A municipal scale eco-balance analysis of carbon and nitrogen cycle in Japanese agriculture

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Abstract
Nitrogen (N) and carbon (C) flow concerning Japanese agriculture were quantified at a municipal scale in Japan for the year 2005 to analyse the influence of different N flows on the environment. Based on activity data from statistics and inventory data from literature, the farmland soil surface nitrogen balance (FSSNB), global warming potential (GWP) and the amount of agricultural production were calculated for each municipality. The average FSSNB of municipalities ranged from -40-10,210 kg N/ha/yr with a weighted mean of 166 kg N/ha/yr. The carbon input to Japanese farmland soil ranged from 0-39.4 Mg C/ha/yr, with a weighted mean of 1.22 Mg C/ha/yr for whole Japan. Livestock production was found to have high influence on the C and N flows. The agricultural production as well as GWP of municipalities showed a positive correlation to FSSNB. Thus, reduction of FSSNB can also reduce GWP, however, the agricultural productivity will also decrease under the present practices. An re-allocation of manure is required to reduce the N load from extremely high regions, but also changes in agricultural production structure that integrate livestock and arable farms are required to manage the N flow related to Japanese agriculture in a more sustainable way.

Key Words
Agriculture, carbon, eco-balance, flow analysis, global warming potential, nitrogen.

Introduction

Nitrogen (N) cycle on earth is known to be highly influenced by agricultural activities. After industrial revolution, anthropogenic N has doubled the reactive N in the world (Galloway 1998). More than 85 % of this increase is related to agricultural activities. The main purpose of anthropogenic N input is to increase crop and animal production. However, over supply of N has led to environmental damages in many areas in the world. Efficient use of N in agriculture is highly required for a sustainable production. Nitrogen flow is strongly connected to carbon (C) flows, since once applied, a big proportion of the applied mineral N will be taken up by crops and micro/macro organism and will exist as organic forms. Thus, the influence of N flow on C flow must also be considered in optimizing N flows, especially if the target area is a regional scale. The amount of production must be maintained or increased and at the same time, green house gas (GHG) emission should decrease if the N flows are optimized. Those targets are sometimes in trade off relation and thus, a quantitative evaluation is required to choose the most sustainable management method under the environmental condition of the target area. The analysis of the trade-off relation is defined as eco-balance analysis (Kimura and Hatano 2007). In this study, C and N flow concerning Japanese agriculture were quantified to analyse the available C and N resources at a municipal scale. The objective of this study was to analyse the N flows of Japanese agriculture in relation to production and GHG emission.

Methods

The C and N flows considered in this study is shown in Figure 1. The flows were simplified to export, import, loss and internal cycling flows (Kimura and Hatano 2007).Following calculations were conducted for the 2520 municipalitlies in Japan for the year 2005. Carbon and N in livestock manure was calculated from the amount of livestock excrement, additional materials such as urban compost and crop residue. The amount of livestock excrement was determined by the kind and number of livestock (MAFF 2009; LEIO 2005). Considered livestock kinds in this study were dairy cow, beef cattle, hog and poultry. The amount of additional materials and crop residue are determined by distribution factors for each kind of livestock manure obtained from inquiries (MAFF 2004). The loss during composting was calculated as a fixed factor, not considering different storing and decomposition methods (Brentrup *et al.* 2000; Sandars *et al.* 2003). The difference of N demand of human and animal to the produced N amount in crop and animal production was considered as exported if the amount of production is more than the demand, and as imported if the production is less than the demand. This calculation was conducted separately for 8 land use types, animal and fish product demands of humans (MAFF 2009).

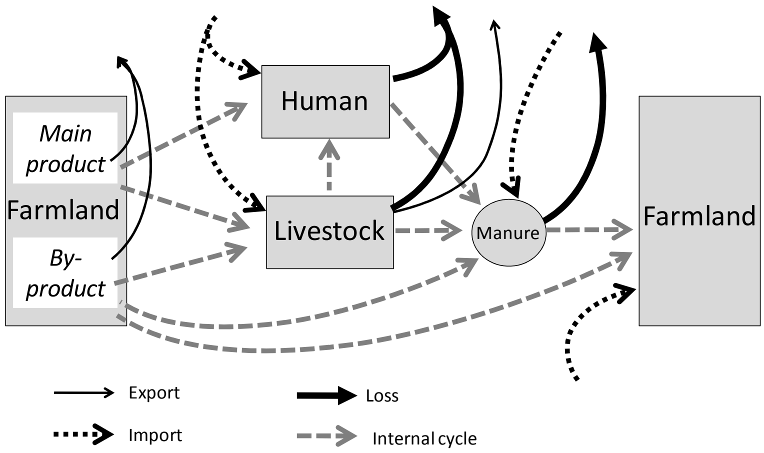

Figure 1. Carbon and nitrogen flows considered in this study.

The agricultural land use types were compiled to 8 categories; paddy rice, cereals (except paddy rice), root crops, beans, fodder crops, grass, vegetable and other crops (fruit, tee, sugar beets, sugar cane etc.). The amount of C and N of crops were calculated from the area, amount of yield (MAFF 2009) and their C and N concentration (Matsumoto 2000). The amount of residue of a given land use type is calculated using the ratio of residue to the yield (Matsumoto 2000). The allocation of manure to farmlands was calculated for paddy rice, upland crops and fodder crops, where upland included cereals (except paddy rice), root crops, beans, and vegetable and fodder crops included fodder crops and grass. The allocation to paddy rice, upland crops and fodder crops are based on farmer's inquiry (MAFF 2004).

The farmland soil surface N balance (FSSNB) was calculated as below:
Soil surface N balance (kg N/ha/yr) = {Chemical fertilizer (Mg N/municipality/yr) + Biological N_2 fixation (Mg N/municipality/yr)) + Atmospheric deposition (Mg N/municipality/yr) – Harvested N in crops (Mg N/municipality/yr)} / total farmland area of the municipality (ha)} --- (1)

Nitrous oxide (N_2O) emission from chemical fertilizer, livestock, manure and composting was calculated from the emission factors (GIO 2009). Methane (CH_4) emission was calculated for paddy rice fields, manure and digestion of ruminants (GIO 2009). The decomposition of organic matter after application to the field was not considered in this study and the C input to farmland was considered as the mitigation potential. Global warming potential (GWP) for each GHG was considered (IPCC 2007) and the GHG mitigation potential was calculated as below;

Green house gas mitigation (Mg CO_2 eq/ha/yr^{-1}) = {C input to farmland (Mg CO_2 eq /municipal/yr) – N_2O emission (Mg CO_2 eq/municipal/yr) – CH_4 emission (Mg CO_2 eq/municipal/ yr)} / total farmland area of the municipal (ha)} --- (2)

Results and discussion

Farmland soil surface N balance

The average FSSNB of municipalities ranged from -40-10,210 kg N/ha/yr (Figure 1). The weighted mean for whole Japan was 166 kg N/ha/yr. There were 117 municipalities that had a higher FSSNB value than 500 kg N/ha/yr. Those municipalities were found in North-East region, Central region, Shikoku region and Kyusyu region. The FSSNB increased exponentially as the proportion of manure to the total N input increased (Figure 2). Municipalities that had a FSSNB value more than 500 kg N/ha/yr showed that their proportion of manure to the total N input were above 66%, indicating that livestock production was the main reason for the high FSSNB. On the other hand, there were 321 municipalities without any manure application, which accounted for 2.7% of the total farmland area in Japan. The extremely high FSSNB values might be wrongly calculated because the allocation of manure to other municipalities was not taken into account. An inquiry conducted in one of the area with high FSSNB showed, however, that the manure applied to farmland soils were up to 900 kg N/ha/yr and the farm gate N balance was up to 1230 kg N/ha/yr (own investigation). The present municipal scale calculation might be an over estimation, however, the trend of FSSNB found in this analysis might be reflecting the real situation at a municipal scale.

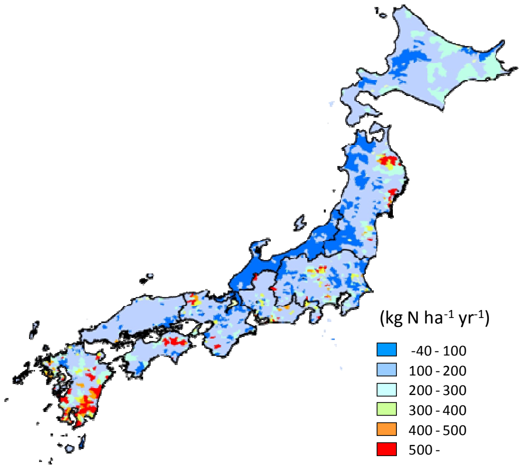

Figure 2. Farmland soil surface nitrogen balance of Japan in 2005 at a municipal scale.

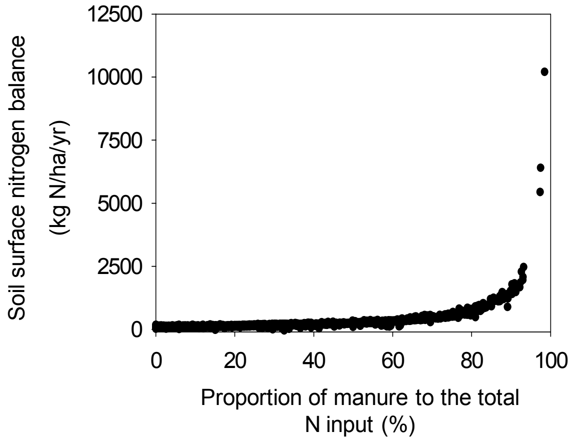

Figure 3. Relation of proportion of manure to the total N input and Soil surface nitrogen balance. Each point stands for one municipality in Japan.

Carbon input to Japanese soil

The carbon input to Japanese farmland soil at municipal scale is shown in Figure 4. The values ranged from 0-39.4 Mg C/ha/yr, with a weighted mean of 1.22 Mg C/ha/yr for whole Japan. Municipals with high C input were similarly distributed as FSSNB and showed high values especially at south of Kyushu region, south Japan.

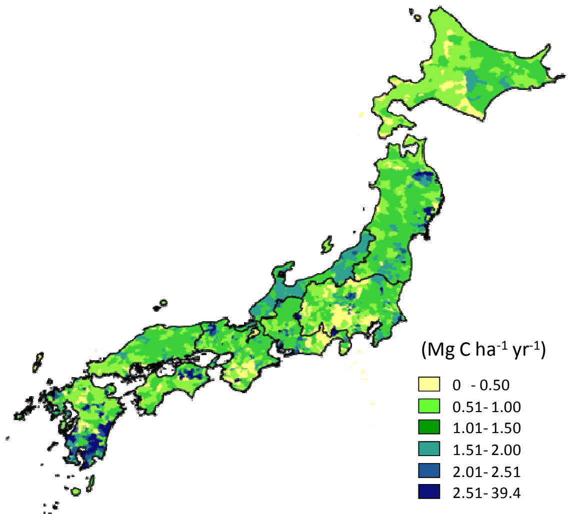

Figure 4. Average carbon input to Japanese farmland soils in 2005 at municipal scale.

Relation of surplus N to Global warming potential and production

The amount of FSSNB is highly influenced by the amount of manure produced in the municipal (Figure 3). The amount of agricultural production per unit area of farmland will increases as number of livestock per unit area increases. Thus, the agricultural production of municipals increased as FSSNB increased (Figure 5a). This relation might be influenced by extreme values, thus the relation for FSSNB values below 500 are shown within the Figure 5a. The relation showed that there was no clear relation of agricultural production and FSSNB for municipalities with FSSNB below 250 kg N/ha/yr. Global warming potential was expected to decrease as FSSNB increase since the amount of carbon input to farmland will increase as the amount of manure increases. However, Figure 5b showed that GWP increased as FSSNB increased. This tendency was also found for municipals with FSSNB below 250 kg N/ha/yr. As the three components of GWP (CO_2, CH_4, N_2O) was compared to FSSNB, GWP derived from CO_2 showed a negative correlation to FSSNB (Figure 6a), while that from CH_4 showed no correlation (Figure 6b) and that N_2O showed a positive correlation (Figure 6c). The increase of GWP derived from N_2O emission was higher than the mitigation GWP by CO_2. In addition, the GWP derived from CO_2 only considers the C input to farmland and does not consider the C decomposition in soil after application. The CO_2 mitigation of farmland soil due to C input is much smaller than the emission of N_2O due to manure application.

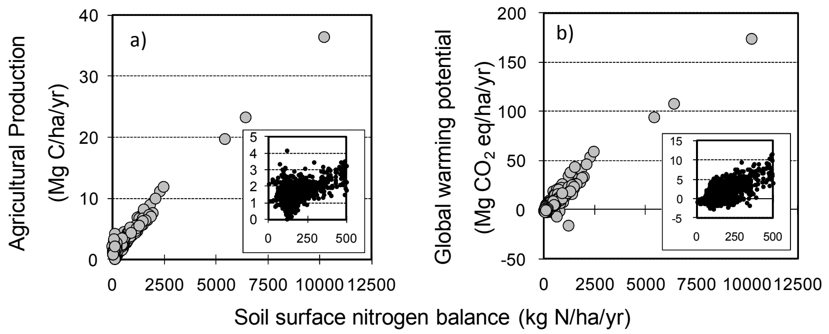

Figure 5. Relation of a) agricultural production and b) global warming potential to farmland soil surface nitrogen balance.

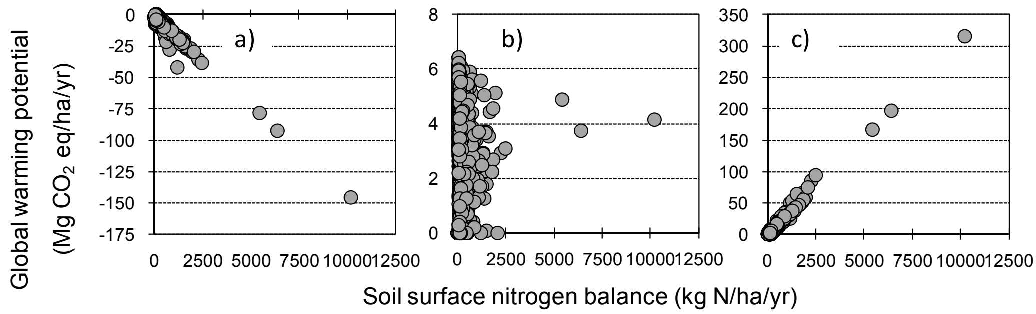

Figure 6. Relation of soil surface nitrogen balance to global warming potential of a) CO_2, b) CH_4 and c) N_2O.

Conclusion

The analysis of FSSNB in relation to amount of manure, agricultural production and GWP showed that the intensity of livestock production has a high influence on FSSNB. The calculated amount might be overestimated since the estimation was conducted at a municipal scale and the tendency rather than the amount should be discussed. The analysis showed that there is a positive relation of FSSNB to agricultural production and GWP. It indicates that the reduction of FSSNB can also reduce GWP, however, the agricultural productivity will decrease under the present practice. An re-allocation of manure is required to reduce the N load from extremely high regions, but also changes in agricultural production structure that integrate livestock and arable farms are required to manage the N flow related to Japanese agriculture more sustainably.

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