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Research Paper

A Case Study of Organic Rice Production System and Soil Carbon Storage in West Java, Indonesia

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インドネシア ジャワ島西部における有機水稲栽培での農作業システムと土壌炭素に関する調査事例

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1. Introduction

With a population of 216 million, Indonesia is the world's fourth most populous country, and its population is growing at a rate of 1.7% per year. Agriculture plays a substantial role in the Indonesian economy, involving more than 55% of the population, and accounting for 19% of the gross domestic product and more than 60% of the value of non-oil exports. Over the last two decades, annual agricultural output has grown by 4% (Pertiwi, 2006). In Indonesia, modern farming technologies have kept production apace with population growth, but major problems with food distribution still plague many communities and regions (Syuaib, 2006).

However, increasing synthetic chemical input to cropland to meet the increasing demand for food has led to decreasing biodiversity in agricultural areas (Millennium Ecosystem Assessment, 2005). The soil management system, which is overly dependent on chemical fertilizers, has also led to decreasing soil organic matter and degrading soil quality (Komatsuzaki and Ohta, 2007).

After the "Green Revolution" program was launched in the late 60's, the application of chemical fertilizer was dramatically increased due to governmental encouragement to achieve food self-sufficiency. In the subsequent decades since then, farmers have been using chemical fertilizer with the recommended composition in conventional farming. Fertilizer consumption in the agricultural sector increased 5-fold between 1975 and 1990 and increased slightly afterwards. However, as a result of the Asian economic crisis, in 1998 the government reduced the subsidies for fertilizers, resulting in increasing cost of agricultural inputs. Since that time, farmers have been reducing the use of chemical fertilizers and have started to utilize more organic fertilizer and improve the methods for its application (Syuaib, 2006).

Public awareness of what "organic agriculture" means and consumer demand for organic products are currently very low in Indonesia,

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where the benefits of organic farming are understood by only a few who are concerned about food safety for their health. Through the efforts of NGOs and the government of Indonesia, however, the interest in organic farming is just emerged (Hsieh, 2005). Organic farming provides a lot of benefits to the farming system in Indonesia, because it can improve soil and food quality, and increase the soil organic carbon (SOC) storage in the soil.

For global environmental conservation, this soil management strategy has great potential to contribute to carbon sequestration, because the carbon sink capacity of the world's agricultural and degraded soil is 50 to 66% of the historic carbon loss of 42 to 72 petagrams (1 Pg $=10^{15}$ g), although actual carbon storage in cultivated soil may be smaller if climate change leads to increasing mineralization (Lal, 2004). The importance of SOC in agricultural soil is, however, not controversial because SOC helps to sustain soil fertility and conserve soil and water quality, and these compounds play a variety of roles in the nutrient, water, and biological cycles.

Organic farming also has great potential to improve soil carbon storage (Pimentel *et al.*, 2005 ; Mariott and Wander, 2006). However, only a few studies have been conducted in Indonesia, and there are few data for comparing soil carbon storage between organic farming and conventional farming. In addition, the organic farming system and associated farm work had not been studied in Indonesia. Therefore, this research was designed to evaluate the ability of soil carbon storage and make comparisons between the conventional farming system and organic farming system for rice production on the island of Java.

2. Materials and Methods

1) Study Area

The study area was the city of Bogor, located in the Cisadane watershed, West Java, Indonesia. The Cisadane River flows through urban areas from Bogor to Jakarta, the capital of Indonesia, and is a major rice and vegetable production area. Soil type is Lotosole. Organic and conventional rice farmer groups for the study were selected from the Situgede district of Bogor.

2) Field Investigations

Field investigations were conducted in March and September of 2008 and details of farming practices and the amount of chemical or organic fertilizer application were obtained from interviews with conventional and organic rice farmers. For organic rice production, farmers use a self-produced organic fertilizer called "*bochashi*", which is composed of 10% rice bran, 20% rice chaff, and 70% cow manure (in volume). Nutrient values of this organic fertilizer are 28.29% for carbon, 0.35% for nitrogen, 0.17% for phosphorus, 2.31% for potassium, 1.87% for calcium, and 0.42% for magnesium (in dry base). Based on the interview data, the cost for farming and amount of labor required for farming were calculated. The prices of materials were also obtained through interviews with merchants.

3) Soil and Crop Yield Analysis

Topsoil samples (from a depth of 0 to 10 cm) were taken from 3 conventional and 3 organic rice fields in September 2008. Soil samples were taken from 3 points in each field and were mixed before analysis. Both fields of organic and conventional rice production were located in the same area. Organic fields were converted to organic farming from conventional farming after August 2003, and we examined the 13th rice crop grown after the switch to organic management. Conventional fields continued to be fertilized with chemical input with no organic fertilizer.

Triplicate air-dried <2 mm particle size samples were analyzed according to standard methods. Organic carbon content was analyzed by the Walkley-Black Procedure (Nelson and Sommers,

1982) and soil organic carbon storage (SCS) was calculated as following.

$$SCS(Mg\ ha^{-1}) = BD \times SC \times DP \times 100$$

where,

BD : bulk density ($g\ ml^{-1}$)

SC : soil carbon content (%)

DP : soil depth (m)

Rice yields were also measured by a quadrate sampling in September 2008 in the 3 organic fields and 3 conventional fields.

3. Results and Discussion

Table 1 shows a comparison of the soil carbon content and carbon storage in the soil between organic and conventional farming. The soil in organic farming showed higher soil carbon content than conventional soils after 4 years of continuous organic farming ; however, there were no significant differences in soil bulk density between the two farming systems. Soil carbon storage in organic farming significantly increased compared with conventional farming.

Using this data, we can estimate that the ability of soil carbon sequestration. Organic farming can increase 1.85 Mg C ha^{-1} $year^{-1}$ in soil carbon storage compared with the conventional farming system. This value also agrees with the data that Shirato *et al.* (2005) obtained from paddy fields in Thailand. The rate of increase in SOC stock resulting from changes in land-use and adoption of recommended farming practices, follows a sigmoid curve that attains the maximum 5 to 20 years after adoption of recommended farming practices (Lal, 2004). In addition, the amount of organic carbon stored in paddy soils is greater than in dry field soils because of different biochemical processes and mechanisms specifically caused by the presence of floodwater in paddy soils (Katoh, 2003). These results show organic rice farming has a lot of potential to improve soil carbon sequestration in Indonesia.

Table 1 Comparison of soil carbon sequestration between organic and conventional rice fields in the top 10 cm soil depth

	Soil Bulk density $g\ ml^{-1}$	Carbon content %	Soil Carbon Storage $Mg\ ha^{-1}$
Organic	0.88	2.89	25.0
Conventional	0.80	2.22	17.6
Significance	NS	*	**

**,* and NS indicate significance at 1% and 5% level and not significance, respectively.

Figure 1 shows the costs for conventional and organic rice production. Organic farming helped to reduce the cost of rice production. For example, conventional farmers had to pay 1,410,000 Rp (rupiah) for chemical fertilizers, while organic farmers only had to pay 30,000 Rp for the *bochashi* organic fertilizer, with the result that organic farming could cut 90% of total cost of rice production.

According to the latest data, the cost of farming with chemical fertilizers is on average twice as expensive as the use of organic products, while production levels are the same (The Jakarta Post, 2 Mar, 2009). This indicates that the economic crisis helped to boost the growth of Indonesia's organic farming sector.

Figure 1 also compares the labor inputs and methods of conventional and organic rice farming systems. The organic farming system required more labor to apply the organic fertilizer and weeding. The amount of organic fertilizer applied was 2 Mg ha^{-1} for each rice growing season, which was 4 times greater than conventional farming due to the lack of appropriate technology for applying the organic fertilizer. Weeding in Indonesia is mainly done by hand, and while there are also traditional weeding tools called "landak" (Fig. 2), these tools still require a lot of manual labor. Total labor time for rice cultivation was 768 man hours ha^{-1} for the conventional system while it was almost twice as high, 1,406 man hours ha^{-1} for the organic system.

Table 2 shows the gross profit and wages per working hour between the organic and

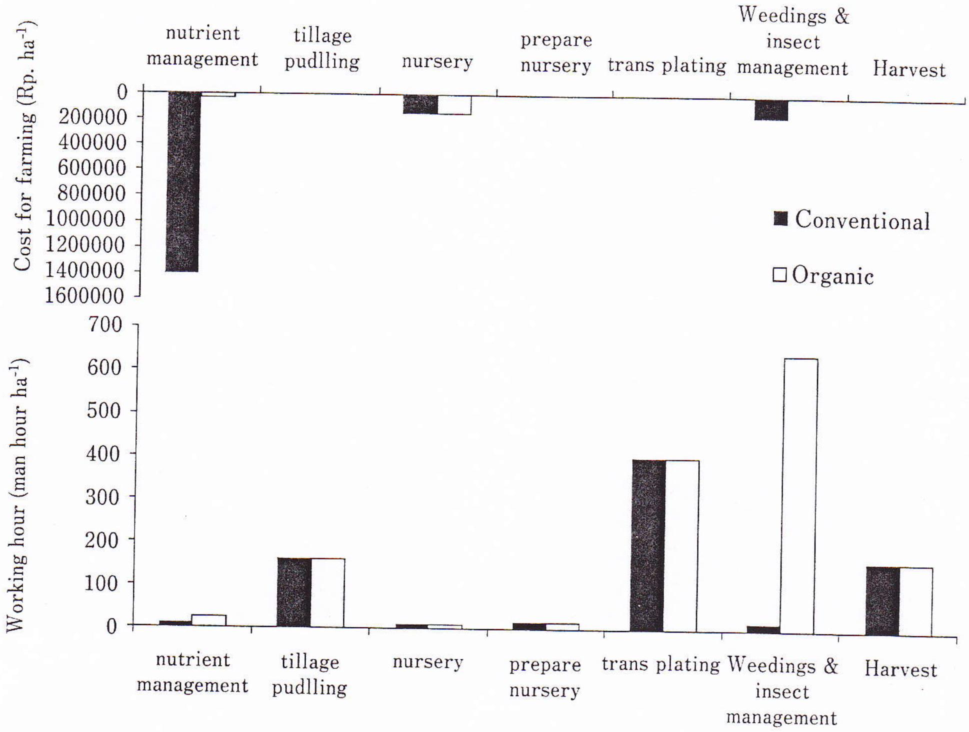

Fig. 1 Comparison of costs for farming and man-hours needed for each farming procedure between organic and conventional rice farming in West Java

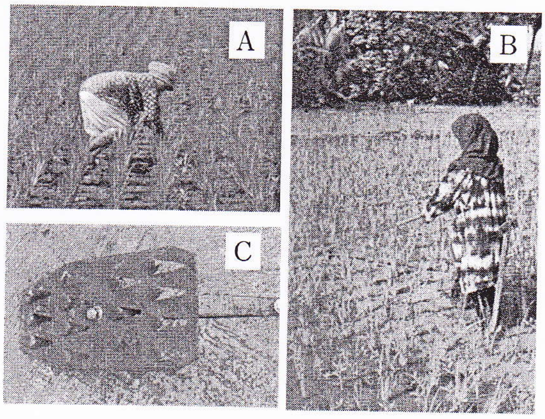

Fig. 2 Hand weeding is the most common method used to control weeds in paddy rice fields (A), but traditional weeding tools called *"landak"* are sometimes used in West Java (B and C)

Table 2 Comparison of gross benefit and hourly wages between organic and conventional farming system

Management	Yield[1] (without husk)	Price (Rp. kg^{-1})	Gross benefits (Rp. ha^{-1})	Hourly wages[2] (Rp.)
Organic	3.2 Mg	6,500	20,800,000	2,955
Conventional	4.1 Mg	5,500	22,550,000	5,872

1) Yields were obtained by quadrate sampling on September, 2008.
2) Hourly wages were calculated by take account of the cost share of total benefit to the landowner, manager and worker.

conventional farming systems. The yield of organic farming was lower than in the conventional farming, while the price of organic rice was 18% higher than conventionally-grown rice, resulting in almost the same gross profits from organic and conventional farming.

The wages per working hour in the organic system, however, were significantly lower, only about half those in the conventional system. The low labor productivity in organic farming is a major factor of limiting the expansion of this farming system in West Java.

According to the soil analysis, organic farming showed significantly higher SOC storage, so it may help not only to improve soil carbon storage, but also to establish a sustainable food production system in Indonesia. In Indonesia, organic farming for paddy rice cultivation also has a lot of potential to improve soil quality, reduce the cost of chemicals that have recently been increasing with the price of fossils fuels, and increase farmers' incomes due its higher price. However, organic farming requires intensive labor such as weeding and applying *bocashi* fertilizer to the fields.

The biggest difference was observed in the sharecropping system of organic farming in Indonesia compared with Japanese organic farmers. In the study area, profits from rice production were shared among the land owners, farmers (managers), and workers, but workers could receive only about 20% of the yield base of rice production. This suggests that by converting conventional farming to organic farming, land owners and farmers can increase their profits, while workers must work harder at organic farming but receive relatively little added benefit. Thus, while organic farming has a great potential to improve environmental quality, it also has problems regarding social justice in Indonesia.

As local environmental quality becomes increasingly degraded by agricultural practices, the importance of protecting and restoring soil resources is being recognized by the world community (Lal, 1998 ; Barford *et al.*, 2001 ; Lal, 2001). Sustainable management of soil received strong support at the Rio Summit in 1992 as well as at Agenda 21 (UNCED, 1992), the UN Framework Convention on Climate Change (UNFCCC, 1992), in articles 3.3 and 3.4 of the Kyoto Protocol (UNFCCC, 1998), and elsewhere. These conventions are indicative of the recognition by the world community of the strong linkages between soil degradation and desertification on the one hand and loss of biodiversity, threats to food security, increases in poverty and risks of accelerated greenhouse effects and climate change on the other. This situation suggests that a global support network system is needed to conserve the local environment such as Indonesia's organic farmlands. Therefore, new farming system research and farm machine development will be needed to establish a sustainable and fair organic farming system in Indonesia. Special emphasis must be placed on developing tools and machinery for weeding and applying organic fertilizer to establish sustainable agriculture in terms of both the local and global environmental levels. Based on these social and ecological situations and understanding, appropriate technology should be developed to conserve the ecological environments in the tropics.

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Summary

Organic farming provides a lot of benefits in Indonesia, because it can improve soil quality, food quality and soil carbon sequestration. This research was designed to evaluate the ability of soil carbon storage by making comparisons between conventional and organic farming systems for rice production in West Java, Indonesia. The results from soil analysis indicated that organic farming had significantly higher soil carbon storage capacity than conventional farming. Organic farming can also cut some costs for farming, but it requires about twice as much labor. The sharecropping system of rice farming in Indonesia is highly exploitative of workers ; therefore, research should be conducted to develop a

fairer organic farming system that can enhance both local and global sustainability.

Key Words

organic farming, rice farming system, soil carbon sequestration, weeding tools, working time, appropriate technology

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要　旨

ジャワ島における米生産については人力及び畜力を主体とした生産システムが基本であるが，近年，石油価格の高騰の影響を受け肥料価格が上昇し，農家が自給できるボカシ肥料を利用した有機農業が広がりつつある．本報告では，ジャワ島における有機農業の作業体系と土壌炭素貯留量の変化について検討した．

土壌調査によれば，慣行栽培の土壌炭素の含有率が 2.31% に対して，有機農業を継続して 4 年目の圃場では，3.24% に増加し，土壌有機物の集積が図られていることが示された．土壌中の炭素は腐植などの形で土壌に封じ込められることから，農耕地の炭素含有量の増加は温室効果ガスである二酸化炭素を農耕地に封じ込める炭素隔離機能も注目される．インドネシアにおいても有機農業を推進していく中で土壌炭素の貯留量増加は温暖化抑制の視点からも注目される可能性が高い．

キーワード

有機栽培，水稲作業体系，土壌炭素貯留，作業時間，適応技術