Research Project

1. Current and Future Status of Contamination of Japanese Agricultural Fields with POPs and Related Compounds

Persistent organic pollutants (POPs) are transferred across borders and are accumulated in animals such as polar bears and seals. This means that POPs are causing contamination on a global scale. To prevent or reduce global environmental contamination caused by these compounds through cooperation among countries around the world, the Stockholm Convention on Persistent Organic Pollutants was adopted in Stockholm in May 2001 and came into effect in May 2004. Most of the compounds specified as POPs in this agreement are organochlorine pesticides such as DDT, dieldrin, and chlordane. Because the Convention is now in effect countries will need to use its principles to manage various problems related to POPs, by means such as prohibition of use, reduction of emissions to the environment, and prediction of future changes in levels of contamination.

The purposes of this project are to elucidate the status of contamination in the agricultural fields with POPs and related compounds from the 1960s up to the present, and to predict future changes in contamination with these compounds, by developing a multimedia model that considers diffusion and outflow to the atmosphere and the aquatic environment from agricultural fields in Japan. This project is composed of the following three subjects: (1) Temporal changes in the status of organochlorine pesticide contamination of agricultural soils; (2) Temporal changes in the status of polycyclic aromatic hydrocarbon (PAH) contamination of agricultural soils; (3) Development of an environmental fate model for POPs and related compounds.

The project was started in FY 2004 and is scheduled to end in FY 2006. In the first year, we obtained some new findings with regard to subject (1): Temporal changes in organochlorine pesticide concentrations in paddy soils reflected the use of pesticides. DDT, dieldrin, and HCH were used on paddy rice until their use was banned in the early 1970s; concentrations of these pesticides have decreased dramatically since the end of the 1960s. Chlordane was used to control domestic pest insects until 1986 but was not used in paddy fields; concentrations of chlordane in paddy soils increased from the 1970s through the 1980s, but since then they have steadily decrease, suggesting that chlordane was transported via the atmosphere and/or water during the period when it was used. Mirex, an insecticide, was never used in Japan, but small amounts of mirex have been detected in paddy soils the 1960s up to the present. Therefore, mirex appears to have been transferred across borders from other countries.

2. Pilot Study in North-East Asia for the Development of Desertification Assessment and Construction of an Early Warning System

The development of benchmarks and indicators for the monitoring and assessment of desertification and the establishment of operational and cost-effective early warning systems (EWSs) for drought and desertification were among the principal items on the agenda drawn up by the Committee on Science and Technology under the United Nations Convention to Combat Desertification (UNCCD).

Desertification occurs through a complex combination of elements on a local scale. However, at the same time, the phenomenon manifests itself on a larger scale. Large-scale monitoring studies of desertification have not been able to gather concrete information on the desertification process at a local level. On the other hand, the results of studies at the local scale have not been connected to those of large-scale assessments of desertification. In other words, previous studies on desertification have not been able to fill the gap between local and large scales. This project employs an integrated desertification model to fill that gap and to develop cost-effective EWSs for desertification. Field-scale assessment of desertification and large-scale observations will be integrated by employing the model.

This project is being supported financially by the Global Environment Research Fund of the Ministry of Environment, Japan, from FY 2004 to 2006. It aims to 1) establish desertification EWSs by employing an integrated model; 2) standardize observation methods for long-term monitoring of desertification indicators on a large scale; and 3) assess land vulnerability through field surveys of soil and vegetation.

The outline of the project is as follows:

1) Construction of an integrated model for desertification EWSs
2) Standardization of observation methods for long-term monitoring of desertification indices
3) Land vulnerability assessment by soil/vegetation/hydrological analysis
   (1) Land vulnerability assessment by field survey
   (2) Physiological and ecological assessment of soil degradation

3. Development of a methodology for assessing risk of crop contamination with Cd on arable lands

Public concern about food safety has been increasing. The international organizations FAO and WHO have been examining a new international safety standard for Cd in foods to minimize the human intake of this heavy metal because it is a matter of urgency that we manage the risk of Cd in foods. In this light, this project, which ran from FY 2002 to FY 2004, was initiated to secure food safety and, in particular, to minimize Cd concentrations in crops. The aim of the project was to develop methods of assessing the risks of Cd contamination of edible parts of crops on arable soils and to reduce Cd uptake by crops from soils. Our main results are summarized below.

1) Method of determining amount of Cd in soil available to crops:

We used porous cups buried in the soil to collect soil solution from paddy fields during the growing season. We found that the degree of Cd contamination in rice could be estimated from the Cd concentration in the soil solution. For upland crops such as beans, wheat, and vegetables, the 0.01 N hydrochloric acid (HCl) extraction method was more suitable for predicting Cd contamination than conventional methods such as 0.1 N HCl extraction.

2) Analysis of soil physico-chemical properties in relation to crop Cd contamination:

Using the database of Cd contamination of crops and vegetables, we analyzed the relationship between crop Cd concentration and soil physico-chemical properties. Multi-variable analysis of the database showed that the degree of Cd contamination of crops could be predicted from 3 soil parameters: Cd concentration, pH, and phosphate absorption capacity. This prediction method was verified in various upland crops grown by farmers in the Hokkaido region and can be applied to the construction of risk maps for Cd contamination.

3) Balance of Cd in arable soils:

We monitored the Cd loading of fields from irrigation and atmospheric dusts and the Cd concentrations in drainage and soil solutions during a growing season. Under common agricultural practices, the risk of Cd contamination may be almost negligible, even if this Cd loading of the soil continues for 100 years.

4) Differences in Cd uptake among cultivars of rice, soybean, and spinach:

Among rice cultivars, early maturing varieties showed a lower risk of Cd contamination of the grain than did late varieties. We also found that soybean cultivars could be divided into 2 distinct groups of lower and higher seed Cd concentration. Cultivars showing higher Cd concentrations could be identified from the Cd concentration in the shoots of the young plant. Spinach cultivars bred in foreign countries tended to show higher Cd concentrations than did Japanese cultivars. Soil amelioration by calcium amendment may reduce the contamination risk.

The outcomes of the project were communicated to MAFF policymakers and contributed to the development of a policy on systems of management for the reduction of Cd contamination risk.

4. A FACE (free-air CO_2 enrichment) study to predict the impacts of atmospheric CO_2 increase on agricultural ecosystems

The projected increase in atmospheric carbon dioxide concentration ($[CO_2]$) and climate change will have significant impacts on future agricultural productivity. To ensure food supplies under changing environments, we need to better predict the impacts and develop agricultural technologies that can adapt to these future conditions. We therefore undertook this project, in collaboration with the National Agricultural Research Center for the Tohoku Region, supported by the Global Environment Research Coordination System of the Ministry of the Environment, to predict the impacts of atmospheric CO_2 increase on rice production and agro-ecosystems. For this purpose, we conducted FACE (free-air CO_2 enrichment) experiments at Shizukuishi in Iwate Prefecture. We also performed TGC (temperature-gradient chamber) experiments and improved a crop growth model and a biogeochemical model on the basis of our experimental observations.

This FACE treatment simulated a $[CO_2]$ condition 200 ppmv above the ambient, with no enclosures in the paddy field, to minimize experimental artifacts. Comparison of biomass enhancement in response to elevated $[CO_2]$ amongst cultivars, nitrogen treatments, and years indicated that low plant N concentration at the panicle initiation stage resulted in low biomass enhancement at harvest. Although elevated $[CO_2]$ significantly reduced the degree of lodging under heavy N fertilization, susceptibilities to blast and sheath blight diseases and chilling-induced spikelet sterility were exacerbated by elevated $[CO_2]$: the mechanisms of these non-photosynthetic effects on grain yield need further investigation.

A generic crop growth model (MACROS, Modules of an Annual CROp Simulator), which was developed to express plant carbon metabolism, greatly overestimated the effect of elevated $[CO_2]$ and underestimated the effect of N application. We therefore developed a model

that introduced Farquhar's photosynthesis model and N-driven leaf area dynamics and was able to reflect the interactive effects of [CO_2] and N on biomass and grain yield. We also made substantial modifications to the original DNDC (DeNitrification–DeComposition) model by introducing the electron donor–acceptor relationship under submerged soil conditions. The revised DNDC model, combined with the plant process model simulated well the redox state of the soil and the time-courses of methane flux observed in the FACE experiments. Testing of the model under different climatic conditions will improve its robustness.

5. Evaluation of Trace Heavy Metal Loadings in Arable Soils

Public concern about food safety is increasing. Some hazardous heavy metals such as cadmium (Cd) tend to accumulate in human bodies through food intake, and it is a matter of urgency to manage the risks posed by these substances. This project, supported by the Ministry of Environment for Research on Pollution Prevention and Control began in FY 2002 and ended in FY 2004. The objectives of the project were 1) to evaluate the environmental loads imposed by some heavy metals through rainfall and through agricultural practices such as fertilization and irrigation in agro-ecosystems; and 2) to clarify the dynamic aspects of heavy metal loading, such as crop uptake, solubilization, and precipitation, in soil–plant systems. The main results obtained are summarized as follows.

1) Estimation of crop uptake of some heavy metals and their loading of arable lands in association with fertilization: We developed a new technique that uses a stable isotope, ^{113}Cd, to estimate Cd uptake by crops. This enabled us to determine the residual effects of Cd contained in phosphorus fertilizers. Quantitative evaluation of Cd loading of arable lands indicated that there is no need to be concerned about the risk of Cd accumulation in the soil under common agricultural practices.
2) Heavy metal loading and crop uptake of animal manure and various agricultural chemicals used on forage crop fields: Quantitative evaluation of the flows of heavy metals indicated that the amounts of heavy metals taken up by crops are very small compared with the amounts incorporated in the form of animal manure, and that heavy metals such as zinc and copper tend to accumulate in soils.
3) Evaluation of heavy metal loading of arable soils by irrigation and rain: the Cd loading of arable soils from irrigation water was much smaller than that from rain and atmospheric deposition.
4) Influence of soil genesis on distribution and movement of trace heavy metals: We constructed a database of the distribution of trace heavy metals on arable lands in Japan. In some hilly soils, the concentration of heavy metals in the soil was closely related to the ion exchange capacity of organic matter and clay.
5) Chemical speciation of soluble heavy metals in arable soils: As the soil was air-dried, the amount of exchangeable Cd increased. Almost all chemical species of Cd in soil solution were found in the cationic fraction when soil was collected under aerobic conditions, but the anionic fraction of Cd in soil solution significantly increased when soil was collected under anaerobic conditions.

6. Studies on the risk assessment of agricultural ecosystems in the face of climate change and variability

Because global environmental change is likely to have enormous impacts on the Asian agricultural ecosystem, evaluation of the vulnerability of the system to such impacts is essential, not only for future food security but also for the sustainable development of societies in the Asian region. From these viewpoints, this study aims: 1) to use both precipitation changes projected by GCM (general circulation model)-derived downscaling methods and changes in soil moisture conditions in the crop root zone (as estimated from a water budget model) to evaluate the impacts of climate change and variation on the environment and production of major crops in China, so as to specify the most vulnerable regions and suggest mitigation strategies; 2) to improve our understanding of the distribution and variability of meltwater as a resource and its contribution to the formation of spring river discharges in Heilongjiang Province in China; 3) to evaluate the effects of global warming on soil N mineralization in the major types of Japanese paddy soils; and 4) to predict the effects of climate change on rice production in Asia using a rice growth model, and thus to suggest technologies for adaptation to future change.

We found that soil moisture conditions are tending to become drier in northeastern China, as well as on the North China Plain (Fig. 1). Agricultural water demand in southern China is projected to decrease generally, and the cropland soil–moisture deficit will decrease as a result of climate change. However, in northern China agricultural water demand is expected to increase, and the soil–moisture deficit will increase generally. Specifically, what we should be concerned about is the fact that growers of rain-fed crops on the North China Plain and

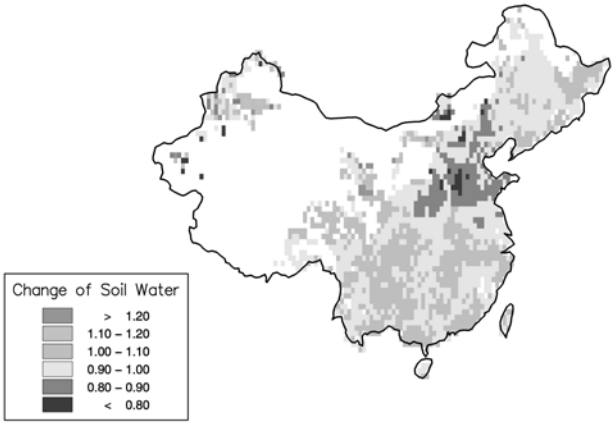

Fig. 1 Changes in normalized soil moisture (ratio of annual mean soil water content to soil water capacity in crop root zone) between 2 periods: 1946–1975 and 1976–1995.

in northeastern China will face water-related challenges in coming decades because of the expected increases in water demand and soil-moisture deficit and an expected decrease in precipitation. The effective adaptation options should include adjustment of the disproportion among plantations, forestry, and stockbreeding; large improvements in the efficiency of water use in agriculture; and an increase in the supply of water to northern China.

Next, we conducted growth and yield simulations for different rice genotypes grown under 700 μmol/mol CO_2 and different degrees of temperature rise at several sites across Asia. Figure 2 shows the results of simulations using the cultivars 'IR72' (indica) and 'Nipponbare' (japonica) at Iwate and Kyoto in Japan, Nanjing and Yunnan in China, and Ubon in Thailand as percentage yield change from the base conditions (700 μmol/mol CO_2 and 2001 and 2002 weather conditions) at each site. The model predicted, for example, higher simulated yield responses to elevated CO_2 in 'IR72' than in 'Nipponbare' at all locations under the current temperature conditions; this result agreed well with observations. Because the model assumed the same leaf photosynthetic response to CO_2 for both genotypes, the higher yield response of 'IR72' to CO_2 was caused by this cultivar's larger sink formation ability and, hence, the greater source limitation under ambient CO_2 than with 'Nipponbare'. A review of previous studies and the model simulation indicated that the anticipated global climate change associated with increased greenhouse gas production will have large and different effects on rice production in Asia, depending on the location and genotype. The model predicts that, although doubling CO_2 with a temperature rise

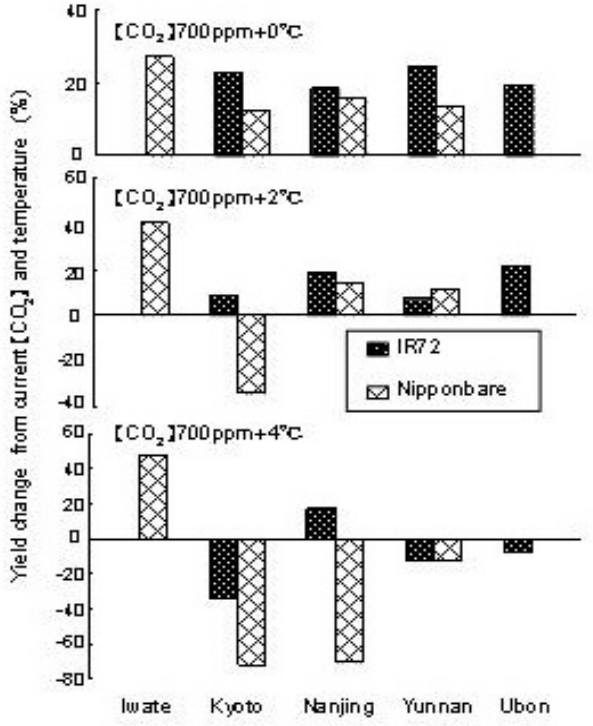

Fig. 2 Percentage yield change from the current conditions of 700 μmol/mol [CO_2] with 0, 2, and 4 °C temperature rises, as simulated for the cultivars IR72 and Nipponbare at Iwate and Kyoto in Japan, Nanjing and Taoyuan in Yunnan, China, and Ubon Rachathani in Thailand. Climate data for 2001 and 2002 at each location were used as base conditions.

of more than 2 °C will significantly increase rice yield in cool temperate areas, it will drastically reduce yield in warm temperate areas and yields of dry season rice in the tropics. The identification of adaptive technologies for mitigating the negative effects of global warming on rice production in each region in Asia is an important subject for further study.

This research project was supported partly from FY 2002 through FY 2004 by the Global Environmental Research Fund of the Ministry of Environment.

7. Use of material cycles in catchments to assess ecosystem acidification and eutrophication caused by acidic deposition

Recently in eastern Asia there has been concern about the effects of increased levels of reactive nitrogen on terrestrial ecosystems. An increase in the atmospheric deposition of nitrate and ammonium has the potential to change material flows and cause acidification and nitrogen saturation of forested catchments. We conducted a 3-year research project from 2002 to 2004 to clarify the

nationwide status of the nitrogen cycle and mechanisms of nitrogen saturation. The project used field surveys and a mass balance model and was run in cooperation with Shinshu University, Hokkaido University, Nagoya University, Tokyo University of Agriculture and Technology, The University of Tokyo, and the Forestry and Forest Products Research Institute. The research was supported by the Global Environment Research Fund of the Ministry of the Environment.

Field surveys of the nitrogen cycle were carried out in several catchment areas (e.g. Mt. Norikura in Nagano, Mt. Shirahata in Hokkaido, Tama in Tokyo). The Norikura catchment area was oligotrophic, and atmospheric input, stream-water loss of nitrogen and N_2O emission rates were low. At Mt. Shirahata, stream-water loss of nitrogen and N_2O emission rate were larger than at Mt. Norikura, although nitrogen deposition rates were almost the same. We found that the higher nitrogen output at Mt. Shirahata was caused by the severe phosphorus limitation in the volcanic ash soils. At Tama, nitrogen input and output were both much larger than in the other catchment areas. Primary production, dry weight of litterfall, and nitrogen content of leaves and litterfall were also larger. The chronic excess nitrogen input stimulated the internal nitrogen cycle and caused a larger external output.

We conducted a nationwide survey of the stream-water quality at 1278 survey points in summer 2003 to determine the current nitrogen status of Japanese catchment areas. The arithmetic mean nitrate concentration was 26.2 μmol/L, and the median was 18.1 μmol/L. Low concentrations were observed mainly in the Hokkaido and Tohoku areas. High concentrations were often observed in the vicinities of Tokyo, Osaka, the Inland Sea, and Kitakyushu. To investigate the effects of nitrogen deposition on stream-water chemistry, we used agricultural statistical data and land-use distributions to estimate the spatial distribution of ammonium emissions from fertilizers and livestock wastes. We then calculated the distribution of nitrogen deposition with a spatial resolution of 1 km by 1 km from the ammonium emission data and from existing data on the emission of nitrogen dioxide. By using a nitrogen balance model that took plant growth and nitrogen removal due to organic matter accumulation and denitrification into account, we estimated the nitrogen concentration in the stream water at each grid cell on the basis of the nitrogen deposition distribution. The estimated concentration roughly corresponded to the measured concentration ($r = 0.65$, $P < 0.001$). These findings suggest that long-term nitrogen deposition is an important factor in determining nitrogen concentrations in stream waters in natural ecosystems.