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Assessment of Soil Organic Carbon Storage in Vegetable Farms Using Different Farming Practices in the Kanto Region of Japan

Eri Matsuura [1], Masakazu Komatsuzaki [2,*] and Rahmatullah Hashimi [3]

1 Graduate School of Agriculture, Tokyo University of Agriculture and Technology, Fuchu 183-0057, Japan; erithacus6@gmail.com
2 Center for Field Science Research & Education, Collage of Agriculture, Ibaraki University, Ami 300-0393, Japan
3 Faculty of Agriculture, Shaikh Zayed University, Khost 2504, Afghanistan; rahmatullah_hashimi@yahoo.com
* Correspondence: masakazu.komatsuzaki.fsc@vc.ibaraki.ac.jp; Tel.: +81-298-88-8707

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Abstract: Agricultural fields can store substantial amounts of atmospheric carbon in the soil. In 2011, the Environmentally Friendly Farming Direct Payment Program (EFFDPP) began as a way to promote sustainable agriculture, but the approved methods for receiving the subsidy are limited to the use of manure and cover crops. For evaluating other options for the EFFDPP, we calculated soil carbon inputs and CO_2 emissions in four nature farming (NF) systems for comparisons with conventional farming (CF) and environmentally friendly farming (EF) systems. In 2015, we collected data on farm management from interviews and conducted a field experiment for NF. According to the calculations using a modified Roth C model, the ability for soil carbon sequestration predicted over the next 20 years is the highest in a no-till NF system with grass mulching. CO_2 emission per ha for CF was 4.8 t CO_2/ha, which was eight times higher than that for NF. However, the highest CO_2 emission per kg of crop was noted in NF with no grass mulching due to very low yield. The total CO_2 emission for CF was similar to that for EF. The NF systems were beneficial in reducing CO_2 emission, but a combination of other approaches is required for satisfying EFFDPP criteria.

Keywords: environmentally friendly farming; life cycle assessment; carbon sequestration; nature farming; grass mulching

1. Introduction

Agricultural practices serve as both sources and sinks for greenhouse gases, such as methane (CH_4) and nitrous oxide (N_2O). Agricultural fields act as carbon sinks that store atmospheric carbon in the soil. Farming practices and technologies, such as conservation tillage and cover crops, are known to increase soil carbon stocks [1]. As a consequence, Canada, Denmark, Spain, and Portugal have chosen to manage agricultural lands as carbon sinks under the Kyoto protocol [2]. Since 1999, the Japanese government has begun encouraging sustainable agricultural incentive programs as these farming practices can increase soil organic carbon storage [3].

In 2011, the Environmentally Friendly Farming Direct Payment Program (EFFDPP) [4] was established as one of the promotion systems for encouraging and supporting sustainable agriculture. For obtaining the subsidy, farmers must reduce the use of chemical fertilizers and other agricultural chemicals by more than 50%, and they must adopt one of the following sustainable options: (1) the use of cover crops; (2) the application of manure; or (3) organic farming practices [4]. Successful adoption of these practices results in a subsidy of \$400–\$730/ha (1 U\$ = 110 JPY) received for each environmentally-friendly farming (EF) practice. EF has multiple benefits, such as soil carbon sequestration and biodiversity and water quality improvement [5,6]. This subsidy program should also attract farmers who are interested in organic farming.

According to a Japanese national survey on agricultural production in 2015, even though 57% of farmers continue to use conventional farming (CF) practices, 28% of new farmers and 49% of current farmers are interested in engaging in environmentally-friendly or organic farming [7]. However, the findings of the survey revealed that these farmers were concerned about their lack of organic farming knowledge, increased labor, and increased cultivation costs. Thus, for widening the area of the adoption of sustainable agriculture, additional options for EFFDPP are required.

The EFFDPP only regulates the input of agro-chemicals and organic matter; it does not consider the soil organic carbon accumulation and greenhouse gas emissions caused by farming practices. Since the agricultural sector accounts for 12% of total global greenhouse emissions caused by humans [8], environmental impact assessments (EIA) of conventional agriculture should be updated to assess an entire farming activities. For example, farming activities use large quantities of organic matter and nitrogen for plant growth and serve as both sources and sinks for greenhouse gases (GHGs), such as CO_2, N_2O, and CH_4. The input and output of these gases should be accounted for in EIAs.

To seek a low-cost farming option for the EFFDPP, we reviewed traditional farming practices. Grass mulching is one traditional Japanese farming practice that was largely replaced when chemical fertilizers were introduced in the 1900s [9]. For example, the Chagusaba method is a traditional tea plantation practice that keeps silver grass (*Miscanthus sinensis*) fields around the plantation [10]. The silver grass is cut and spread over the plantation as grass mulching for improving tea quality. By introducing grass species around the mono-culture tea plantation, and using the grass regularly, the plantation can maintain plant biodiversity compared to conventional tea plantations [11]. In addition, the regular grass input increases the carbon concentration of the soil [12]. This unique agricultural system was registered as one of the Globally Important Agricultural Heritage Systems of the Food and Agriculture Organization in 2013.

On the other hand, agricultural fields could be a source of GHG emissions because of farming activities, such as the application of organic matter and nitrogen fertilizer [13]. In order to understand the true environmental impact of different farming practices, the storage of soil organic carbon, as well as GHG emissions, should be considered. GHGs from agricultural fields are estimated by Life Cycle Assessment or direct GHG flux measurement, however, there are few studies that assess net CO_2 emissions associated with different farming practices in Japan. Therefore, the present study used a widely recognized method for estimating soil carbon accumulation to evaluate potential farming practices for the EFFDPP. In particular, we used the Rothamsted Carbon Model (RothC model) [14] to assess the environmental impact of existing farming systems and grass mulching systems.

The demands for organic products have been increasing with growing public health awareness [15]. To meet this demand the Japanese Ministry of Agriculture, Forestry, and Fisheries (MAFF) has targeted an increase the area of organic farming from 0.4% to 1.0% by 2018 [15]. The EFFDPP is an entry point for farmers to engage in organic farming. Therefore, the establishment of more organic farming oriented methods is urgently needed. Understandably, the environmental impacts of new farming methods should be lower than those of existing farming practices to qualify as new EFFDPP methods. We tested the hypothesis that green manure, and grass mulching, as alternatives to animal manure and chemical fertilizers, could reduce GHG emissions as N_2O and CO_2 after application. Since 68% of organic products in Japan are vegetables, we aimed to evaluate net CO_2 emissions in existing vegetable cultivation systems.

Limitation of the study: we looked at traditional farming practices that could be appropriate for the EFFDPP and chose to examine a grass mulching method. However, there was no farm using only grass mulching. In order to investigate pure effects of grass mulching, we collected data from a field experiment instead of interviewing farmers.

2. Materials and Methods

2.1. Experimental Details

In 2015, we created an experimental field at the field research education center of Ibaraki University (36.01° N, 140.12° E). Long-term mean annual temperature and precipitation at this location are 14.9 °C and 1147 mm/yr. The soil at this site is Andosol [16] (sandy loam texture in the surface then gradually increasing clay proportion in deeper layers), with pH 6.5 in water (1:1 soil water ratio), 33.7 g/kg of T-C, and 3.5 g/kg of T-N (0–15 cm depth).

The experiment was designed as a randomized split-plot with four replicates. Individual plot size was 2.4 m × 5 m (12 m^2), and five seedlings of eggplant (*Solanum melongena*) were planted per plot as the main crop for this experiment. Rotary or zero tillage was the main plot treatment, and presence or absence of grass mulch was the subplot treatment. A total of 16 experimental plots (four replicates × two tillage rates × two grass mulch rates) were made in the nature farming (NF) field. The field has been used for nature farming since 2009 and has a history of cultivation of vegetables, such as corn (*Zea mays* L.), bell pepper (*Capsicum annuum* var. *grossum*), daikon (*Raphanus sativus* var. *Longipinnatus*), okra (*Abelmoschus esculentus*), and squash (*Cucurbita moschata*). Nature farming is a sustainable farming practice that does not use chemical fertilizers or agro-chemicals, but maximizes the soil's fertility and its ecosystems [17]. It is a variation of organic agriculture, but NF only uses fertilizer materials that have plant-based origins. Ten tons/ha of leaf mold (0.44 g/kg as T-N, 18.8 g/kg as T-C and 42.7 of CN ratio) were scattered as basal dressing on the NF field in late April. Four tons/ha of grass weeds cut from around the field boundaries were applied to the grass mulching plots. Weeds on no-till plots were cut using a hammer knife mower and were left on the field before planning the eggplant seedings. The eggplant was harvested every 2–3 days from July until October. The different farming practices used for this study are summarized in Table 1.

Table 1. A summary of cultivation management strategies used in different farming practices.

	CF Conventional Farming	EF Environmentally Friendly Farming	NF1 Nature Farming	NF2 Nature Farming	NF3 Nature Farming	NF4 Nature Farming
Tillage	Rotary tiller	Rotary tiller	Rotary tiller	Rotary tiller	no tillage	no tillage
Nutrient strategy	Chemical and organic fertilizer	50% reduced chemical and organic fertilizer	Grass mulching	no application	Grass mulching	no application
Manure application	cattle manure	cattle manure	green manure *	green manure *	green manure *	green manure *
Weed control	brush cutter/herbicide	living mulch/brush cutter	brush cutter	brush cutter	brush cutter	brush cutter
Pest control	pesticide	50% reduced pesticide	no control	no control	no control	no control
Insect control	insecticide	companion planting	manual	manual	manual	manual

Note: these information of CF and EF were obtained by interviews. NF managements were designed as a field experiment. *: green manure (leaf mold)

2.2. Measuring the Environmental Impact among Different Farming Systems

2.2.1. Life Cycle Assessment Analysis

To calculate greenhouse gas emissions from existing farming systems, we interviewed three CF farmers and three EF farmers in the Kanto region of Japan. Here, CF refers to farming practices that follow each prefectural crop cultivation guideline and EF refers to farming practices that follow the EFFDPP guidelines. Farm sizes varied from 0.07 to 0.15 ha, which reflects more than 50% of croplands in the Northern Kanto region [18]. The soil is classified as Andosol, a typical upland soil in the region, which is a volcanic soil rich in humus that has good permeability and water-holding properties [16]. These farms use several crop rotations, including eggplant (*Solanum melongena*), okra (*Abelmoschus esculentus*), daikon (Japanese radish; *Raphanus sativus* var. *Longipinnatus*), cabbage (*Brassica oleracea* var. *sabellica*), and green onion (*Allium fistulosum* L.).

The interviews were conducted in the summer of 2015. The farmers were asked for details regarding their cultivation management practices. In particular we obtained information on the following: fertilizer management (i.e., the types and amounts of fertilizers used); pest and weed management methods (i.e., the types of chemicals and tools used); farm work (i.e., the number of laborers and their working hours); cultivation costs (i.e., fuels used for agricultural machinery, agro-chemicals, and plastic mulch); and crop yields. The same data were collected from the NF field experiment.

The guidelines for life cycle assessment (LCA) of agricultural practice in Japan [19] were adhered to for calculating the amount of GHG emissions as a measure of the environmental impacts of the different farming strategies. LCA was originally developed in the field of engineering and as a method for assessing environmental impacts associated with all stages of a product's life cycle, from raw materials until their disposal. In the case of agricultural production, LCA covers the period from seeding until harvesting. Thus, we looked at the environmental impacts of the uses of energy, fertilizers, agro-chemicals, and plastic materials during the vegetable cultivation period. For example, the effects of fertilizers and chemicals were estimated as levels of GHG emissions and converted into CO_2 equivalent emissions. Alternatively, if a farmer used agricultural machinery for harvesting or tillage, we calculated the fuel consumption for the machinery as CO_2 emissions based on the type of petroleum fuels used. These CO_2 emissions were totaled for generating an annual CO_2 emission level for each farming system.

2.2.2. The Estimation of Soil Carbon Stocks

The turnover of soil organic carbon was calculated for each farming system using a soil carbon calculation tool [20]. The tool was developed by the Ministry of Agriculture, Forestry, and Fisheries (MAFF) and is based on a modified RothC model [21]. This model was designed for providing more accurate calculations for Andosol soils. The amount of CO_2 absorption and soil organic carbon stock from the CF and EF systems was calculated by adding information, such as soil types, rainfall, crop and fertilizer types, and the input of plant residues.

Tilling is another widely-used practice in Japan as a means to incorporate manure before seeding. To seek other EF approaches, we used NF systems for examining the effect of plant residues instead of animal manure. The soil carbon calculation tool was applied to the four NF systems. The annual soil organic carbon accumulation was calculated along with the estimates of soil organic carbon stock for 20 years. To understand the total CO_2 balance from farming management and soil carbon sequestration, net CO_2 emissions were calculated from the LCA and the soil carbon calculation tool:

Net CO_2 emission per area (t CO_2-eq/ha/yr) = A (t CO_2-eq/ha/yr) − B (t CO_2-eq/ha)

Net CO_2 emission per kg of product (t CO_2-eq/ha/yr) = A (t CO_2-eq/ha/yr) − C (t CO_2-eq/ha)

- t: Ton (Mg);
- CO_2-eq: Equivalent carbon dioxide;

- *A*: Annual soil carbon accumulation (t C/ha/yr) × CO_2/C;
- *B*: Total greenhouse gas emissions (CO_2 equivalent) per area in cultivation; and
- *C*: Total greenhouse gas emissions (CO_2 equivalent) per kg of product (yield) in cultivation.

For comparison, the soil carbon stocks of the four NF treatments were also calculated.

2.3. Statistical Analysis

The NF systems were analyzed using a split-plot model with tillage as the main factor, and presence or absence of grass mulching as the subplot factor. Tukey-Kramer method (Equation (1)), a multiple comparison procedure was used in conjunction with analysis of variance (ANOVA) to determine differences in crop yields. Total CO_2-eq emissions were tested by Student's *t*-test (Equation (2)), All statistical comparisons were made at the α = 0.05 probability level. Calculations were made using Stat View (version 5.0, SAS institute Inc., Cary, NC, USA).

$$\text{HSD} = M_i - M_j / \sqrt{MS_w / n_h} \tag{1}$$

where HSD is the honest significant difference; $M_i - M_j$ is the difference between the pair of means. To calculate this, M_i should be larger than M_j; MS_w is the mean square within, and n is the number in the group or treatment.

$$t = \frac{\overline{x}_1 - \overline{x}_2}{\sqrt{\frac{{s_1}^2}{n_1} + \frac{{s_2}^2}{n_2}}} \tag{2}$$

$\overline{x}_1$: Mean of first set of values
$\overline{x}_2$: Mean of second set of values
s_1: Standard deviation of first set of values
s_2: Standard deviation of second set of values
n_1: Total number of values in first set
n_2: Total number of values in second set

3. Results

3.1. Farm Management and Yield Response

3.1.1. Fertilizer Management

According to the interviews, cattle manure was used as basal dressing for both the CF and EF farms. The amount of basal dressing varied from 20 t/ha to 40 t/ha for CF and around 20 t/ha in EF. The EF farmers used 1.00–3.87 t/ha of organic fertilizer and living mulch for additional nutrients, while the CF farmers used 0.67–2.40 t/ha of organic and inorganic compound fertilizers (Table 2). For the field experiment, natural leaf mold was used on NF treatments as basal dressing. Young wheat (*Triticum aestivum*) and weeds such as *Echinochloa crus-galli*, *Eleusine indica*, *Digitaria ciliaris*, *Cyperus microiria*, *Chenopodium album*, *Persicaria longiseta*, and *Commelina communis* were cut as grass mulching materials in May. Then they were dried for a week under a greenhouse and applied around the seedlings. The details of the interviews are summarized in Appendix A Tables A1 and A2.

Table 2. Fertilizer management in each farming practice.

Treatment	Basal Dressing [t/ha]	Additional Dressing [t/ha]	
	Manure	Chemical	Organic
CF1	20	0	2.4
CF2	40	1.2	1.2
CF3	30	0	0.67
EF1	21.4	1.43	1 ^
EF2	20	0	3.87 ^
EF3	20	0	33.3 ^
NF1	10 *	0	4.8 #
NF2	10 *	0	0.8 #
NF3	10 *	0	11.5 #
NF4	10 *	0	7.0 #

Data collected by interviews are shown in bold letters. *: green manure (leaf mold); ^: the sum of organic fertilizer and living mulch biomass on furrows; #: the sum of grass mulch and weed (dry weight) on the experimental plots.

3.1.2. Weed and Pest Management

CF and EF farmers preferred agricultural machinery, such as rotary tillers or brush cutters, instead of herbicides for controlling weeds. EF farmers used barley as living mulch for controlling weeds, but CF farmers used agro-chemicals only for pest management. On the contrary, EF farmers used fewer pesticides than CF farmers. Integrated pest management, such as the use of companion planting or plastic mulch, was used along with the pesticide.

The cost of agro-chemicals for CF was $640 (USD) on average (calculated as 1 USD = 110 JPY) per year, but was only $291 (USD) for EF. There was no cost for agro-chemicals in NF because agro-chemicals were not allowed in this farming practice.

3.1.3. Yield Response

The yield was the highest for CF at 60 t/ha, but there was no significant difference between CF and EF (Figure 1). Tilling and no grass mulching (NF2) had the greatest yield among the four NF treatments. Grass mulching did not have a positive effect on yield in the tilling system, but it had a strong response in the no-till system and improved yields at the same level as that of tilling with grass mulching (NF1).

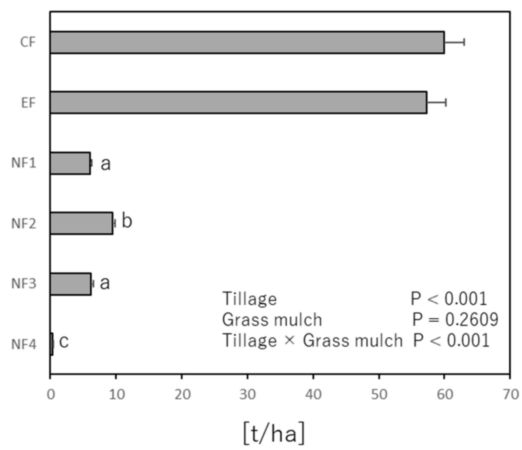

Figure 1. Total yield among the different farming systems. Different letters indicate significant differences among the treatments at p = 0.05 using the Tukey-Kramer test. The yield of CF and EF were tested separated from NF treatments because these data were obtained by interviews. However, there was no significant difference in CF and EF.

3.2. CO_2 Emissions for Each Farming System

The amount of CO_2 emissions per hectare was 4.8 t CO_2-eq/ha for CF and 3.9 t CO_2-eq/ha for EF. CO_2 emission in CF was significantly greater than that in EF (Figure 2). The major CO_2 emission sources were fertilizer and soil respiration. CO_2 emissions from NF systems were very low because the input of organic matter was less than half of what was used for CF and EF. However, CO_2 emission per kg of product became the highest in zero tillage with no mulching (NF_4).

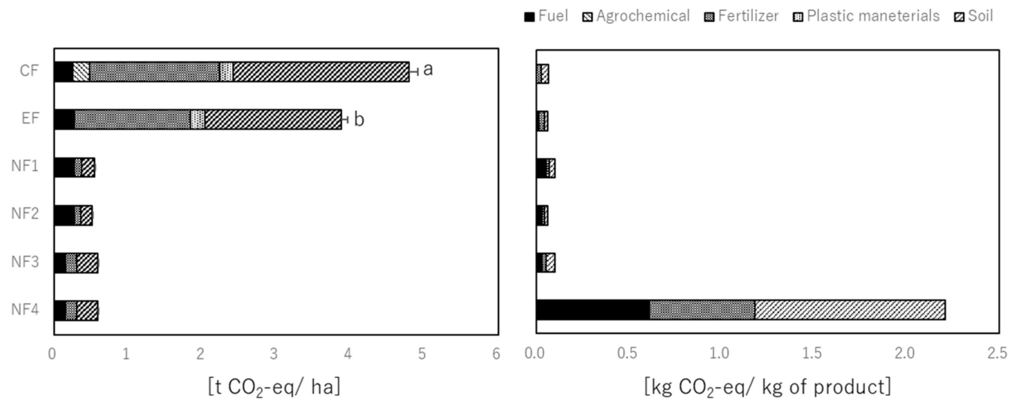

Figure 2. Total CO_2 emissions during the cultivation period. Different letters indicate significant differences at $p = 0.05$ determined by Student's *t*-tests.

The changes in soil organic carbon predicted over the next 20 year period are shown in Figure 3. Soil carbon storage for CF and EF was expected to increase by 120% relative to the present. NF sites with zero tillage are also expected to increase soil carbon by 110–120% of the levels found in CF and EF. In contrast, NF sites with tilling are expected to remain the same or lower over the next 20 years, suggesting that the input of organic matter is not enough for maintaining soil organic carbon.

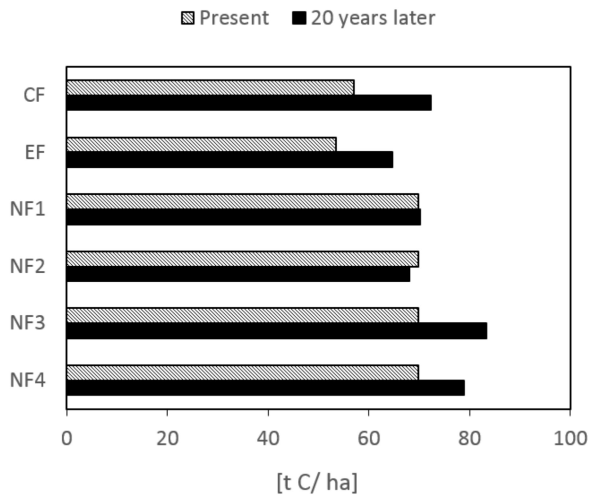

Figure 3. Predicted estimates of soil carbon accumulation in the next 20 years.

Net CO_2 equivalent emissions of each farming practice are listed in Table 3. The soil carbon sink for CF is the greatest among the treatments, at 2.81 t CO_2-eq/ha/yr. CO_2 emission per hectare for CF also was the highest, but because of the high carbon sink ability, net CO_2 emission per hectare became less than half of the CO_2 emission. The NF systems with no tillage had great carbon sink ability, and they also had very low CO_2 emissions. As a result, the carbon sink for NF with no tillage exceeded CO_2 emissions of other farming practices. The net CO_2 emission per hectare for CF was the greatest, but there was no significant difference compared with EF. The net CO_2 emissions per kg of product in CF and EF became lower than NF with tilling. The high carbon sink ability for NF with no tillage neutralized their CO_2 emissions.

Table 3. The comparisons of soil carbon sinks and CO_2 emissions among treatments. The negative quantities in net CO_2 emission means absorption of CO_2 equivalents.

	Soil Carbon Sink [t CO_2-eq/ha/yr]	CO_2 Emission [t CO_2-eq/ha/yr]	CO_2 Emission [kg CO_2-eq/kg of Product]	Net CO_2 Emission [t CO_2-eq/ha]	Net CO_2 Emission [kg CO_2-eq/kg of Product]
CF	**2.81**	**4.79**	0.06	**1.98**	0.02
EF	2.07	3.88	0.06	1.81	0.02
NF1	0.07	0.55	0.10	0.48	0.09
NF2	−0.33	0.52	0.06	0.85	**0.10**
NF3	2.46	0.59	0.10	−1.87	−0.30
NF4	1.69	0.59	**2.22**	−1.10	−3.94

The negative quantities in net CO_2 emission means absorption of CO_2 equivalents. The greatest numerical value in each category are shown in bold letters

4. Discussion

We assessed the potential soil carbon sink and levels of GHG emissions due to CF, EF, and nature farming. The CO_2 emissions and soil organic carbon accumulation rates were different for each farming practice.

There are two reasons why both CF and EF farms used almost the same amount of manure. First, when MAFF established the sustainable agriculture incentive program in 1999, they encouraged the use of manure along with chemical fertilizers in each prefectural cultivation guideline. Therefore, the application of manure became a common practice for farmers. For instance, 20 t/ha of manure and a total of 370 kg/ha of nitrogen, 280 kg/ha of P_2O_2, and 270 kg/ha of K_2O were recommended to use for eggplant cultivation in the vegetable cultivation guidelines in Ibaraki prefecture [22]. The interviews revealed that the CF farmers used less fertilizer than suggested in the guidelines, because the prices of chemical fertilizers (N, P, K) have doubled over the past 10 years. As chemical fertilizers contribute to 40% of the production costs, the increased cost of fertilizers had serious negative effects, such as a financial pressure on farming operation and difficulties in obtaining essential fertilizers. In fact, the use of chemical fertilizers in crop fields decreased by 30% compared with that 30 years ago [23]. The findings of this study showed that the EF system can maintain the same yields without relying on chemical fertilizers as long as appropriate amounts of organic matter are applied. According to the interviews, the EF farmers in this study have maintained the same level of crop yields for 5–7 years after shifting to EF practices. In addition, in an international comparison of the use of chemical fertilizers, 259 kg/ha of chemical fertilizer (the total of N, P, and K) was used in Japan, but only 131 kg/ha in the United States, and 199 kg/ha in Germany [23]. To prove the overuse of chemical fertilizers in Japan, the Ibaraki Agriculture Institute reported that it was possible to reduce the amount of chemical fertilizers recommended by the prefectural cultivation guideline by 20–40% without sacrificing yields on eggplant cultivation [24]. This suggests that it is still possible to use less chemical fertilizer in Japan. In addition, chemical fertilizers are the major source of N_2O emissions in crop fields [6]. Thus, less use of chemical fertilizers will contribute to reducing not only farming operation costs, but also N_2O emissions in the crop fields.

The cost of the chemicals in EF was approximately half of that in CF, which reflects the fact that EF required more than a 50% reduction of chemical use to meet the standards of the EFFDPP. Thus, the finding that there was no substantial difference in the crop yield between EF (5.7 t/ha) and CF (6.0 t/ha) is important because, according to a national agricultural survey in 2016, 36% of farmers were concerned that yield would be compromised by following the EF practice [7]. EF products have additional value for consumers and can be sold at a higher price than CF products. Thus, our results showed the additional potential benefits of EF compared with CF for farming operations.

The change of soil organic carbon for CF is expected to rise from 57.1 t-C/ ha to 72.4 t-C/ ha over the next 20 years. The potential for a soil carbon sink for EF was from 53.4 t-C/ ha to 64.7 t-C/ ha which is similar to that of CF. On the contrary, the NF system with tilling slightly decreased soil organic carbon from 69.8 t-C/ ha to 68.1 t-C/ ha in 20 years. The decomposition of organic matter may be faster with tilling. Therefore, the amount of manure appears to be the key component for storing soil organic carbon. Yokozawa et al. estimated the carbon sequestration potential from the RothC model and reported that 5.1–5.7 t/ha of organic matter was required for maintaining soil carbon in Andosol crop lands [25]. In addition, the analysis of soil organic carbon accumulation rates using the database of the national soil profile survey revealed that the treatment of a total of 15–40 t/ha of chemical fertilizer and manure kept soil organic carbon at levels similar to that at the beginning of the experiment 20 years ago [26]. However, the treatment of 50–80 t/ha chemical fertilizers and manure increased solid carbon accumulation by 5%. Since both the EF and CF farmers used more than 20 t/ha of cattle manure, it is understandable why soil organic carbon increased in both treatments. Andosol is known to decompose soil organic carbon faster than paddy soils and non-Andosol croplands. Thus, larger amounts of organic matter are required for maintaining soil organic carbon in Andosol fields. However, when we look at the fertilizer efficiency in cattle manure [27], as in the case of this study, 20–40 t/ha of cattle manure application means that 68–137 kg-N, 30–61 kg-P, and 57–114 kg-K were slowly released from cattle manure and were accumulated into soil over several years [28]. Katayama et al. reported that when cattle manure was over-applied, 80% of nitrogen leached from the soil to the surrounding environment [29]. The Ibaraki Agriculture Institute also recommended that 10 t/ha of cattle manure was ideal in the case of continuous manure use to avoid nutrient accumulation [30]. Recently, cattle manure application has been overused as a replacement for chemical fertilizers but it should be limited based on the soil type in each prefecture. The application of organic matter should also be combined with other sources of organic matter not to contaminate underground water, but to maintain soil organic carbon.

The effects of tilling in NF had low environmental impact as measured by CO_2 emissions. This is because the input of organic matter was roughly half of that used in CF and EF. Ten tons/ha of leaf mold was applied to the field experiment, but it was not enough for long-term maintenance of soil organic carbon. This suggests that regular input of organic matter is crucial for maintaining soil fertility. Concurrently with maintaining the soil carbon level, nitrogen inputs are also an important factor for crop productivity. We calculated the fertilizer response of organic fertilizer used in this study and found that about 14–20 kg of N were added as organic fertilizer during the cultivation period in CF and EF farms. On the other hand, nitrogen originating from the 400 kg of grass mulch was only 4.8 kg. To improve crop yield, at least three to four times the amount of green manure will be required to match commercial levels [31]. The timing of the application and the type of green manure also needs to be studied to increase crop yield. NF treatment with no tilling showed a high potential for storing soil organic carbon. The highest yield of the NF systems was one sixth of the CF yield. Although NF may not be economically feasible as a regular farming operation, organic farming products could sell at 20–30% higher prices than CF products [32] and the no-till system has advantages of less labor and greater carbon sequestration [33]. To maximize these advantages, we would suggest using a no-till system in a different way. By the year 2015, there were 423,000 ha of agricultural fields and paddies that had been abandoned in Japan [34]. If we could maintain half of these abandoned fields as no-till forage fields or local community gardens, this could generate 3.4 million t-C/ha/yr, with only minimum labor. This can match the target of MAFF to increase the area of organic fields. This no-tillage system could also contribute to a substantial increase in organic products and domestic feed.

The existing EIA methods, such as LCA and the RothC model, only consider carbon input. In this study, the carbon input and output in different farming practices were assessed using both methods. As a result, high carbon sink ability was observed in the NF with a no-tillage system. The soil carbon accumulation in the NF with no tilling exceeded the CO_2 emissions of other farming practices. This practice could have the potential to mitigate GHG emissions from agriculture. In particular for

Asian and African countries that have limited access to chemical fertilizers, the use of local plant residues could improve soil organic carbon storage and crop yields. This could be a good way for introducing novel climate-smart agricultural methods in these countries.

5. Conclusions

Japanese CF practices can store soil organic carbon at the same level as EF due to cattle manure application. Net CO_2 equivalent emission in CF was almost the same as that for EF, but EF practice is beneficial in terms of reduced farming operation costs and higher sales prices of products. A no-till system had very low environmental impact and, thus, a great potential to become a source for generating a carbon sink. However, further research is required to determine the best practices for combining these varied farming approaches for the EFFDPP.

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Author Contributions: Eri Matsuura designed this study and funded the project. Masakazu Komatsuzaki conducted the interviews to the farmers, and the calculation of LCA analysis and soil carbon stocks. Rahmatullah Hashimi carried out the field experiment.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Summary of interviews to CF farms.

	Farm 1		Farm 2		Farm 3	
crop sp. and variety	eggplant	kurobee	eggplant	kurobee	eggplant	kurobee
面積 (Farm area)		15a		10a		15a
Irrigation methods	rainfed		rainfed		rainfed	
1. Fertilizer Management	**Fertilizer Name**	**Amount (kg)**	**Fertilizer Name**	**Amount (kg)**	**Fertilizer Name**	**Amount (kg)**
Basal dressing	cattle manure	3000	cattle manure	4000	cattle manure	4500
manual or type of machinery	manure spray		manure spray		manure spray	
type of energy (L)	light oil	8		8		12
working hours (hours)		1.5		1		2
No. of man		2		2		2
NPK sources	sanchoku-club * (6-7-3)	160	sanchoku-club * (6-7-3)	120	sanchoku-club * (6-7-3)	100
Ca + Mg sources	sealime	80	sealime	40	sealime	100
	magnesium multi-phosphate				magnesium multi-phosphate	60
application method	manual		manual		manual	
type of energy (L)	na		na		na	
working hours		2		1		1.5
No. of man		2		2		2
Additional dressing						
Brand name and no. of application	sanchoku-club * (6-7-3)	50 kg×4	sanchoku-club * (6-7-3)	30 kg × 4	chemical fertilizer (18-4-12)	25 kg × 4
application method	manual		manual		manual	
type of energy	na		na		na	na
working hours	1 h × 5 times	5	0.5h × 4 times	2	1 h × 4 times	4
No. of man		1		2		2
A: Sum of labor (hours × man)		**12**		**8**		**15**

Table A1. *Cont.*

	Farm 1		Farm 2		Farm 3	
2. Pest Control						
application method	manual + chemical use		manual + chemical use		manual + chemical use	
list of pesticides						
アファーム (Afaamu)	150 mL × 2	300	na		na	
コテツフロアブル (Kotetsufuroaburu)	150 mL × 2	300	na		150 mL × 4	600
ピラニカ (piranika)	na		150 mL × 2	300	na	
モスピラン (mosupiran)	na		150 mL × 2	300	na	
chemical application						
application method	sprayer		sprayer		sprayer	
type of energy (L)	petrol	2.5	petrol	2	petrol	2.5
working hours (hours)	1.5 h × 4 times	6	1 h × 4 times	4	1.2 h × 4 times	4.8
No. of man		1		1		1
3. Weed control						
application method	machinery		machinery		machinery	
type of machinery	brushcutter		brushcutter		brushcutter	
type of energy (L)	petrol	2.5		1.5		2
working hours	1 h × 5 times	5	0.75 h × 4 times	3	1.5 h × 5 times	4
No. of man		1		1		1
4. Yield (kg/10a)	**6000**		**6200**		**5800**	
5. Use of plastic materials						
Length of plastic mulch (m)	20		12		18	750
B: Sum of labor (hours × man)		11		7		8.8
Total labor (A + B)		**23**		**15**		**23.8**

Note: The amounts of fertilizer shown in the table are the amount that applied into actial farm size; *: organic fertilizer (N-P-K%).

Table A2. Summary of interviews to to EF farmers.

	Farm A		Farm B		Farm C	
crop sp and variety	eggplant	senryo	eggplant	kurobee	eggplant	senryo
面積 (Farm area)		7a		8a		10a
Irrigation methods	rainfed		rainfed		rainfed	
1. Fertilizer Management	**Fertilizer Name**	**Amount (kg)**	**Fertilizer Name**	**Amount (kg)**	**Fertilizer Name**	**Amount (kg)**
Basal dressing	cattle manure	1500	cattle manure	1600	cattle manure	2000
manual or type of machinery	manure spray		manure spray		manure spray	
type of energy (L)	light oil	4	light oil	8	light oil	8
working hours(hours)		0.5		1		1
No. of man		1		1		1
NPK sources	Super IBS222 [#] (12-12-12)	60	Kani no megumi * (8-6-6)	100	Agret 666 * (6-6-6)	160
Ca + Mg sources	magnesium multi-phosphate	60	magnesium multi-phosphate	60	magnesia lime powder	70
	sealime	60				
application method	manual		manual		manual	
type of energy (L)	na		na		na	
working hours		2		1.5		2.5
No. of man		1		1		1
Additional dressing						
Brand name and no. of application	NK17 [#] (17-0-16)	20 kg × 4	Kaburayuki * (5-7-11)	15 kg × 8	Kaburayuki * (5-7-11)	8 kg × 10
	living mulch	71 [†]	living mulch	89 [†]	living mulch	93 [†]
application method	manual		manual		manual	
type of energy (L)	na		na		na	
working hours(hours)	1 h × 4 times	5	0.75 h × 8 times	6	1 h × 10 times	5
No. of man		1		1		1
A: Sum of labor (hours × man)		7		7.5		7.5

Table A2. *Cont.*

	Farm A		Farm B		Farm C	
2. Pest Control						
application method	manual + chemical use		manual		manual	
list of pesticides						
アファーム (Afaamu)	150 mL × 1	150	na		na	
chemical application						
application method	sprayer		manual		manual	
type of energy (L)	petrol	1.25	na		na	
working hours (hours)	1 h × 5 times	5	1 h × 8 times	8	1.5 h × 7 times	10.5
No. of man		1		1	1	1
3. Weed control						
Type of living mulch	barley	3 kg	barley	4 kg	wheat	6 kg
control method	machinery		machinery		machinery	
type of machinery	brushcutter		brushcutter		brushcutter	
type of energy (L)	petrol	1.5	petrol	2	petrol	2
working hours	1 h × 3 times	3	1 h × 4 times	4	1.5 h × 2 times	3
No. of man		1		1		1
4. Yield (kg/10a)	6000		5500		5700	
5. Use of plastic materials						
Length of plastic mulch (m)	10		12		15	
B: Sum of labor (hours × man)		8		12		13.5
Total labor (A + B)		**15**		**19.5**		**21**

*: organic fertilizer (N-P-K%), #: slow-release chemical fertilizer, †: dried biomass weight. Living mulch was cut by a brushcutter in mid June and left in furrows. The amounts of fertilizer shown in the table are the amount that applied into actial farm size.

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