects have been concerned about recently. Another objective of the research is to estimate the historical changes of nitrogen load due mainly to agriculture in Asian countries.

3. Research Method

3.1. Field survey for estimation of balances of acidic substances in catchment areas

Field measurements were made at the selected oligotrophic forest catchment areas: the

Maekawa catchment area on the eastern slope of Mt. Norikura in Nagano Prefecture (1500-3026 m above sea level) and 5 small catchment areas at Mt, Shirahata (321 m) in Hokkaido Prefecture. Rainfall, thoughfall, $A_0$ layer percolation, soil solution and stream water were collected periodically and concentration of ionic elements were determined. Element contents in leaves and needles, litterfall and soil were also measured. Nitrogen cycles in these catchment areas were investigated based on these measurements and compared them each other and with those in other catchment areas in Ibaraki Prefecture, Nikko areas etc.

A nationwide survey (1,278 points) on streamwater quality was conducted in summer season in 2003. The relationship of spatial distribution of $NO_3^-$ concentration with nitrogen deposition, meteorology, vegetation, landform etc. were investigated.

3.2 Internal cycle of nitrogen and sulfur

Element contents of soils, leaves and needles, litterfall were analyzed in several areas with various nitrogen statuses, including nitrogen saturated Tama catchment area, Chichibu catchment area at intermediate nitrogen status and oligotrophic Norikura catchment area. Mineralization rates and nitrification rates of soils in Tama catchment area were compared with those in Norikura catchment area by incubating soils in situ and in laboratory. Based on these data, effect of increasing nitrogen on the internal nitrogen cycle was evaluated.

The amounts of accumulated organic sulfur in Japanese soils were measured for 83 forest soil samples (Andisols and in Inceptisols) collected in Kanto and Chubu districts. Organic sulfur was classified into C-bonded and HI-reducible S (with an ester bond) types and stability of each type of organic sulfur was evaluated. The processes of sulfur transformation in soil and mechanisms of stabilizing organic sulfur were investigated by incubating the forest surface soils (Inceptisols and Spodosol) and by isotope ratio measurements.

3.3 Estimation of nitrogen load in Asian scale and creation of a numerical model

A simple nitrogen cycle model was created, which evaluated carbon and nitrogen flow due to plant growth, litterfall/withering, accumulation and decomposition of organic matter. Stimulated plant growth by nitrogen enrichments and decomposition process of soil organic nitrogen depending on soil C/N ratio were taken into consideration. This model was modified for the regional estimation. Spatial distribution of ammonium deposition was estimated at the 1 km by 1 km scale based on the statistical data on fertilizer consumption, food production etc. and annual accumulated NDVI distribution was synthesized from the satellite data as an indicator of the current biomass of forests. Based on these data, spatial distribution of nitrogen leaching from catchment areas was estimated with the regional model and was compared with the results of nationwide streamwater survey.

Statistical data on food production in 13 eastern Asian countries from 1961 to 2002 were analyzed and changes in nitrogen load due to agriculture, food consumption and also due to atmospheric $NH_3$ and NOx deposition were estimated.

## 4. Result and Discussion

### 4.1. Field survey for estimation of balances of acidic substances in catchment areas

Nitrogen fluxes such as atmospheric deposition, litterfall, downward movement of nitrate in soil, nitrous oxide emission from forest floor, and streamwater losses were extremely small in the Maekawa catchment area in Norikura in comparison with the other catchment areas in Japan. In the other oligotrophic catchment area of Mt. Shirahata in Hokkaido, there were three fold difference in atmospheric N deposition and two times difference in streamwater loss among the adjacent small catchment areas. A significant positive relationship was observed between the atmospheric N deposition and the growth of larch. This indicates stimulation of tree growth by atmospheric N deposition. Although nitrogen deposition in Mt. Shirahata was as low as in Maekawa catchment area, nitrogen in streamwater loss in Mt. Shirahata was higher. Extremely high N/P ratio of larch needles was detected at Mt. Shirahata compared with the values in Norikura and several European areas. Severe P limitation of the forest at Mt. Shirahata might result in sensitive ecosystem responses such as increased streamwater loss of N and nitrous oxide emission even in the low range of the atmospheric N deposition.

In the nation wide survey on streamwater, more than half of the points had the nitrate concentration in the range of 5 – 20 μM. The arithmetic mean was 26.2 μM and the median was 18.1 μM. Low nitrate concentrations were mainly observed in the streamwater of Hokkaido and Tohoku areas. High nitrate concentrations were often observed in the vicinities of Tokyo, Osaka, the Inland Sea, and Kitakyushu (Fig.1). Nitrate concentration of streamwater showed a positive relationship with temperature and a negative one with annual rainfall, but those relationships were statistically not significant. There was a

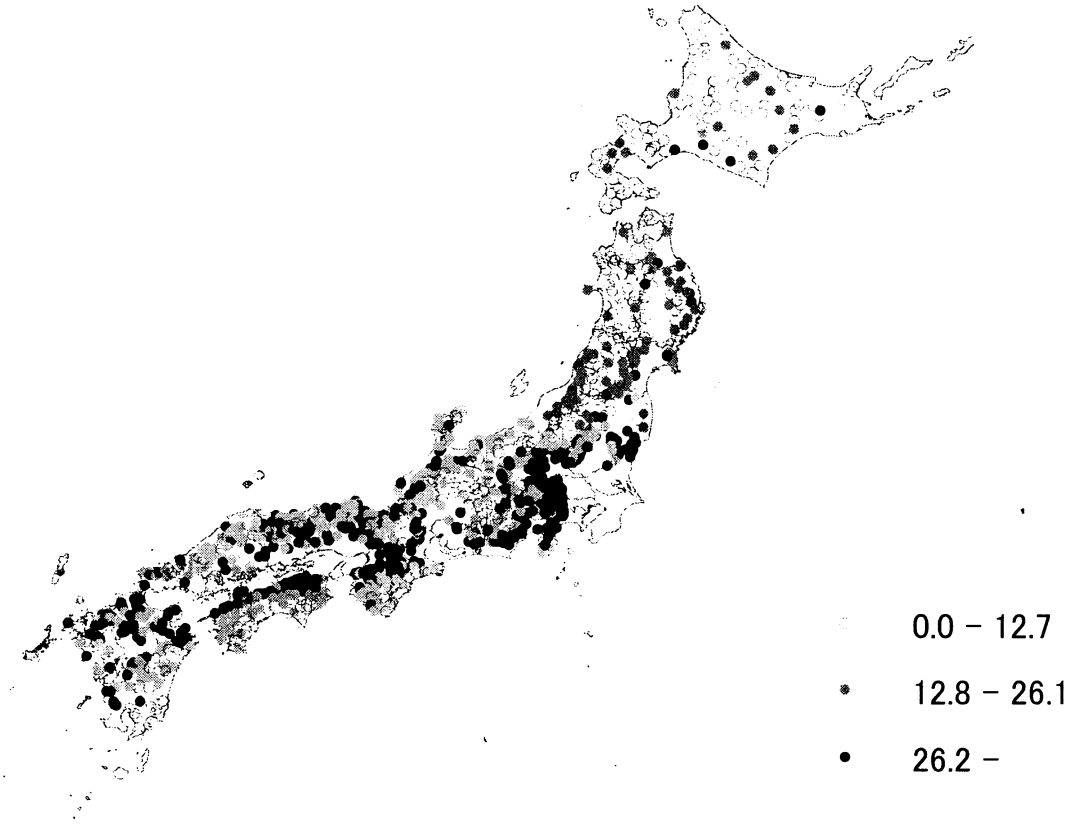


Fig. 1 Spatial distribution of $NO_3^-$ concentration (μM)

significant positive relationship between the atmospheric N deposition estimated in section 4.3 and the nitrate concentration of streamwater. Comparison of the result of this survey with that conducted about 50 years ago revealed that among various dissolved ions only nitrate and ammonium showed a marked increase during the last 50 years. The present nationwide survey clarified that the anthropogenic atmospheric N deposition greatly affects the streamwater nitrate in Japan.

## 4.2 Internal cycle of nitrogen and sulfur

In Tama that is a nitrogen saturated catchment area, primary production, dry weight of litterfall, nitrogen contents in leaves and needles and in litterfall were larger than those in other study areas. The rate of N internal cycle in Tama was twice of that in Chichibu. It was considered that excess nitrogen changed the physiological feature of trees: ratio of N translocation before leaf abscission was smaller and the timing of the translocation was one month later in Tama than in Chichibu. According to the in situ incubation of soils, net nitrification rate and $N_2O$ emission rate were large for soils in Tama than for soils in Norikura and those rates were strongly related with soil C/N ratio in each area. It was clarified that the enhanced nitrogen deposition caused not only the nitrate leaching but also stimulation of internal flow.

Andisols originated from volcanic ash contained much more sulfur than Inceptisols. The dominant form of accumulated organic sulfur was HI-reducible S (with an ester bond) that had been considered to be rather decomposable. Large amounts of adsorbed sulfate were also contained. In the soils in western countries, C-bonded S is dominant. Amount of HI-reducible S had a strong relationship with the amount of crystalline Al oxides. Soil incubation experiments showed that HI-reducible S was stabilized by coexisting Al oxides. Based on these experiments and measurements of isotope ratio ($\delta^{34}S$) in each form of sulfur, a scheme of sulfur internal cycle was proposed (Fig.2). The most important factor to control sulfur cycle is mineral composition of soils and Andisols, which generally contains much Al oxides, has possibility to accumulate larger amount of atmospheric S deposition than other soils

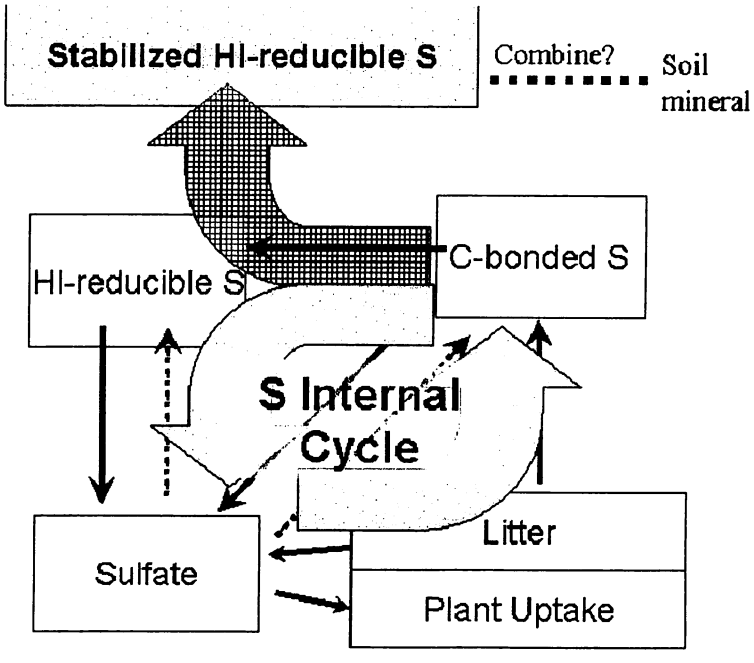


Fig.2 Sulfur cycle in forest soil

4.3 Estimation of nitrogen load in Asian scale and creation of a numerical model

Predicted results of nitrate leaching with a nitrogen cycle model qualitatively coincided with the existing knowledge on nitrate leaching patterns from forested catchment areas. It was shown that current biomass of the forests was the most important parameters to determine nitrogen leaching. In order to make a nationwide estimation, ammonium emission rates were estimated as $39\times10^3$ t N $y^{-1}$ from fertilizer and $185\times10^3$ t N $y^{-1}$ from livestock in Japan. Assuming a isotropic diffusion with exponential decay, the average ammonium deposition rate per unit area was estimated as 4.6 kg N $ha^{-1}$ $y^{-1}$. Based on the ammonium and NOx deposition and current biomass distribution derived from NDVI, nitrogen concentration in streamwater was estimated spatially. The results were significantly correlated with the nitrate concentration obtained by the nationwide survey ($r=0.65$, $p<0.001$, Fig. 3). It suggested that long-term nitrogen deposition is an important factor to determine the nitrogen concentration in stream water in the natural ecosystems, despite the large uncertainties in the simplified model and assumed parameters.

Analysis of the historical data on food production in eastern Asia showed that the increase of cereal production was rapider than the population increase from 1960s to 2000s. Large amounts of nitrogen fertilizer have begun to use particularly after 1980s. Crop production was the main origin of nitrogen load in this area. It was shown that nitrogen load in China occupied about 70 % of the total nitrogen load in eastern Asia, nitrogen load per unit land area and also atmospheric nitrogen deposition in South Korea were twice as much as in Japan and they were increasing rapidly in some Southeastern countries.

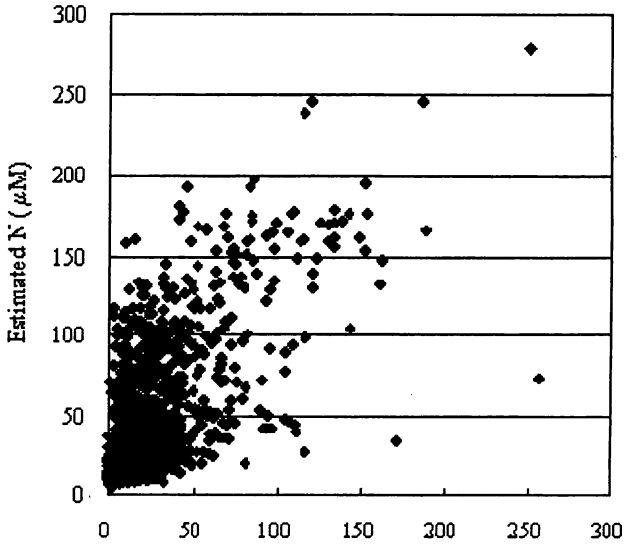


Fig. 3 Relationship between estimated nitrogen concentration and measured nitrate concentrations

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