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# Do Sustainable Agricultural Practices Improve Rice Productivity and Soil Fertility? An Empirical Study in Shiga Prefecture, Japan

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Japan is one of the top greenhouse gasses (GHGs) emitters in the world. The overuse of chemical fertilizers has resulted in polluting air, water, and soil, especially hardening the soil, reducing soil fertility, and weakening soil microbial activity, thereby affecting soil health. The Japanese government has recognized its responsibility to address agri-environmental issues in its domestic agricultural policy. This paper aims to investigate the benefits of sustainable agricultural practices (SAPs) on rice productivity and soil fertility in Shiga Prefecture, Japan. Observational data were obtained from survey questionnaires and key informant interviews. Soil samples were also collected from eight rice fields. The results from the propensity score matching technique showed that farmers' age, land ownership, farming scale, awareness of sustainable agriculture on soil health, and awareness of receiving direct payment subsidies significantly influence farmers' choice to implement SAPs. SAPs have lower rice productivity by 37.4 kg/10a compared to conventional farming practices. Nevertheless, the soil fertility analysed using the Soil Fertility Index (SOFIX) in SAPs (i.e., organic farming) performs significantly better than those of conventional farming practices. More specifically, the amount of bacterial biomass is higher in organic rice fields, ranging from 14.5 – 23.3 ($10^8$ cells/g) than that in conventional rice fields of 8.8 – 11.5 ($10^8$ cells/g). Total carbon (TC) is significantly higher in sustainable rice fields (14,850 – 20,074 (mg/kg) compared to that in conventional rice fields (13,560 – 19,190 mg/kg).

## 1. Introduction

Japan is the top fertilizer consumer in the world with the highest consumption of about 324.6 kg per ha in 2000 and decreasing into the top three at 253.7 kg per ha in 2018 (World Bank, 2021). The overuse of chemical fertilizers for a long period of time has resulted in polluting air, water, and soil, hardening the soil, reducing soil fertility, and weakening soil microbial activity, affecting soil health (Pahalvi et al., 2021). In addition, Japan is also the world's top GHG emitter, with nearly 1,187 million tons of carbon dioxide equivalent in 2018 (Mt $CO_2$ eq) (World Bank, 2021). Especially, $CH_4$ emitted from rice paddy fields is the third largest contributor (23 %) in the Japanese agricultural sector. The Japanese government has recognized its responsibility to address agri-environmental issues in its domestic agricultural policy. The Ministry of Agriculture, Forestry and Fisheries (MAFF) started developing agri-environmental policy using the term "environmentally friendly agriculture (EFA)" for the first time in The Direction for New Policy for Food, Agriculture, and Rural Areas in 1992. Article 32 of the Food, Agriculture, and Rural Areas Basic Act in 1999 reports the necessity of securing the proper use of agricultural chemicals and fertilizers and improving soil fertility through the effective use of livestock manure to promote the cycle of agricultural systems. On the other hand, the Three Acts on Agri-Environment in 1999 outlined a reduction in chemical fertilizers and agrochemicals and improved soil quality by the application of organic fertilizers (Nishizawa, 2015). Although soil type largely determined soil properties (Wiesmeier et al., 2012), agricultural management practices seem to change soil microorganisms (García Orenes et al., 2013), soil organic carbon (Wilson et al., 2011), and soil nutrients (Shinjo and Takata, 2021).

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Shiga Prefecture in Kinki region, which is located near Kyoto and includes Lake Biwa has a unique policy of paying direct subsidies to farmers since 2004 for implementing sustainable agricultural practices (SAPs) (Nishizawa, 2015). Supported farmers can receive 30,000– 80,000 Japanese yen (JPY) per ha when implementing SAPs including integrated pest management (IPM), use of slow-release fertilizer, cover cropping, manure application, or local special practices with crop production based on the level of reduction in synthetic pesticides and chemical fertilizer use. This research uses the term SAPs which is broadly defined as a variety of agricultural practices that put efforts into reducing its impacts on the environment by improving soil fertility and sequestering carbon for climate change mitigation, improving crop yields (Manda et al., 2016). They may include both organic farming and EFA farming methods. According to the report from MAFF (2019), SAPs significantly reduce approximately 143,393 t $CO_{2\text{-eq}}$/y. Especially, many previous studies reported SAPs significantly improve farmers' income and crop yield. Nevertheless, several meta-analyses indicated that organic agriculture-managed crop yields are 19 – 25 % lower than those of conventionally grown crops but with substantial variability and a geographical bias based on data from Europe and North America (Seufert, 2019). There are very few studies investigating the effect of management practices on soil fertility in rice fields, especially in Japan (Tran et al., 2021). Therefore, this paper aims to investigate the benefits of SAPs on rice productivity and soil fertility in Shiga Prefecture, Japan.

## 2. Sustainable agricultural practices in Shiga Prefecture and data collection

Lake Biwa, which occupies one-sixth of the entire prefecture area of Shiga, is the largest lake in Japan. Lake Biwa was seriously polluted due to population growth and industrial development in the 1960s. The extensive use of chemical fertilizers and agrochemicals in the agricultural sectors was another cause of the water pollution in Lake Biwa. Recognizing the mission of protecting Lake Biwa and its ecosystem, Shiga Prefecture has enacted special laws, regulations, and promotion policies for water management and biodiversity conservation. The government has established the Ordinance for Promotion of Environmentally Friendly Agriculture in March 2003 to proactively promote EFA to reduce pollution load to Lake Biwa and conserve its biodiversity as well as to provide consumers with safe and reliable agricultural products. As early as 2004, Shiga Prefecture started an agri-environmental policy namely the Environmentally Friendly Agriculture Direct Payment Scheme which is the most advanced and unique policy with the aim of Lake Biwa conservation. This unique policy by Shiga Prefecture was adopted at the national level by Measures to Conserve and Improve Land, Water, and Environment (2007-2011) and has developed into the national direct payment policy since 2011. Shiga was proven as a successful case since it has the largest supported area for this environmental agriculture program (12,987 ha), accounting for 44 % of the total cultivated rice are and nearly 90 % of the total sustainable agriculture (Figure 1). Wet-rice cultivation is the base of the agriculture in Shiga Prefecture.

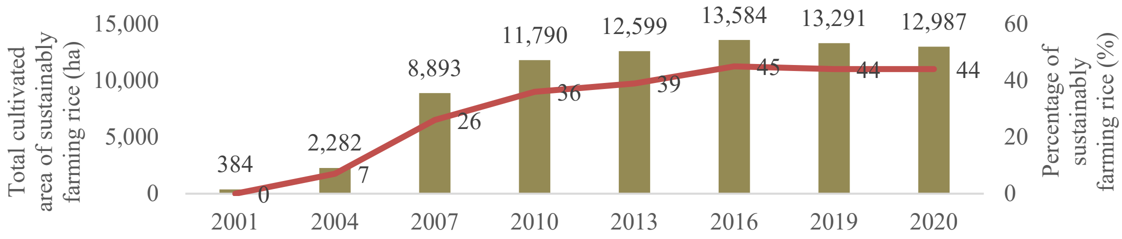



*Figure 1: Change in the total cultivated area of sustainable rice farming in Shiga Prefecture. Source: Shiga Prefecture, 2022*

### 3. Materials and method

### 3.1 Data collection

The data for this research were obtained from 64 rice farmers in three cities in Shiga Prefecture including Nagahama City, Higashiomi City, and Omihachiman City. This study applies the propensity score matching (PSM) method to investigate the impact of SAPs on rice productivity in consideration of selection bias. Self-selection, researcher selection, or geographic selection may lead to not only endogeneity bias and bias estimation of causal effects. Conceptually, the process of PSM has two analytic steps (Guo and Fraser, 2015). In the first step, the propensity scores for each subject are calculated by a binary logistic model. Then matching treated and control subjects who share a relatively similar or neighboring propensity score and estimating the treatment effects are undertaken in the second step.

### 3.2 Soil samples

Soil samples were also collected from eight rice fields in Kusatsu City and Nagahama City. Rice fields in Shiga Prefecture are mainly characterized by Lowland paddy soil (F1), Gulai lowland soil (F2), and Grey lowland soil (F3). The soil samples were collected from the 0 to 15 cm depth of the surface layer in rice fields. The soils were sieved through a 2 mm sieve and preserved at 4°C until analyzed. Then soil fertility (i.e., bacterial biomass and total carbon (TC)) was analyzed using the Soil Fertility Index (SOFIX). Quantifying the environmental DNA (eDNA) based on the slow-stirring method was applied to estimate bacterial biomass (Aoshima et al., 2006). Meanwhile, TC was analyzed with a Total Organic Carbon Analyzer (TOC-VCPH; Shimazu, Kyoto, Japan). Besides, bacterial community was analyzed by 16S-rRNA sequencing method. PCR amplification was implemented using primer pair 515f (5' -GTGCCAGCMGCCGCGGTAA-3') and 806r (5' -GGACTACHVGGGTWTCTAAT-3') generating a 250 bp amplicon from the variable V4 region of the 16S rRNA gene. The PCR amplicon was performed using the 10 µl reactions containing 5 µl 2 ×PCR buffer for KOD FX Neo, 2 µl dNTPs, 0.2 µl of both Forward and Reverse primer, 1 µl Template DNA, 0.2 µl KOD FX Neo, and 1.4 µl Nuclease-Free Water. Thermal cycling conditions were as follows: initial denaturation at 94°C for 2 min, followed by 98°C for 10 s, 50°C for 30 s, 68°C for 30 s, and 68°C for 7 min. An AMPure XP was used to purify PCR products (Beckman Coulter). The purified amplicons were loaded on a MiSeq Reagent Kit V3. The sequencing with 2×2300 bp was run on an Illumina MiSeq instrument (Illumina, San Diego, CA, United States).

## 4. Results and discussion

### 4.1 Data description

About 69 % of surveyed rice farmers implement SAPs while 31 % implement conventional rice farming. SAPs in rice are commonly integrated pest management (IPM), manual weeding of ridges and long-term drying, and the use of slow-release fertilizers and long-term drying (Figure 2). Regarding the application of organic and compost fertilizer, Shiga rice farmers often applied local agricultural materials such as cow manure fertilizer and compost fertilizer from food wastes and fermented Lake Biwa's grasses.

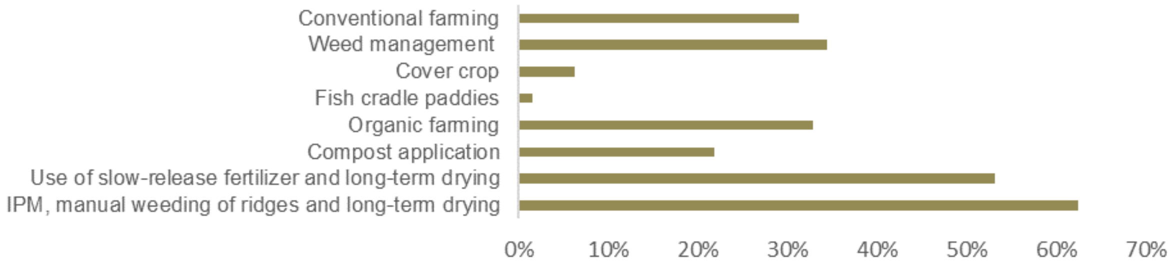



*Table 1: Descriptive statistics and difference test*

| Variable | All farm (n=64) | SAPs (n=44) | Conventional farming (n=20) | Difference (1-0) | T statistic |
|---|---|---|---|---|---|
| Productivity (kg/10a) | 509.3 | 502.3 | 524.7 | -22.3 | -0.791 |
| Age (Years) | 4.76 | 5 | 4.25 | 0.75** | 1.691 |
| Land ownership (1=owner, 0=other) | 0.76 | 0.68 | 0.95 | -0.27** | -2.417 |
| Small-scale farm (< 1 ha) | 0.13 | 0.07 | 0.25 | -0.18** | -2.075 |
| Medium-scale farm (1-5 ha) | 0.61 | 0.41 | 0.25 | 0.16 | 1.225 |
| Awareness of sustainable agriculture on soil health (1=Yes, 0=No) | 0.41 | 0.50 | 0.20 | 0.30** | 2.324 |
| Awareness of direct payment subsidies (1=Yes, 0=No) | 0.34 | 0.41 | 0.20 | 0.21* | 1.641 |

Source: Author's survey

The descriptive statistics in Table 1 show that aged farmers were more likely to implement SAPs. It also suggests that farmers who own their land and small-scale farming are less likely to implement SAPs compared to those who rent land or both own and rent land and medium or large-scale farming. Importantly, rice productivity between SAPs and conventional farming practices is not statistically different. Farmers implementing SAPs have a higher awareness of sustainable agriculture on soil health than farmers implementing conventional rice farming. Farmers implementing SAPs are more aware of direct payment subsidies than conventional farmers.

### 4.2 Farmers' decision on SAPs and its impacts on rice yield

The PSM approach is employed to investigate the farmer's decision-making on SAPs and its impact on rice yield. In the first step, the binary logistic model is used to provide the propensity score estimates and identify the influencing factors driving the choice of SAPs (Table 2). The result showed that farmers' age, land ownership, farming scale, awareness of sustainable agriculture on soil health, and awareness of receiving direct payment subsidies significantly affect farmers' decision to implement SAPs. Aged farmers are more likely to implement SAPs for their rice. Farmers who often rent the land or both own and rent land for their rice farming are more likely to implement SAPs for their rice compared to those owning their land. The result also showed that farm scale can significantly affect farmers' decisions. Especially, small-scale farmers are less likely to implement sustainable rice farming compared to medium or large-scale farmers. It was also found that the scale of rice farms significantly affected to enhance the aggregate eco-efficiency of Japanese rice production (Masuda, 2019).

To overcome the problem of selection bias, the PSM approach was used to match the sustainable farmers and conventional farmers with similar propensity scores estimated in the first step and calculate the difference or the effect of SAPs on rice productivity. The study found that SAPs produce lower rice productivity by 37.4 kg/10a compared to conventional practice (Table 3). This result is different with the study from Manda et al. (2016) which reported a positive effect of SAPs on maize yield. Possible reason for a decrease in rice productivity may be the reduction of input uses (i.e., chemical fertilizers and pesticides). Nevertheless, the importance of SAPs is not just about improving productivity but also about reducing the burden on environment and promoting social equity. In fact, the government's direct payment policy can help compensate for the productivity loss and enhance farmers' motivation for sustainable agriculture.

Figure 3 shows that the propensity score distributions of sustainable and conventional farmers overlap, meeting the assumption of substantial overlap for the treated and control groups.

*Table 2: Influencing factors on rice farmers' decision on SAPs implementation*

| Variable | Coefficient | Marginal | S.E. | p-value |
|---|---|---|---|---|
| Age | 0.614** | 0.088** | 0.270 | 0.023 |
| Land ownership | -2.195* | -0.340* | 1.317 | 0.096 |
| Small-scale farm | -2.165** | -0.316** | 1.098 | 0.049 |
| Medium-scale farm | 0.207 | 0.036 | 0.847 | 0.807 |
| Awareness of sustainable agriculture on soil health | 1.315* | 0.176* | 0.786 | 0.095 |
| Awareness of the direct payment policy | 1.651* | 0.259* | 0.893 | 0.065 |
| Constant | -0.788 | | 1.538 | 0.609 |
| Observation | 64 | | Probability | 0.000 |
| LR Chi-square | 23.49 | | Pseudo $R^2$ | 0.295 |

Note: *, **, and *** mean significance with the confidence interval of 90 %, 95 %, and 99 %. Source: Author's survey

*Table 3: Effect of SAPs on yield with Nearest Neighbor Matching algorithm*

| Rice yield | Coefficient | p-value |
|---|---|---|
| ATE, SAPs (1 vs 0) | -46.444 ** (21.646) | 0.032 |
| ATET, SAPs (1 vs 0) | -37.365 * (22.496) | 0.097 |

Note: Standard errors are in parentheses. *, **, and *** means significance with confidence interval at 90 %, 95 %, and 99 %. ATE means average treatment effect while ATT means average treatment effect for the treated.

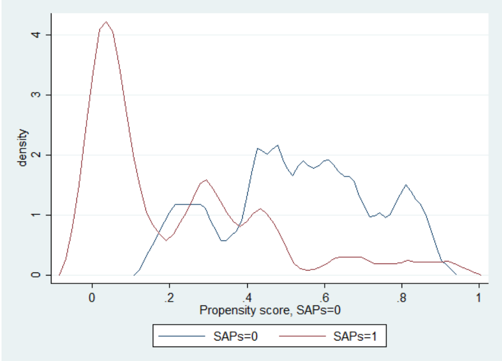
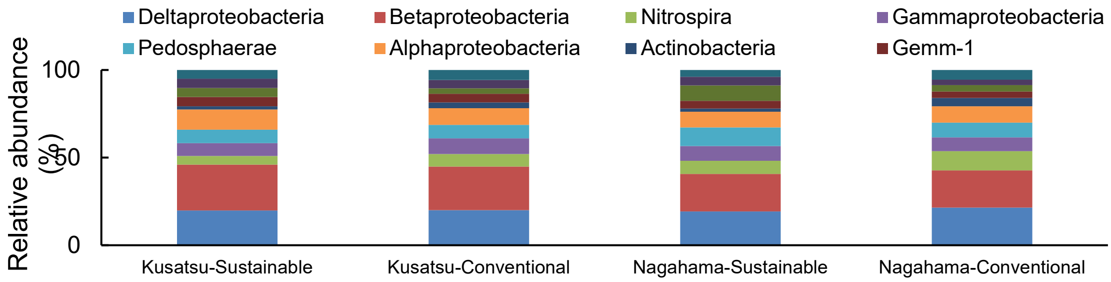



*Figure 3: Distribution of propensity score*

### 4.3 Soil fertility of sustainable rice farming

Soil health is defined as the capacity of soils to provide a sink for C to mitigate climate change and a reservoir for storing essential nutrients for sustained agricultural ecosystems (Toor et al., 2021). According to Tran et al. (2021), bacterial biomass, TC, and TN might be influenced by agricultural practices rather than soil types. Especially, the use of agrochemicals can decrease bacterial biomass in the soil (Dangi et al., 2017). The result of this study showed that the amount of bacterial biomass is ranging from 14.5 – 23.3 ($10^8$ cells/g) in sustainable rice fields which is higher than 8.8 – 11.5 ($10^8$ cells/g) in conventional rice fields. According to previous studies, organic fertilizers can increase the accumulation of C, sequentially affecting the soil physical properties (Sheng et al., 2012). The result of this study reported that total carbon (TC) is significantly higher in sustainable rice fields (14,850 – 20,074 (mg/kg) compared to that conventional rice fields (13,560 – 19,190 mg/kg). It can be explained that higher TC can improve soil structure; provide substrate and energy to support microbial activity; and create a reservoir of organic nutrients for plant productivity (Iqbal et al., 2023). The previous study from Hoang et al. (2021) also implied that the application of compost increases the quality and yield of vegetables, and improves the soil properties and microecological structures of the soil.
The result of bacterial community is shown in Figure 4. The class Deltaproteobacteria and Betaproteobacteria were dominant in both sustainable and conventional soils. Nitrospira phylum in conventional soil was higher than that in sustainable soils. The increase of Nitrospia, a nitrite oxiding bacteria in soil, was probably explained by the addition of chemical nitrogen in conventional fields. Sphingobacteria in sustainable soil was higher than that in conventional soil. There was no difference in the other bacteria abundances between sustainable and conventional soils.




### 5. Conclusion

This research attempted to understand the influential factors on farmers' decision to implement SAPs and investigate the effects of SAPs on rice productivity and soil fertility. The results showed that farmer age, land ownership, farming scale, awareness of sustainable agriculture on soil health, and awareness of receiving direct payment subsidies significantly influence farmers' choice towards SAPs. SAPs produce lower rice productivity of 37.4 kg/10a compared to conventional farming practices. Nevertheless, it is important to note that SAPs are not just about improving productivity but also about promoting social equity and environmental sustainability. The soil fertility in sustainable rice farming (i.e., organic farming) performs significantly better than those of conventional rice farming. More specifically, the amount of bacterial biomass is ranging from 14.5 – 23.3 ($10^8$ cells/g) in sustainable rice fields and 8.8 – 11.5 ($10^8$ cells/g) in conventional rice fields. Total carbon (TC) is significantly higher in sustainable rice fields (14,850 – 20,074 (mg/kg) compared to that in conventional rice fields (13,560 – 19,190 mg/kg). There were differences of relative abundance of Nitrospia and Sphingobacteria in sustainable and conventional soils. The authors acknowledge limitations associated with the limited observations from rice farmers as well as soil samples from paddy fields. However, information on SAPs and its implementation in this study are deployed from both key informants and rice farmers. The soil analysis was conducted based on the most advanced techniques. This empirical study hopes to provide some of the relative merits of the benefits of SAPs from economic and environmental perspectives which can be introduced to other prefectures in Kinki region. These SAPs could be considered for developing countries, especially Southeast Asian countries with the modifications of rice varieties and local agricultural materials use.

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