Case Study on Development of the Sustainable Agricultural System for Various Agro-ecosystems Through Assessment of Nitrogen Flow

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Abstract

Importance in the sustainability of agricultural systems has long been recognized in relation to maintaining and improving agricultural productivity in harmony with the surrounding environment. In many cases, however, the sustainability is discussed rather qualitatively, not quantitatively. This is mainly because of lack of measurable indicators to express the degree of the sustainability in the system. The nutrient is an essential element for the agricultural systems and the appropriate management of such nutrient should be one of the key points for sustainable development of the system. Moreover, the nutrient flow within the system can be quantified at a certain degree and the nutrient budget that is a consequence of balance between input and output may be closely related to sustainability. Optimization of nitrogen cycling in the farm community is considered to be an important aspect as nitrogen is a major nutrient to increase agricultural production. In this paper, a whole picture of the nitrogen cycle for agricultural production that was constructed based on data collected from agricultural statistics, research reports, study reports, field observation, interview with farmers and information from experts, will be presented with particular focus on three areas in the East and Southeast Asian countries such as Shandong province in China, Northeast Thailand, and Mekong Delta. The obtained nitrogen budget is also discussed in order to improve sustainability of the system.

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Introduction

The nutrient flow, especially for nitrogen, has been studied to obtain accurate budget in the field even before issues on the sustainability became hot spot in the agricultural research. A nitrogen balance sheet makes it possible to (1) assess the flows of nitrogen through society in order to decide on the most efficient measures to reduce surpluses (in setting up such an overview, a number of uncertainties or knowledge gaps are invariably identified), and (2) to quantify complex variables that cannot be measured directly, for example,) excretion of nitrogen by farm animals and loss of nitrogen to air, soil, ground and surface water. Various models are now available to estimate the nutrient budget in the system. In order to assess inputs, redistribution and losses relative to soil fertility, Brown et al (1999) developed a nutrient budget model that can accept yield, input and management data obtained from farm interviews. The nitrogen turnover model developed by Rothamsted uses readily available input parameters to simulate N turnover in the soil-crop system. Nitrogen turnover is described in the model by a set of zero and first-order equations for (i) uptake of mineral N by the crop, (ii) mineralization-immo bilization turnover of organic matter, and (iii) gains and losses of N from the soil-crop system (Smith et al, 1996).

The nitrogen flow can be drawn not only for the particular farmland but also for regional and even sub-national or national level (Mishima et al. 1999, De Koning et al. 1997). As the spatial coverage is expanded, more parts of the flow should depend on speculation or extrapolation from the statistical data or other scientific information. Even though the accuracy may be reduced by the spatial expansion, it should be very important to have overall view on the nutrient flow in the target area as problems related to inflow and outflow in the farmland can be identified and the way to optimize the nitrogen flow can be proposed. Recent research reveals considerable potential to combine nitrogen balance and information from soil and other maps with statistical, mathematical and geographical information system (GIS) techniques for spatial expansion. The nutrient balances establish a link between agricultural nutrient use, and changes in environmental quality and the sustainable use of soil nutrient resources (Parris, 1998).

Although various types of farming systems can be seen in East and Southeast Asian countries, the dominant systems in the region largely depend on local biophysical conditions, especially climatic factors that most affect agricultural production and can not be modified by the effort of the individual farmer. The agro-ecosystem in the region can be broadly classified into six categories according to the FAO definition as can be seen in Fig. 1. The FAO agro-ecological zoning system is based on simple parameters such as length of growing period, mean monthly temperature and daily mean temperature (Pingali et al, 1997). In this paper, an example of typical farming operation will be picked up from three agro-ecosystems (warm semiarid subtropics with summer rainfall, warm sub-humid tropics and warm humid tropics) and direction of sustainable development of farming systems will be briefly discussed based on research outcomes that have been produced by the projects that the Japan International Research Center for Agricultural Sciences (JIRCAS) conducted in the region. Special attention will be placed to analyze agricultural production from the viewpoint of nitrogen flow for its sustainable development.

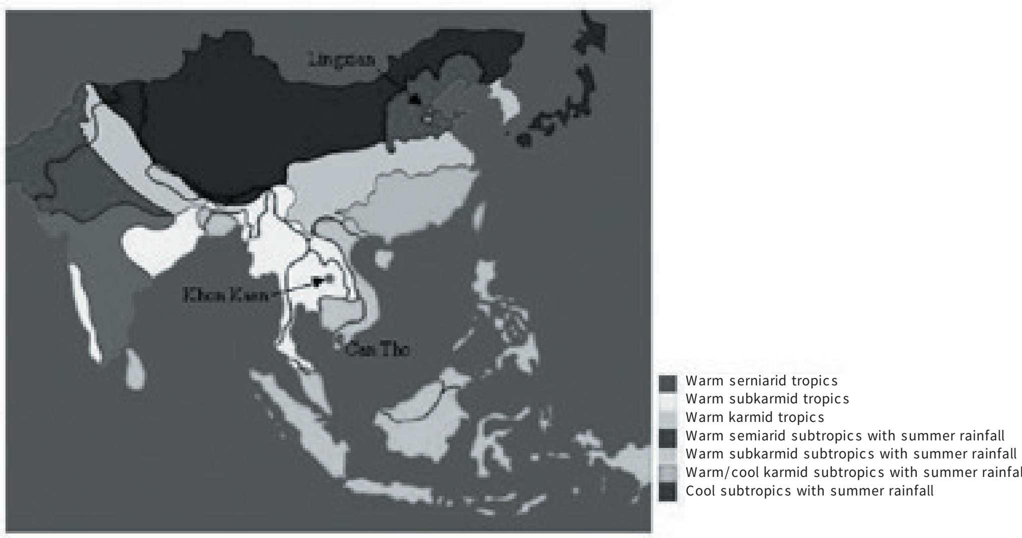

Fig 1 Agroecological zones in south, south east and east Asia
(modified from Pingali et al. 1997)

Estimation of Nitrogen Flow

A whole picture of the nitrogen cycle for agricultural production in three target regions was developed based on data collected from agricultural statistics, research reports, study reports, field observation, interview with farmers and information from experts (Matsumoto et al, 2000, Matsumoto et al, 2003).

Nitrogen Flow in Shandong Province in China

The first example is from Lingxian County, Shandong Province, China that belongs to warm semiarid subtropics with summer rainfall (Yagi and Hosen, 2000). The intensive upland cropping is dominant with wheat, maize, vegetables and cotton as major crops. The regional analysis of the nitrogen flow indicated an excessive load of nitrogen to arable land and the environment (Fig. 2). The load is mainly due to increasing consumption of chemical fertilizer in addition to increasing manure application. The analysis of nitrogen budget based on statistics suggested that the balance between input and output of nitrogen in arable land was 288 kg N/ha/year in 1997. There was an increasing trend in the nitrogen load; for example, the balance in 1981 was 159 kg N/ha/year that accounted for 55% of that in 1997. Nitrate pollution to groundwater due to excessive application of nitrogen fertilizer should be a major concern in near future, but the present level of nitrate in the groundwater collected from wells is still within the acceptable range, indicating that the nitrate pollution has not been widely spread in the region despite increasing amount of nitrogen application.

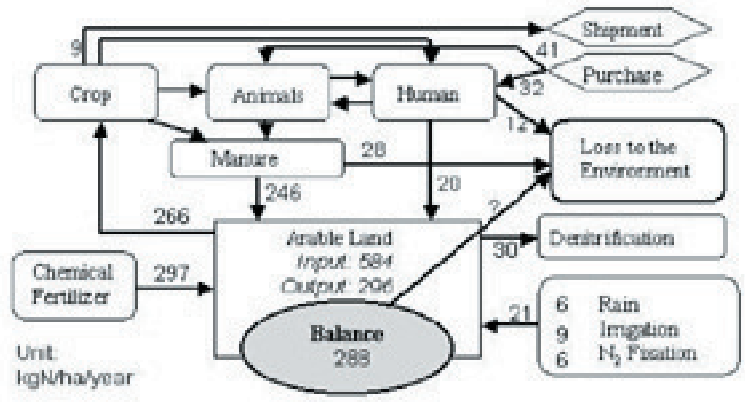

Fig 2 Nitrogen flow in agro-ecosystem of Lingxian province in China (1997) modified from Yagi and Hosen 2000

Nitrogen Flow in Northeast Thailand

The second example is from Northeast Thailand that belongs to the warm sub-humid tropics. Northeast Thailand receives annual rainfall ranging from 700 to 1600 mm, depending on location and year. More than 90% of the annual rainfall occurs between May and October. Major agricultural activities are carried out during the rainy season (Lindsay, 2000). Soils are often sandy or skeletal, and problems of salinity are extensive in this region. Nearly 55% of the total land area in Northeast Thailand has been already exploited for agricultural production. Within the area in agriculture, however, less than 10% is supplied with irrigation. Thus agriculture in Northeast Thailand depends primarily on the quantity and pattern of rainfall received (Pattanee, 2000). Rainfed lowland paddy, cassava and kenaf have been major crops since the 1960's, but lately sugarcane has become a major cash crop. Deforestation has led to changes in the hydrologic environment and has caused widespread salinity problems in this region. Soil erosion and soil fertility deterioration are also becoming serious problems in cassava growing areas. Because of these problems, the agricultural productivity is on the decline. One possible way to improve soil fertility may be more efficient use of locally available nutrient resources such as crop residues and animal feces. In order to identify the available resources, it is necessary to quantify nutrient cycle through agricultural activities such as crop and livestock production in the region, and clarify limiting factor for effective utilization of the nutrient resources.

Developing technologies to assure sustainable crop production requires a better understanding of the material cycling (especially nitrogen) of this region, together with efficient management and utilization of water resources, reforestation, minimization of soil erosion, arresting further decline in soil fertility, and crop diversification. Also, development of improved production systems that can utilize local resources and create employment opportunities for the local population should be promoted in this region. Livestock industry including dairy farming should be further promoted in Northeast Thailand as rapid economic growth in other parts of this country is expected to create a substantial demand for milk and meat in the near future. Thus, integrated agricultural development that can functionally link agricultural crop production and livestock industry together with vegetable and horticultural production should be the goal for improvement in the overall productivity of this region, which may reduce the negativity in the nitrogen balance owing to more availability of animal wastes as organic manure, and which should then lead to improvement of the soil fertility decline.

Although nitrogen in crop residues amounts to more than 50 kg N/ha/year, more than half of them is removed from the field or burned (Fig. 3). Most of animal feces are returned to the field, but its production is still limited because of underdevelopment of livestock industry. The return of human excrements and fresh garbage is insignificant. The local farmers do not actively practice yet the application of nitrogen fertilizer. Thus the nitrogen balance in the farmland results in negative value. Nitrogen that has been returned to the farmland is less than nitrogen that has not been returned to the farmland such as the one burned after harvest. It is important for optimization of nitrogen balance to establish the efficient use of those returnable organic resources.

Many workers have identified soil organic matter as a key factor in maintaining soil fertility and crop production. Its maintenance is an essential requirement for increasing and maintaining productivity. Long-term straw incorporation has improved soil fertility and productivity of the soils at the Surin Rice Experiment Station in Northeast Thailand (Withbread et al, 1999). However, the incorporation of rice straw can only return part of the nutrients to the soil as nutrients are removed in grain. The estimated nutrient removal from paddy fields in Northeast Thailand, with average rice grain yields of 1.7t/ha, is about 28 kgN, 6.2 kg P, 3.4 kg S, and 24 kg K ha/year. In the extremely sandy soils of Northeast Thailand with inherently low cation exchange capacity, organic matter amendments are essential if mineral N fertilizers are to be used without risk of acidification causing crop damage (McDonagh et al, 1995). Although nutrient balance analyses are seen as a powerful tool for the assessment of critical components of the sustainability of these land-use systems as shown here, such tools are challenged by the complexity of these systems. This complexity arises from spatio-temporal biophysical, socio-economic and institutional variability at different spatial scales and with different stakeholders being involved (Konboon et al, 2002).

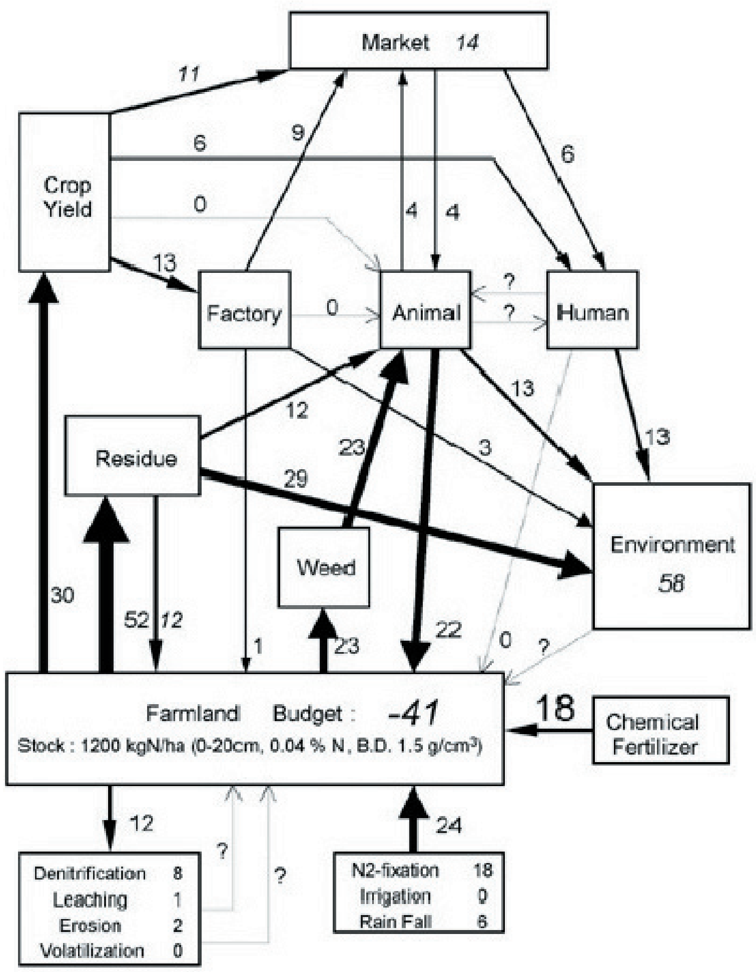

Fig 3 Nitrogen flow in Khon Kaen province, Thailand (Matsumoto et al. 2003)

Nitrogen Flow in Mekong Delta

The last example is from Mekong Delta that belongs to the humid tropics according to the FAO definition. The Mekong Delta is situated from 8 °35 ′N to 11 °N with average temperature 27 °C in Can Tho City. The annual rainfall is around 1,600mm, most of which occurs during rainy season with almost no rain in February and March, which are the middle of dry season. The Mekong Delta is rich in water resources with the dense network of canals that function as irrigation, drainage and transportation for various types of boats. Moreover, major road systems are constructed along the canals, indicating multifunctional importance of the canal network. In the area with less developed canal network, flooding is the most serious problem because of insufficient drainage. Currently, some 17 million people live in this area, but the number is expected to increase up to 21 million by the year 2010.

Although intensive rice production is the major agricultural activity in the region, integrated farming operation has been widely adopted by the local farmers. The system is specifically named VAC that stands for garden (Vuon), pond (Ao) and pen (Chuong) in Vietnamese language. The system has been very effective to sustain agricultural production of the region in the past. In the Mekong Delta, approximately 400,000 ha are suitable for freshwater aquaculture, but today less than 10% of the area is used for this purpose. After the Mekong Delta was turned to be major area for rice exportation, many problems that threaten the sustainable development of local agriculture become visible. One of the problems is the imbalance of inflow and outflow of nitrogen. The detailed study to normalize the balance through more efficient use of local resources was initiated as one of the international projects conducted by JIRCAS.

The application of nitrogen fertilizer is becoming excessive. Nearly half of the rice straw is burned after the harvest, resulting in loss of nitrogen into the atmosphere. It should be important to establish a more efficient way of usage for the rice straw. The Can Tho province belongs to a major rice-exporting region in the country, and export of nitrogen in milled grain is equivalent to one third of nitrogen applied as chemical fertilizer. The rice bran left after milling is effectively utilized as hog feed. Comparatively a large amount of nitrogen is put to the fishponds. Major nitrogen source to the ponds is animal excreta. In order to reduce the river pollution due to excessive dumping of animal excreta, it is important to introduce such processes as the use of a bio-digester and composting. Currently, nitrogen pollution in the river has not been quantitatively detected. This is mainly because of dilution by tremendous amount of water in the Mekong River. With increased dumping, the pollution may become serious in the near future. The nitrogen balance in the farmland of Can Tho province is showing already positive value and has tendency to be more positive. The rice-fish farming provides a sustainable alternative to rice monoculture, if the farmer takes full advantage of the natural productivity of the rice field ecosystem. The aim should be to reduce the resource use, avoid overuse of agrochemicals and improve production efficiency through increased recycling of nutrients and matter. The introduction of fish into the paddy fields has been shown to reduce the need for pesticides, increase the farm household income and diversify agriculture production. Thus, it is believed that integrated farming systems can help farmers increase their farm incomes and enhance sustainable agriculture and rural development (Berg et al, 2000).

Concluding Remarks

It is demonstrated by this study that approach to make a quantitative analysis of nitrogen flow in an administrative unit should be a very useful tool to identify constraints for sustainable development of farming systems in the region. As a result of analysis, the way to promote local resource utilization will be suggested, which provides decision makers with realistic options for sustainable development of agricultural production that best fits to the region.

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