B-6.4.1 Modeling of Carbon Cycle in a Rural Area

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Abstract A carbon cycle model was developed to analyze an organic materials flow and carbon dynamics in a rural area. Organic materials flows were analyzed in Ushiku-lake basin , Toride city, Fukuhara area of Kawagoe city and Satomi village using a database constructed from official statistics and related scientific papers. Soil respiration rates were estimated by a SOC (soil organic carbon) model. The rates were 1.71, 2.81, 1.87 and 3.08 Mg/ha/yr in Ushiku, Toride, Kawagoe and Satomi, respectively. The rates are a little lower than some reported values on organic soils in temperate regions. This method should be valuable for estimating carbon budget in several types of rural area.

Key Words Carbon cycle, Rural area, Soil respiration, Organic material flow, Modeling

1. Introduction

Large amounts and many kinds of organic materials derived from agriculture, fisheries and forestry flow in not only global scale but also local scale of a food and feed system. We will state in this paper the importance of studies on carbon (C) and nitrogen (N) cycling in several scales of food and feed systems to clarify causality of global/local environmental problems and to develop effective policies. Object of this paper is to estimate of the organic material flow through the application of organic resources such as animal waste and crop residues in rural areas in central Japan and to evaluate the rural system of the areas from a carbon cycling point of view.

2. Methods

(1) A model of an organic material flow in a rural area

The model of an organic material flow (Fig. 1) in a rural area consists of four parts: 1) the food and feed supply system, 2) a treatment system of livestock waste, crop residues and home waste, 3) a manure application system, and 4) input and output system in farmland (see Fig. 1). The food and feed supply system includes organic material flows from crops, residues and purchased food and feed to home and/or livestock. It also includes self-supplied food flow from livestock to home, and self-supplied feed such as meal residues, causing an organic material flow from home to livestock. Additionally, this system includes an organic material flow from crops and animal products to a market. The treatment system includes an organic material flow of utilization as manure and disposal of these resources. Livestock waste is mainly excrement of livestock. Livestock waste is used as manure on the farm itself, sold or otherwise disposed of. Home wastes are human excrements and garbage. They discharge organic materials from home. Treated home waste can be applied to farmland and consumed by plants. Since sewage is not supplied to farmland in Japan, can not be discharged in this way. Discharge from livestock and house, except treated livestock waste and home waste, takes place into the environment. Treatments of crop residues can be several such as

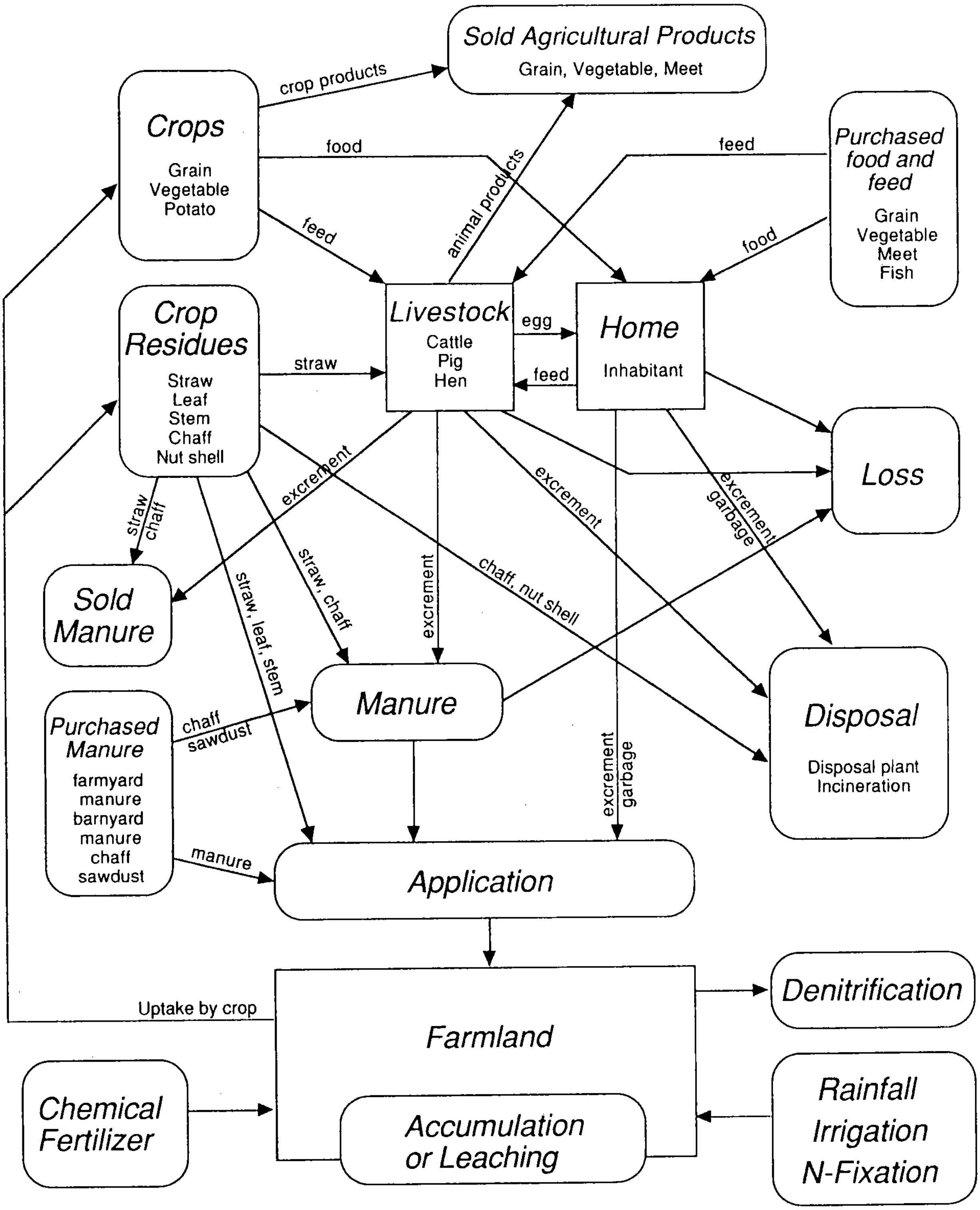

Fig. 1 A model of an organic material flow in a rural area (see text in detail)

making manure, selling for manure production, plowing back, and incinerating. The manure application system includes application of self-supplied manure, purchased manure, plowed residues, and home waste. Additionally, this system includes an organic material flow from purchased resources such as chaff and sawdust for the making manure but also, during the manure maturity process, to the loss. The organic material input system in farmland includes input from the application of manure, chemical fertilizer, etc. In Japan, an organic material input exceeds usually an organic material output in farmland.

(2) Methods to estimate the organic material flow in a rural area

Crop production is estimated from agricultural statistics (Ibaraki Statistics and Information Office, 1986), while residues production is estimated by multiplying of crop production and residues production ratio (Resources Survey Laboratory, 1982). Food and feed consumption and animal production are estimated from statistics of living expenditure in farm household (Statistics and Information Department, 1986b) and production cost of livestock products (Statistics and Information Department, 1986a). Sold crop products are calculated as the total crop production minus own consumed food and feed. Discharges of animal excrements, human excrements, and garbage are estimated by multiplying the number of livestock or population by the discharge per head or inhabitant, based on data from related studies (Resources Survey Laboratory, 1982, Livestock Industry Bureau, 1978). Treatment ratios of livestock waste are estimated from statistics of livestock (Statistics and Information Department, 1988, 1993a, 1993b, 1994), and treatment ratios of crop residues and home waste are estimated from data from related studies (Labor Science Institute, 1986). Applied manure is estimated from the results of a survey by the Ministry of Agriculture, Forestry and Fisheries. Chemical fertilizer application is estimated from the standard application for crops in each prefecture as also the total crop area. Data on crop area, crop production, number of livestock, and population were available per community or municipality. Data on food and feed consumption, treatment ratios of residues, human excrements, and garbage were available nation wide.

(3) Study areas

The study areas were Ushiku lake basin, Toride City, Fukuhara Town of Kawagoe City and Satomi Village in Kanto district of Japan. The result of an analysis, however, only on Ushiku lake basin shall be mainly described here due to the lack of space in this paper. The Ushiku lake basin, which covers 159 km^2, is located in the western part of the Tsukuba City and also in the central part of Kanto district. The total population in the area is about 83,000 people. About 30% of this population are farm household. The area is located on alluvial plain and diluvial upland. Cultivated land area is 35% of the total area. It consists roughly of 40% paddy fields, 60% upland fields. Crops consist roughly of 40% rice, 10% wheat, and 10% vegetables. About 11,000 pigs and 900 cattle are bred.

3. Results

Fig. 2 shows flow of an organic material in the basin of Ushiku Lake. Produced crops were sold and taken out from the area. On the other hand, food and feed consumed in the area were purchased from the outside of the area. The quantity of purchased food and feed were slightly greater than the sold products. A large part of crop residues and two thirds of animal wastes were recycled to the farmland. However, almost all of human wastes was not recycled. In total, 75% of the available organic matter was recycled to the farmland. And finally, 10 kt C / y (1.83 t C / ha) was emitted from the soils as CO_2. And 64 kg N / ha was mineralized in the area. Increase of nitrate N level of ground water was recently reported in the area.

A forest part of a rural system is excepted in the above mentioned figure. Two thirds of Japan are covered by a forest. A forest ecosystem has an important role on C cycling in a

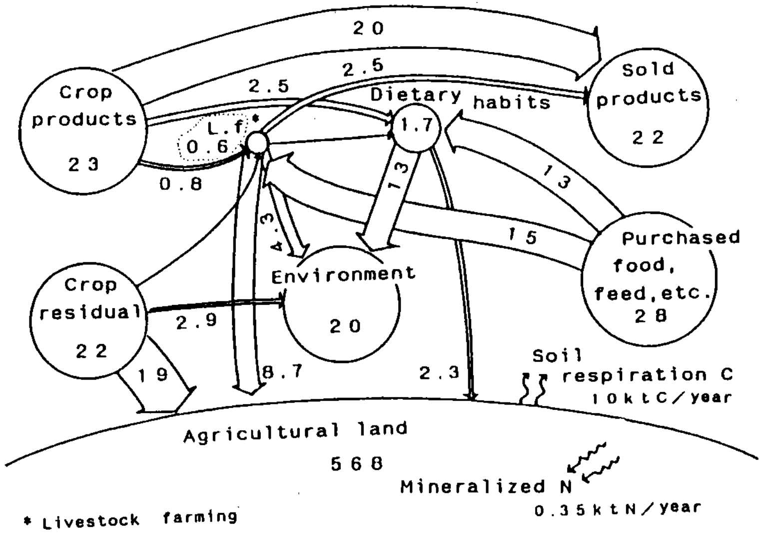

Fig. 2 Organic material stock (in boxes; DM kt) and flow (with arrows; DM kt / year), respired carbon from soil and mineralized nitrogen in the basin of Ushiku Lake.

rural system in Japan. The second national report of Japan for COP3 shows that the forest in Japan sequester 90,834 Gg of CO_2 in 1994 which is equivalent to 7.5 % of total emission of CO_2 in Japan (Japanese Government, 1997). We have to clarify quantitatively C cycling in agro-forest ecosystems.

The C storage in the managed agro-forest, the abandoned agro-forest, and the natural forest (Matsumoto et al., 1998) was estimated 43, 45, 108 tC / ha in plants, and 80, 88, 224 tC / ha in soil, respectively. The C sink in each plot was estimated 3.7, 3.5, 2.2 tC / ha / yr in plants, and -0.8, 1.3, 1.5 tC / ha / yr in soil, respectively. Raking litter and cutting undergrowth reduce C sink of forest.

In the basin of Ushiku Lake, about one thirds of the basin is covered by forests, major parts of which are abandoned agro-forest. It can be estimated that the emitted C in the basin is sequestered by the forest ecosystem.

3. Discussions

Soil respiration rates were estimated by a SOC(soil organic carbon) model. The rates were 1.71, 2.81, 1.87 and 3.08 Mg/ha/yr in Ushiku, Toride, Kawagoe and Satomi, respectively. The rates are a little lower than some reported values on organic soils in temperate regions. This method should be valuable for estimating carbon budget in several types of rural area

We can say from the results of our study that balanced C cycle and unbalanced N cycle of an agricultural sector in Japan should be seriously regarded. We have to realize a new balanced system of nutrient cycling, especially of N cycling. It might lead better balanced C cycle in agricultural field.

N cycling through food and feed systems was more closed and limited in environmental loading in 1960 as we understand now. In the 1960s, the economy of Japan went into a period of high growth and introduced technological innovation even in agricultural fields. The process after that was undertaken without proper attention to the environment, and the result was serious pollution-related damage. It was only after experiencing this damage that Japan began implementing proper pollution control measures.

We have to think about the best ways to balance the N cycling. Can we manage such a large amount of N in present day's agricultural lands in Japan? We had 5.2 million ha of cultivated land in 1992. If we returned whole N to the land, fertilizing rate of N would be 440 kg / ha, including N from chemical fertilizers and byproducts of crop. This level is higher than the N carrying capacity of agricultural lands in Japan, which is estimated to be 250 kg / ha.

Can we secure enough area to produce the same amount of feed as imported in Japan? (Hakamata & Hirata, 1994) The necessary area of crop lands for feed can be estimated, supposing average yield of each crop equals 3 t / ha, to be 5.79 million ha. Breakdowns of them show 4.10 million ha for corn, 1.23 million ha for sorghum and 0.46 million ha for barley. Area of agricultural land, area of planted field and cropping ratio, which have been decreasing, should increase and techniques for such high yield as 4.7 t / ha for corn and 10 t/ha for sorghum which are established in Japan should be extended to realize it. Agro-forestry is also useful even in Japan.

We can say there are two available ways, one is decrease of food and feed entered into Japan and the other one is increase of agricultural land including efficient use of agricultural land. We can say there are capabilities to balance the nutrient cycling only after changing not only agricultural but also many other measures to better ones in Japan.

We can address the new balanced system of nutrient cycling by learning from our history of nutrient cycling in food and feed systems in Japan. The general necessary conditions are as following:

1) The self-sufficient ratio of food and feed should increase in not only Japan but also each other country; and after that necessary import and corresponding export should be planned.
2) Construction of toxicant free sewerage systems should be realized; or reconstruction should be done in some developed countries, like Japan. But this is also a hard work for our posterity.
3) New organic fertilizers and fertilizing technologies should be developed following the new sewerage systems.
4) All other techniques in each cropping system should be innovated in harmony with nature from nutrient cycling point of view.

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