

Estimating soil organic carbon sequestration change with applying modified Rothamsted Carbon model to paddy and upland fields in Japan

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Abstract

Sustainability of the soil organic carbon (SOC) sequestration of farms producing the cereals which are raw materials of the biomass ethanol is an important issue. We estimated SOC sequestration change of a paddy field soil (Anthrosols) and an upland field soil (Andosols) in Japan with applying the modified RothC models, and suggested appropriate farming management for sustainable agriculture on the basis of SOC sequestration. In the paddy field experimental plots, at forage rice of Tachisugata plots, compost application of 0.5 - 1.2 Mg ha⁻¹ each year was required to maintain SOC content. In contrast, only plant residues in forage rice of Leaf star plots were sufficient to maintain SOC sequestration. In the upland field experimental plots, considering from the prediction, 2 Mg ha⁻¹ compost applications each year at the tillage and chemical fertilizer application plot is sufficient for maintain SOC content. Furthermore, plant residue was vital source of organic matter for chemical fertilizer plot, and SOC content would decrease 14.0 Mg-C ha⁻¹ from 2007 to 2030 if plant residue is carried out from the field. SOC sequestration under diverse assumed management conditions in Japanese fields is predicted. The modeling tool of RothC would be useful to field management for sustainable agriculture, so it is necessary to consider about the field management with using these modeling tools.

Keywords: *carbon sequestration, soil organic matter, RothC, farming management, paddy field, upland field*

1. Introduction

One of the renewable energy resources is biomass, and biomass ethanol is made from cereals such as corn, sugar cane, or rice at farmlands. So, the sustainability of the farmland is important. "Sustainability" is a critical issue for agriculture in recent years, and satisfying the requirement, environmentally-friendly agriculture is demanded in addition to stable crop production. One of the environmental concerns associated with agricultural activities is the emission of greenhouse gas from fields. The greenhouse gas will discharge when soil organic carbon (SOC) in fields is decomposed and unfavorable farming management would promote that. To prevent the SOC from decomposition, and simultaneously, to enrich the amount of sequestration of SOC in fields, adequate management as reduced tillage, compost application and/or covering fields by plants have been significantly effective.

A variety of models for assessing SOC dynamics varied by organic matter input and its decomposition have been developed around the world. Soil organic matter is considered as a mass of organic matter with different decomposition rates. Jenkinson and Rayner suggested that organic matter can be compartmented into inert organic matter (IOM) and active organic matter; decomposable plant material (DPM), resistant plant material (RPM), microbial biomass (BIO) and humified organic matter (HUM) [1].

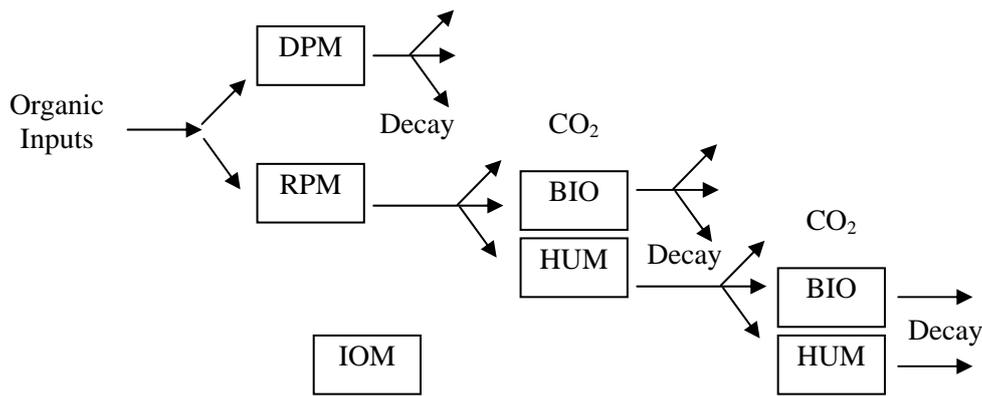


Fig. 1 Structure of Rothamsted carbon model

Each compartment decomposes with its particular decomposition rate. Based on this concept, Rothamsted carbon model (RothC model) which is one of the most popular SOC turnover models was developed [2].

RothC model have been widely utilized in Europe and in the United States, but this model was not sufficiently applicable to Japanese fields. Modifications of RothC model have been performed in recent year for a better application to Japanese characteristic fields [3, 4, 5]. Paddy field soils and Andosols which are major field soils in Japan have slow organic matter decomposition rates. The main reason for this is that and reductive environment during cultivation season and abundance of active aluminum holding organic matter strongly, respectively. The modified RothC model for paddy field was set the decomposition rate with 0.2-fold in irrigated season and 0.6-fold in other season compared with the original model. For Andosols, a factor $H(f)$ was newly incorporated. The decomposition rate of HUM compartment was calculated by dividing original one by the $H(f)$ and the $H(f)$ was provided by equation related to pyrophosphate extractable aluminum (Al_p); $H(f) = 1.20 + 2.50 \times Al_p$ (%).

This study was carried out at a paddy and an upland field in Japan and its characteristics affecting the turnover of SOC was determined. The data were interpreted with the modified RothC models and we suggested appropriate farming management for sustainable agriculture on the basis of organic carbon sequestration.

2. Materials and methods

2.1 Fields explanation

The paddy field and upland field in Tokyo University of Agriculture and Technology were utilized for this study. The paddy field is located at 35°40'N, 139°28'E and in the alluvial plain of the Tama River. The farming management experiment with different rice cultivar, planting density and/or fertilizer application has started since 2008. Compost of 28 Mg ha⁻¹ was equally applied to all the plots. The upland field is located at 35°41'N and 139°29'E and the soil is derived from volcanic ash. The field has been managed as a long-term experimental field since 1993. The field had experimental plots with different tillage and/or fertilization and has been grown forage corn or soybean in summer and wheat or ryegrass in winter. Soil samples were taken in May 2008 at the paddy field and in August 2007 at the upland field. The main soil characteristics of the fields are shown at Table 1.

Table 1 Soil characteristics of study fields

Field utilization	Soil classification	Cultivated crops	Soil organic carbon (g kg ⁻¹)	Total nitrogen (g kg ⁻¹)	Bulk density (Mg m ⁻³)	Clay content (kg kg ⁻¹)	Al _p (kg kg ⁻¹)
Paddy field	Fluvic Hydragric Anthrosols	forage rice	53.4	4.8	0.64	0.342	n.d.
Upland field	Melanic Silandic Eutrosilic Andosol	soybean	88.5	6.0	0.68	0.356	0.0067

Soil classification was based on IUSS Working Group WRB [6]. Cultivated crops were at the starting time of this study. At the paddy field, soil was sampled from Tachisugata dense planting and conventional fertilization plot. Tillage and chemical fertilizer plot at the upland field were collected. Both soils were analyzed for other characteristics. Bulk density of the soil taken from the paddy field was determined using soil sample after harvest. Al_p represents pyrophosphate extractable aluminum. The n.d. means not detected.

2.2 Parameters for RothC model

A set of parameters are required to estimate the SOC turnover by RothC model. The amount of carbon input from plant residue and compost is given in Table 2. The carbon originated from plant residue was calculated by its weight and carbon content. Soil covering was defined as vegetated during cultivation season and bare during other season. The data of monthly rainfall and monthly air temperature were referred from published database of Japan Meteorological Agency [6]. At the paddy field, estimation was carried out based on that the management in 2008 would be continued in future. On the other hand, at the upland field, measured data was used in 2007 and 2008 and data standing on the cultivated crops in 2009 was used for future estimation.

Table 2 Carbon input from plant residue and compost into each management plot in paddy field and upland field

Field	Term	Cultivated crop	Farming management	Carbon input	
				Plant residue (Mg-C ha ⁻¹)	Compost
Paddy field	2008-2042	forage rice (Tachisugata)	conventional planting density conventional fertilization	1.85	4.30
			dense planting conventional fertilization	1.76	4.30
			dense planting adapted fertilization	1.87	4.30
		forage rice (Leaf star)	conventional planting density conventional fertilization	2.30	4.30
			dense planting conventional fertilization	3.78	4.30
			dense planting adapted fertilization	2.82	4.30
			conventional planting density no fertilization	1.90	4.30
Upland field	2007 (from August to December)	soybean and ryegrass	tillage compost application	3.61	0.00
			reduced tillage compost application	3.26	0.00
			tillage chemical fertilizer application	1.65	0.00
			reduced tillage chemical fertilizer application	2.37	0.00
	2008	ryegrass, soybean and wheat	tillage compost application	4.63	5.38
			reduced tillage compost application	4.19	5.38
			tillage chemical fertilizer application	2.31	0.00
			reduced tillage chemical fertilizer application	3.22	0.00
			tillage compost application	4.44	5.38
	2009-2030	wheat and soybean	reduced tillage compost application	3.82	5.38
			tillage chemical fertilizer application	2.69	0.00
			reduced tillage chemical fertilizer application	3.29	0.00
tillage compost application			4.44	5.38	

The rotation crops in upland field were changeable and the three types of carbon input were estimated on the bases of cultivated crop.

3. Results and discussion

3.1. Application of modified RothC model to paddy and upland fields in Japan

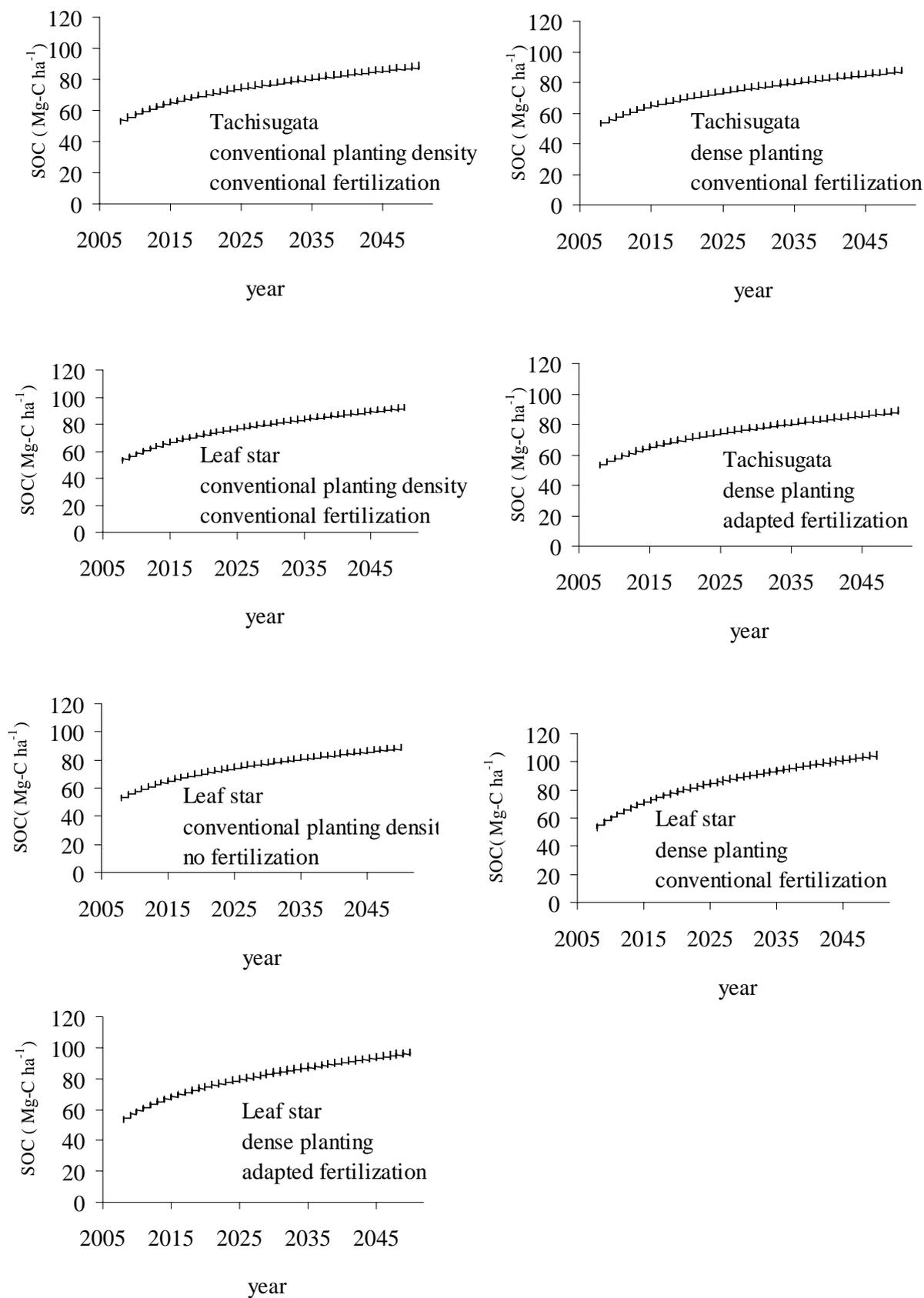


Fig. 2 Estimation of soil organic carbon sequestration in the paddy field

Figure 2 shows the estimation of SOC sequestration in the paddy field. SOC was calculated to gain at all plots in the paddy field. The differences of estimated SOC between the plots were only influenced by input of plant residues due to equal compost application. The forage rice production of Leaf star of dense planting plots was highest among the plots, and that caused much plant residue. That induced the highest prospect of SOC.

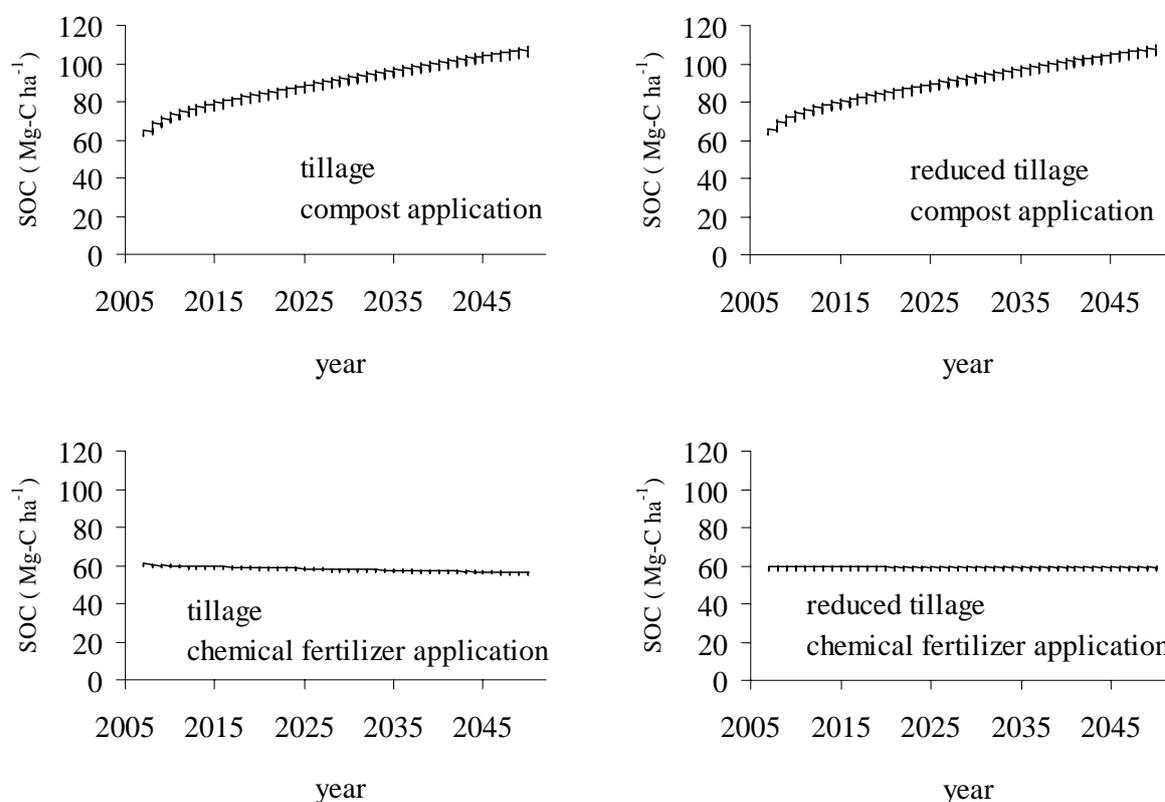


Fig. 3 Estimation of soil organic carbon sequestration in the upland field

Figure 3 shows the estimation of SOC sequestration in the upland field. Predicting from the modified RothC model, SOC content at compost application plots increased 41.6 - 42.0 Mg-C ha⁻¹ by 2050. In contrast, SOC content at chemical fertilizer application plots reduced 0.87 - 5.17 Mg-C ha⁻¹ by 2050. The average content of SOC at compost plots was 3.7 Mg-C ha⁻¹ larger than at chemical fertilizer plots in 2007 and the differences among them got greater at 48.6 Mg-C ha⁻¹. Compost application can enrich carbon contents in soils as reported in previous study [8].

Those predictions indicate compost application at the upland field is effective to preserve SOC for long term.

3.2 Fields management for environment conservation

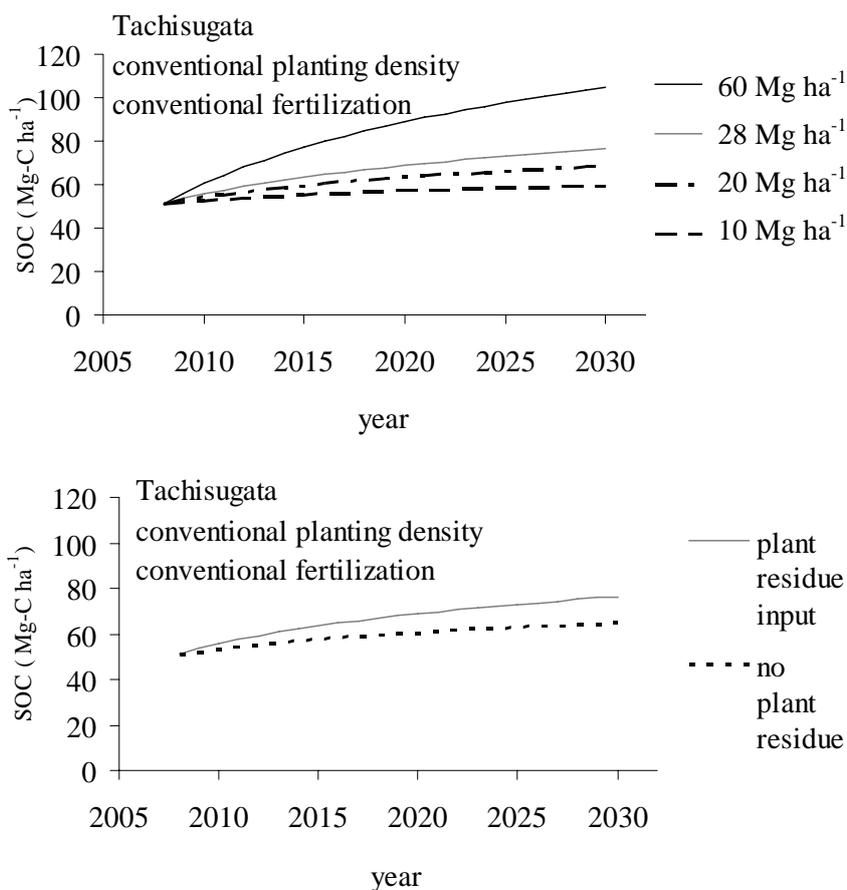


Fig. 4 Estimation of soil organic carbon sequestration at variable assumed management in the paddy field

Figure 4 illustrates SOC turnover of the some presumed management in the paddy field. Average value of SOC content of paddy field of Gray Lowland soil between 1999 and 2003 in Japan is $22.8 \text{ Mg} \cdot \text{kg}^{-1}$ [9], so the SOC sequestration in this experimental plot was already so high. At Tachisugata plots in the paddy field, compost management of $0.5 - 1.2 \text{ Mg ha}^{-1}$ each year was required to maintain this high SOC content. In contrast to that, only plant residues in Leaf star plots were sufficient. On the other hand, even though plant residue input didn't occur, SOC was predicted to be maintained with the current compost application.

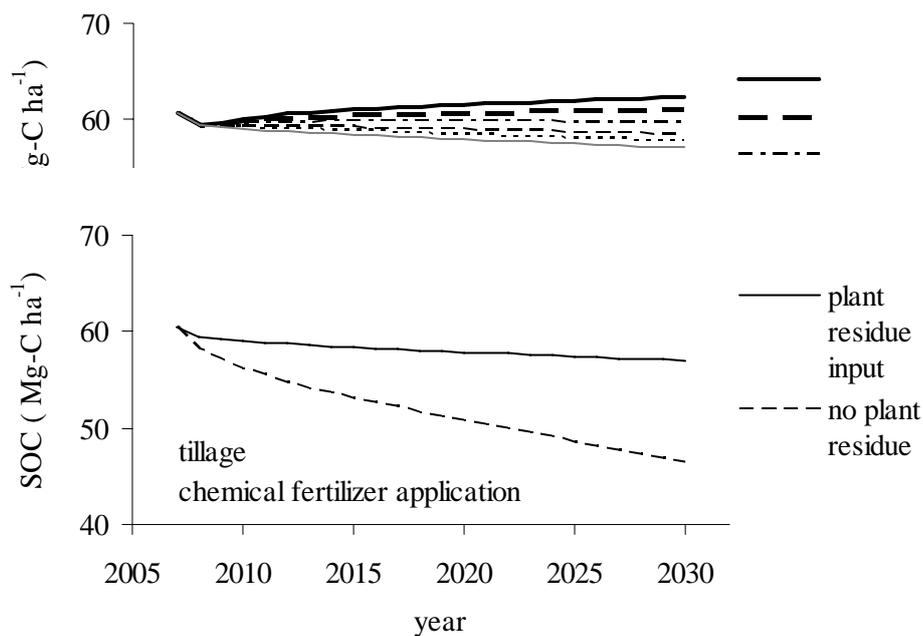


Fig. 5 Estimation of soil organic carbon sequestration at variable assumed management in the upland field

Figure 5 illustrates SOC turnover of the some presumed management in the upland field. Average value of SOC content of upland field of Andosols between 1999 and 2003 in Japan is 51.0 Mg-kg^{-1} [9], so the SOC sequestration in this experimental plot was already high. Considering from the prediction, 2 Mg ha^{-1} compost applications each year at the tillage and chemical fertilizer application plot in the upland field is sufficient for maintain high SOC content. Furthermore, plant residue was vital source of organic matter for chemical fertilizer plot, and SOC content would decrease $14.0 \text{ Mg-C ha}^{-1}$ from 2007 to 2030 if plant residue is carried out from the field.

As noted above, SOC sequestration under diverse assumed management conditions in Japanese fields is predicted by using the modified RothC models. The modeling tool would be useful to field management for sustainable agriculture, so it is necessary to consider about the field management with using these modeling tools.

Acknowledgements

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