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# Life cycle environmental and economic impact of food waste recycling: A case study of organic vegetable farming in Japan

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## Abstract

Closed food recycling systems include not only the recycling process, but also the utilization of recycled materials. This study conducted a life cycle assessment of the impacts of food waste treatment and spinach farming systems on environmental loads and regional economies. Two recycling technologies, on-site composting (in-vessel) and centralized composting (aerated static pile), were compared to waste incineration. The results showed that on-site composting had a high environmental impact and lower cost, whereas centralized composting had a lower environmental impact, but also a lower economic benefit. These tradeoffs will need to be considered when deciding which food recycling system to introduce, based on the situation of the local area.

***Keywords:** Food waste; composting; spinach farming; input-output analysis*

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## 1. Introduction

Reducing and recycling food waste have recently been discussed in the context of Sustainable Development Goals (SDGs). Recycling food waste creates new resources and can improve the environmental and economic impacts of the food system. A closed food recycling system, which incorporates the composting of waste, the utilization of food compost, and the consumption of agricultural products in same area where the food waste is generated, could achieve a sustainable food system. In Japan, these kinds of closed system, called "food recycling loops," are promoted by the government, in participation with recycling companies, agricultural producers, and retailers/food service companies.

Relatively few studies have focused on the life cycle assessment (LCA) of food waste recycling from retail and food service sector, compared to the household sector. In one areal case study, Mu et al. (2017) performed an LCA of the environmental impact and economic cost/benefit of composting food waste from a university campus. It focused on an in−vessel composting system, which includes waste collection, composting, growing vegetables from this compost, and providing these vegetables for consumption in the student cafeteria. The study revealed that such a system can reduce greenhouse gases (GHGs) and diminish the impact of eutrophication. The benefits of this particular system exceeded its costs, taking the selling of the vegetables into consideration. A further study by Mondello et al. (2017) involved an LCA of the treatment of food waste from supermarkets in Italy, considering five scenarios: landfill, incineration, composting, biogas, and compost and feed production using insects. It did not cover a closed recycling system, though it did evaluate waste collection and treatment processes, and avoided impacts of chemical fertilizer and electricity production. The study revealed that all recycling scenarios reduced environmental impact compared to the landfill scenario, while the incineration scenario also displayed advantages in some impact categories when considering energy recovery.

Existing studies mainly focus on the recycling processes of the system; they, do not consider how agricultural practices might change with the use of alternate fertilizers. This question will be key to how this kind of system could become sustainable, because it is related to the merit of agricultural producers. Furthermore, impacts on the regional economy is often considered when analyzing regional systems. However, the economic and environmental impacts of food recycling-farming systems have not been analyzed comprehensively to date.

This study aims to reveal the impacts of a food waste treatment and farming system the environmental load and regional economy, through LCA.

## 2. Material and methods

This study targeted greenhouse organic spinach farming in Shiga prefecture, Japan. The farm investigated conventionally uses organic fertilizer with domestic and imported ingredients; the use of agrochemicals is avoided. The farmer cultivates leaf vegetables four times per year, while greenhouses are used to prepare rice nurseries for several months.

Two food recycling scenarios were simulated, one where the system was closed within the neighborhood area (on-site composting scenario, OC), and another where composting was performed in a centralized facility (centralized composting scenario, CC). Food waste from food services was either composted by an in-vessel composting machine with heating on site (OC; 50 kg/day capacity) or was transported to a centralized composting facility that operated by aerated static pile (CC; 25 t/day). Food compost was used for vegetable farming, and products were sold to the local community, including food services. The distances from the farm to the food services and centralized composting facility were assumed to be 5 km and 50 km, respectively, to consider the effect of transportation. The results of a test cultivation (around 400 $m^2$) with food compost generated in a university campus were used for inventory analysis (Table 1).

**Table 1: Overview of spinach cultivation**

| | | Food compost | Organic (Conventional) |
|---|---|---|---|
| Cultivation period | Seeding | Late October, 2016 | |
| | Harvest | Late December, 2016 | Mid January, 2017 |
| Fertilizer | Type | Food compost (N2.5%, $P_2O_5$0.2%, $K_2O$0.6%) | Commercial organic fertilizer (N8%, $P_2O_5$4%, $K_2O$4%) |
| | Amount (kgN/10a) | 29.2 | 16.7 |
| Area of greenhouse ($m^2$) | | 201 | 288 |
| Yield (kg/10a) | | 896 | 778 |

The system boundaries included food composting, waste incineration, input material production, spinach cultivation, and shipment. Food composting can avoid waste incineration and chemical/organic fertilizer production, including the importing of ingredients. Energy recovery during the incineration process was not considered. The functional units were kg-spinach or 1 ha of cultivation. The system also contained treatment of food waste. In this test cultivation, 43.62 t/ha of food waste were used, so a functional unit "1ha" contained 1 ha of vegetable cultivation and waste treatment of 43.62 t of food scrap.

The environmental impact was estimated using foreground data collected from the farmer, the solid waste incineration facility, experimental data, and literature. In particular, the OC scenario was based on experimental waste composition and electricity use data from an in-vessel composting machine at Ritsumeikan University. The CC scenario composting process was derived from Yuyama et al. (2006). Japanese life cycle inventory database IDEA v1 was used for background

data. Field GHG emissions were estimated by the DNDC(Denitrification-Decomposition) model to reflect differences between the practices.
Environmental loads (global warming and eutrophication) were integrated by the Japanese impact assessment model (LIME2). Integrated values were represented as economic value (Japanese Yen). The economic ripple effect and job creation effect were calculated to evaluate impact on the regional economy. Input-output (IO) analysis using the Japanese IO table for 2011 was performed considering primary and secondary effects. Increases in production from income raised due to rippled production were considered to be a primary effect, and savings in production costs in spinach cultivation were considered to be a secondary effect.

## 3. Results and Discussion

Figure 1 shows the environmental impact of each scenario, OC, CC and conventional farming (CV). OC had the highest impact because of GHG emissions from electricity used by the in-vessel composting machine. The environmental impact of CC is lower than OC, though the transportation of food waste and compost increased its GHG emissions (50 km). Food waste treatment (incineration) is the main contributor in CV. Organic fertilizer production had only a small environmental impact compared with the other scenarios. The impact of fuel for cultivation was higher for CC and OC than for CV because of the working time of tilling. $N_2O$ and $CH_4$ emissions from composting were significant, 22% and 37% in the total environmental impacts of OC and CC (5 km), respectively.

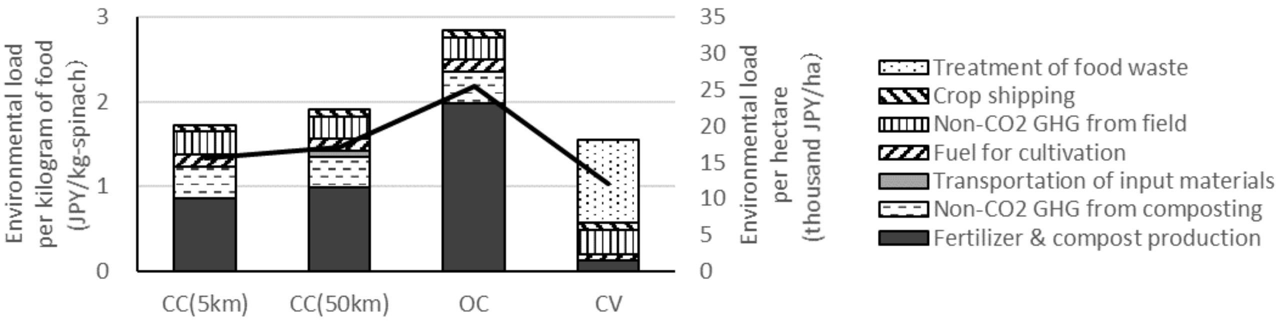


**Figure 1: Environmental impact of food recycling and vegetable farming system**

The life cycle cost of food recycling and fertilizer use by stakeholders is shown in Figure 2. Food services pay waste treatment costs to the municipal government, which is charged by quantity as business-related municipal waste. However, this did not cover all actual costs. The cost of the public sector shows the difference between actual costs and the fee paid by food services. For agricultural producers, the food recycling scenario was preferable because they can save fertilizer costs, while more working time was needed to treat compost. The food service sector could reduce waste treatment costs in the OC scenario because this system reduced waste collection and waste treatment fees, outweighing machine and electricity costs. The CC scenario reduced fertilizer costs for the agricultural producer, although the waste treatment cost (total of food service and municipality) was not saved. OC had the lowest cost among the three scenarios.
Figure 3 shows the economic impact of each scenario. The primary economic effects of OC and CC decreased from CV because the cost of fertilizer was reduced. The secondary effect for OC exceeded that of CV by 13.7% per ha. Around 88-93% of the economic ripple effect remained within Japan. The ripple effect outside of Japan was relatively high in OC because coal and oil imports for electricity production increased (to run the composting machine). The job creation effects of OC and CC were higher than CV by 10.1% and 8.3% per ha respectively, but were however, lower by 4.4% and 5.9% per kg-spinach (because of the positive effect of yield growth

and the negative effect of waste management job decreases).

The results of environmental load, life cycle cost, and economic impact revealed tradeoffs between each scenario. OC does not have the best environmental impact, does reduce the life cycle cost of the waste management-vegetable production system. CV had the smallest environmental impact in this study, which implies that using a waste-based organic fertilizer is better than food compost if food compost substitutes as organic fertilizer. If this is the case then farmers in the area can get enough organic fertilizer, and no longer need chemical fertilizer. CC had a better environmental impact than OC, but had a lower economic ripple effect than the other scenarios. This shows that CC used low-input technology, however, recycling costs were relatively high, suggesting large income increases through cost reduction are unlikely.

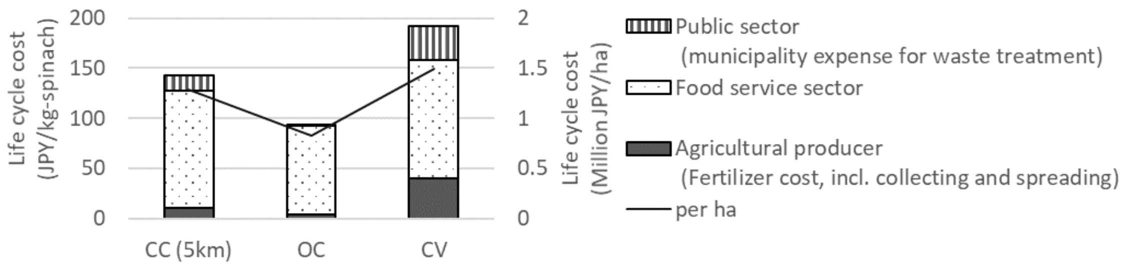


**Figure 2: Life cycle cost of food recycling and fertilizer use**


**Figure 3: Economic impact of food recycling and vegetable farming system**

## 4. Conclusions

This study compared the environmental and economic impacts of food recycling and agricultural production systems with a conventional system. A case study of on-site composting, centralized composting, and a spinach farming system showed tradeoffs between environmental and economic impacts. The on-site system needs further reductions in electricity consumption to reduce its environmental impact to the same levels as the other scenarios. It is important to consider tradeoffs based on the situation of the local area when deciding what combination of recycling/farming technology should be introduced. It is important to accumulate knowledge based on case studies, including conventional farming using chemical fertilizer, because results vary by assumptions.

## 5. References

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