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Potentialities of organic and sustainable rice production in Japan from a life cycle perspective

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Abstract. Many cultivation practices have been improved in order to decrease environmental burdens of paddy rice production in Japan. Therefore, the importance of life cycle assessment (LCA) to assess the environmental impacts of whole production systems particularly that of rice production has increased. However, the applications of LCA to rice production are still limited, although rice is the staple food in Asian countries. In this study, we apply LCA to organic and sustainable (environmentally-friendly) rice production and compare the two systems by using global warming and eutrophication potentials as indicators. Although both of these production systems generally outperform conventional farming, our results indicate that the environmental superiority of organic and sustainable farming depends on the functional unit. Our results imply that organic and sustainable farming have the potential to reduce environmental burdens depending on the functions of farming systems used for the analysis.

Key words: organic farming, sustainable farming, life cycle assessment (LCA), environmental evaluation, rice production

INTRODUCTION

Public concern about the sustainability of food production has increased recently because of the rise in world population and the growing scarcity of natural resources. Although various sustainable cultivation practices have been developed so far, the total impacts of the introduction of these practices into farm management are still unclear. Life cycle assessment (LCA) will play an important role in evaluating the environmental impact of whole production systems from the life cycle (cradle-to-grave) perspective.

Although LCA has been applied to agricultural systems, especially in European countries (Hayashi et al., 2006; Williams et al., 2006; Blengini & Busto, 2009), the applications of LCA to rice production are still limited despite the fact that rice is the staple food in Asian countries. The recent increase in organic rice production may necessitate the assessment of the overall environmental impacts of agricultural practices.

In this study, we applied LCA to rice production in Japan; the potentialities of organic and sustainable rice production systems were analyzed, with a particular focus on global warming and eutrophication potentials.

MATERIALS AND METHODS

The farm surveyed in this study is located in Nagano Prefecture in Japan; the total area is approximately 55 ha, which is very large as compared to the size of the average Japanese farms (< 2 ha). Data for the life cycle inventory were collected only during rice production in 2007 and 2008. The area surveyed included paddy fields where sustainable (environmentally-friendly) farming, i.e., the application of herbicides and limited amount of chemical fertilizers, and organic farming, i.e., farming without the use of agricultural chemicals, were carried out. The average area of the former was 14.06 ha, while that of the latter was only 1.12 ha; smaller areas are used for organic farming because herbicides are not used, and weeds need to be removed by means of special machines. The details of the differences in the field work processes are shown in Fig. 1. The model of conventional rice production in the region was based on the guidelines obtained from the agricultural extension workers of the prefecture. In conventional farming, the number of pesticide application was much higher than that of sustainable farming and the use of mechanical equipment in both systems is considered to be the same.

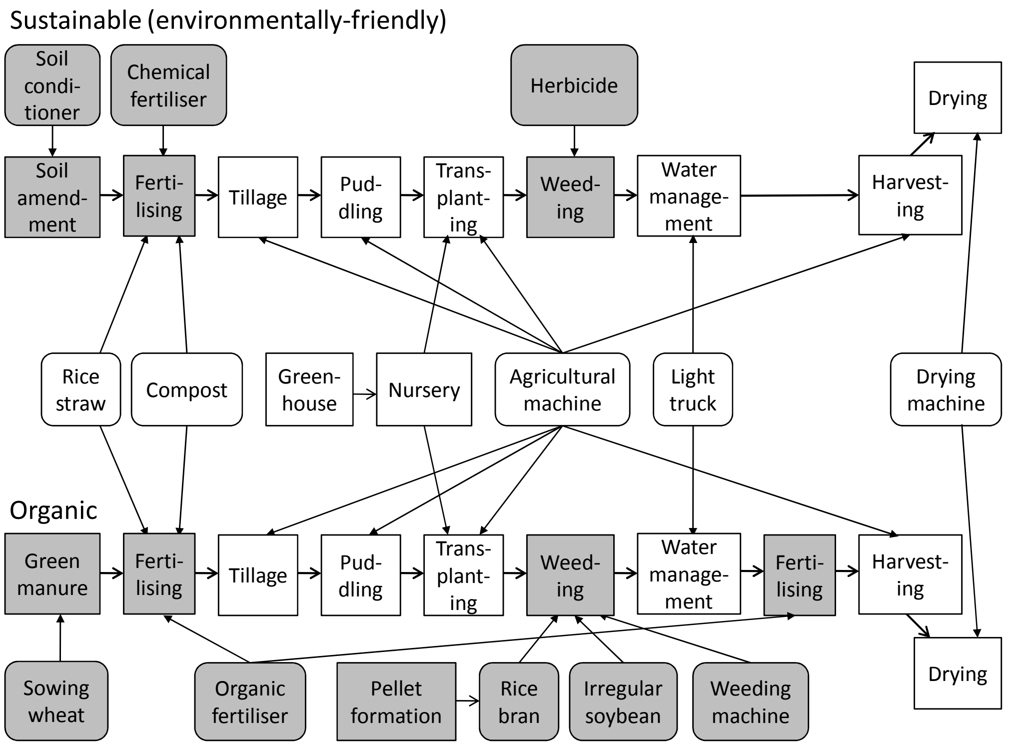

Fig. 1 Sustainable and organic farming systems in the case farm.

The average yields for two years were 5960, 5580, and 4970 kg ha^{-1}, while the sale prices were 250, 283, and 367 yen kg^{-1}, respectively, for the conventional, sustainable and organic farming systems. These values are very important for LCA because these data affect the results.

The methodology used in this study conforms to the framework of LCA, which is described in ISO 14040 and 14044. The system boundary encompasses the processes from rice production in the case farm to the manufacturing of machines, chemicals, fertilisers, and other materials that were used for the rice production. Machines and materials that have been used for more than one year were segregated depending on the duration of their useful life. The contribution of machines shared with other crop production was allocated according to the area and operation frequency. Although the mass of products is often used as the functional unit in LCA, we used three types of functional units in this study, namely, area, mass, and monetary value, in order to analyze the relationship between the functions of the systems and results.

Two impact categories – global warming and eutrophication – were used in the present study, because both of them are a major concern in Japan. Greenhouse gas (GHG) emissions were evaluated as CO_2 equivalent emissions by using global warming potentials – 1 for CO_2, 25 for CH_4, and 298 for N_2O – for a period of 100 years (IPCC 2007). The eutrophication potential was estimated from the amounts of total nitrogen (T-N), total phosphorus (T-P), NH_3 and NO_2. EPMC (eutrophication potential considered marine material circulation) indices – 0.26 for T-N, 3.065 for T-P, 0.092 for NH_3 and 0.011 for NO_2 – were used in this study (Hirosaki, 2005).

The redundant nitrogen and phosphorus levels were calculated by subtracting the amount assimilated into rice plants and the amount involved in denitrification to the atmosphere (for nitrogen) from the total amount of applied fertilizers and crop residues in addition to the contents in precipitation and irrigation water. Since nitrogen is easily leached through the percolating water as NO_3^- and there is excess accumulation of phosphorus in the soils in fields in Japan, this calculation process based on T-N and T-P is suitable for assessing eutrophication.

Data are collected from various sources, including survey interviews with the manager of the case farm. The fuel consumption for each of the mechanical fieldwork processes was estimated from the database of National Agricultural Research Center (1999). The amount of CO_2 and NO_x emitted during the manufacturing of agricultural machines and materials such as herbicides and fertilizers was calculated using the 3EID database that is estimated from the input-output table in Japan (Nansai and Moriguchi 2002). Direct field emissions of CH_4 and N_2O are determined with reference to the National Greenhouse Gas Inventory Report of Japan 2008 (Greenhouse Gas Inventory Office in Japan 2008).

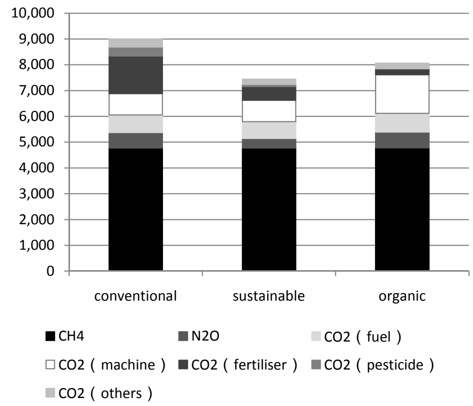

Fig. 2 GHG emissions per unit area (kg CO_2 eq./ha).

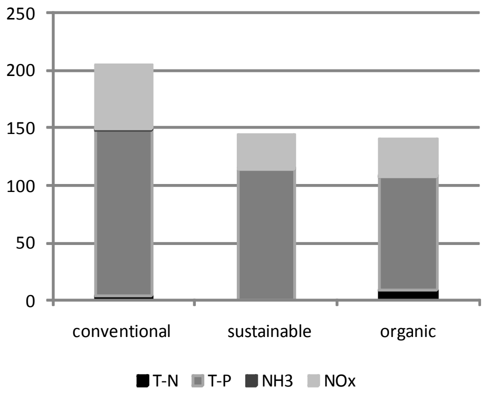

Fig. 5 Eutrophication potential per unit area (kg PO_4^{3-} eq./ha).

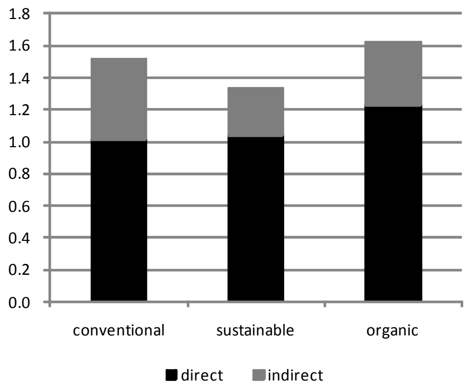

Fig. 3 GHG emissions per unit mass (kg CO_2 eq./ kg-brown-rice).

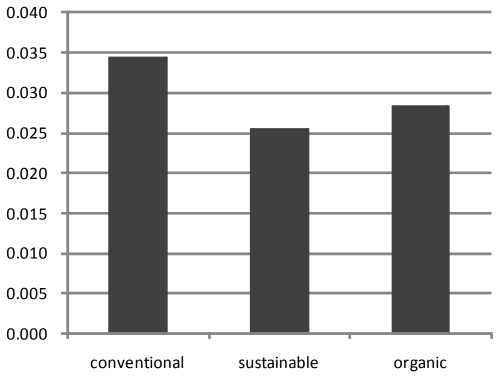

Fig. 6 Eutrophication potential per unit mass (kg PO_4^{3-} eq./kg-brown-rice).

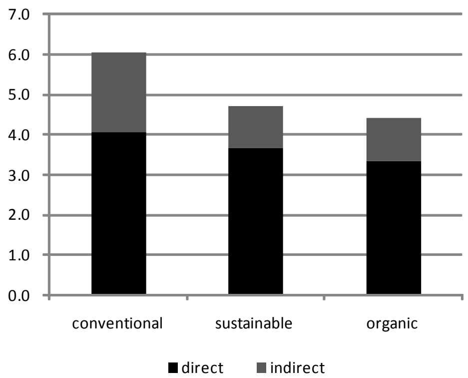

Fig. 4 GHG emissions per unit value (kg CO_2 eq./ 1,000yen-brown-rice).

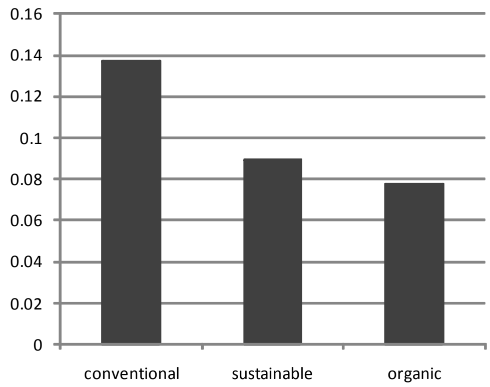

Fig. 7 Eutrophication potential per unit value (kg PO_4^{3-} eq./1,000yen-brown-rice).

RESULTS AND DISCUSSION

The GHG emissions (CO_2-eq.) per ha were 9.0, 7.4, and 8.1 Mg for the conventional, sustainable, and organic farming systems, respectively, as shown in Fig. 2. The GHG emissions for conventional farming were the highest level because of the large amounts of chemical fertilizers used. As for the other two, the amount of GHGs emitted during organic farming was higher than that during sustainable farming despite the fact that agricultural chemicals are not used in the former. Because the area for organic farming is much smaller, the large amount of emissions during manufacturing of special machines for weeding is allocated for unit area. Methane emissions released from paddy fields account for more than half of the emissions, and are the same for three farming systems because methane emissions were estimated on the basis of the soil taxonomy. In order to obtain a better comparison, it is necessary to measure field emissions from various types of fields cultivated using different farming systems.

The GHG emissions based on per kg of brown rice are shown in Fig. 3, in which direct and indirect emissions are illustrated. The result is reversed between conventional and organic farming because of the lower grain yields obtained by organic farming. However, if the results are compared by taking into consideration the value of brown rice, the emissions for organic farming become the lowest because of the higher price of organic brown rice (Fig. 4). The functional unit of the economic value is important in considering both economic and ecological performance of farming systems.

The eutrophication potentials are indicated in a similar manner as the GHG emissions (Figs 5–7); we observed that the eutrophication potentials were dominated by T-P. The eutrophication potential in conventional farming per ha was 45% higher than that in both sustainable and organic farming mainly because of the high levels of phosphorus fertilizers. The total eutrophication potentials per ha were almost the same in sustainable and organic farming despite the highest value of the T-N potential per ha in organic farming. Although LCA studies conducted in European countries often suggest that organic farming increases the eutrophication potential, our results imply that this is not necessarily true for organic rice production in Japan. Moreover, the results of sustainable and organic farming were dependent on the selection of functional units, as observed in the case of GHG emissions.

CONCLUSIONS

The comparative study on rice production systems from a life cycle perspective reveals that organic and sustainable rice production systems have the potential to mitigate global warming and eutrophication. Organic farming reduces environmental burdens but at the same time is capable of generating farm income, while sustainable farming reduces environmental burdens and results in increased food production due to higher grain yields. These findings indicate that the environmental and economic performance of organic and sustainable farming is higher than that of conventional farming. In addition, scale expansion of the area and the development of technologies for organic farming are expected to further reduce the environmental burdens. The development of the indicators for biodiversity will be important in appropriately assessing the positive impacts of organic farming.

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