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Soil Organic Carbon, Labile Carbon and Organic Carbon Storage under Organic and Conventional Systems of Chinese Cabbage in Baturiti, Bali Indonesia

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Abstract

Soil organic carbon storage (SOCS) is one of indicator for soil quality. It requires several years to be able to detect the SOCS and the impact on crop yields. A research was conducted to study soil organic carbon (SOC), labile carbon (SLC), SOCS and the yields of Chinese cabbage (*Brassica chinensis* L.) under organic and conventional farming systems. The location was at the area of vegetable farming in Baturiti village, Tabanan regency, Bali province, Indonesia, between 08^{0}32'93"SL and 115017'64"EL, 975 m above sea level. Soil samples were taken from the land of organic system after one, three and five years of application, and from the conventional system accordingly in the neighboring area. Variables of SOC, SLC, SOCS, total nitrogen, soil respiration and bulk density were measured. The yields of Chinese cabbage were obtained from the last five years of farmer records. Results of this study indicated that SOC, SLC, SOCS, total nitrogen and soil respiration, but not soil bulk density, were significantly ($P<0.05$) higher under organic than under its conventional counterpart after five years application of organic system. The SOCS increased 3.37 Mg C ha^{-1} annualy under organic compared to that under conventional system. The SOC, SLC and soil microbial respiration significantly 68.6%, 49.01% and 38.5% higher respectively under organic farming system after five years, but soil nitrogen did not increase. The organic system was highly correlated (r= 0.836**, r=0.846**) with levels of SOC and SLC respectively. During the first three years the yield of Chinese cabbage was lower under organic but after five years the yields (25.78 t ha^{-1}) was not significantly different from that in conventional system. This explains that significant yield increases in organic farming system could only be expected after five years of application.

Keywords: Soil organic carbon, soil organic carbon storage, labile carbon, organic farming system, conventional farming system, Chinese cabbage (*Brassica chinensis* L.).

1. Introduction

Climate change as an implication of global warming due to the effect of increasing concentration of glasshouse gas in the atmosphere has been an important issue during the last decades. Agriculture plays important roles in the mitigation of the climate change by minimizing the emission of glasshouse gas to the atmosphere through increasing organic carbon storage in the soil and in the plants. The capacity of the world'agricultural and degraded soils to sequestrate the carbon loss of 42-78 Pg is about 50-66% (Lal, 2004). The rate of soil organic carbon sequestration depends on soil texture and structure, rainfall, temperature, farming system, and soil management.

Most vegetable farmers have been practicing conventional farming system to increase crop production instantly. In the system, farmers manage their lands with high cultivation intensity, use high rates of chemical fertilizers and pesticides, irrigate the crops intensively or leave the soil surface open and receives rainfall strokes. This activities enhance the degradation of soil structure, decrease soil fertility, lost of fertilizers and other chemical elements due to erosion and leaching (Reijntjes *et al*, 1999; Shukla *et al.* 2004; Liu, *et al.* 2006), water pollution and decreases soil biodiversity (Reganol *et al.,* 1993). In the long term the impact could reduce the soil quality and productivity due to soil degradation. The reduction of upland vegetable yields resulted from intensif soil cultivation in West java, Indonesia was reported by Kurnia *et al*.(2002). The production of potatoes, cabbages and carrots decreased from 16.6 t ha^{-1}, 22.1 t ha^{-1}, 15.9 t ha^{-1} in 1998, to 14.9 t ha^{-1}, 20.9 t ha^{-1} and 15.5 t ha^{-1} respectively in the year of 2002. This condition could threat the sustainability of the agricultural system if the soil is not managed properly.

Organic farming system offers several opportunities for mitigating the negative impact of conventional system and consequently results in supporting sustainable agriculture. The organic system applied organic inputs (viz. agricultural and livestock wastes) to increase soil fertility and without using chemical pesticides. Hsieh, 2005; Komatsuzaki & Syuaib, 2010) stated many benefits of this organic system to agriculture due to increase soil and finally food qualities through increases in organic carbon in the soil (SOC). Marriot & Wander (2006) found that SOC concentrations of surface soils increased by 14% after using organic farming practices compared to conventional counterparts. The SOC is reactive and able to control several important functions that influence the physical quality and productivity of the soil (Komatsuzaki and Ohta, 2007; Blair *et al*., 1995), maintaining soil fertility and function in biological cycles, water and nutrients (Bronson *et al.*, 1997). The application of organic manures is important in maintaining SOC, therefore should be advocated in the nutrient management of intensive cropping system for sustainable crop production and soil quality (Moharana *et al*., 2012).

Distric of Baturiti, Tabanan regency has been as a center for upland vegetable production in Bali province of Indonesia. This area produces 43,673 ton of vegetables in year of 2011 or around 35.8% of total vegetable production in Bali (Balai Pusat Statistik, 2012). Initial survey indicated that most entirely those vegetables produced intensively in conventional farming system, in which high rates of chemical fertilizers and pesticides were used but on the other hand less organic fertilizer was applied. The conventional method has been practiced since the first time of horticultural crops was cultivated in the area in 1980s. Chinese cabbage (*Brassica chinensis* L.) is one of vegetable crops most-produced in the area with the production of 29-32 ton ha^{-1} (pers comm.). Rising in consumer's awareness to the importance of chemical residual free in vegetables consequently increases the demand for the crop and the price of the commodity. Several farmers begin to apply organic fertilizers and bio pesticides to reduce negative impacts of chemical fertilizer and pesticides. Since the last nine years several farmers have been practicing organic system and finally received organic certificate from the authority in 2011. However, there are numbers of farmers still practicing conventional system.

Research on increasing productivity and soil quality protection in organic farming has been a focus of attention since several decades (Ikemura & Shukla, 2009). Evaluation on SOC under organic and conventional farming systems is one of important approaches to understand the effect of farming system on SOCS and changes in soil quality (Sanchez-Maranon *et al*., 2002; Shukla *et al*., 2004). Soil organic carbon is a key indicator of soil quality and sustainability of agriculture. According to Blair *et al*. (1995), organic carbon dynamics could be indicated in the form of total SOC and labile SOC. Additionally, dynamis of soil organic carbon due to soil cultivation mainly appears on labile carbon that has important roles in providing nutrients for crops. In fact labile SOC, not total SOC, mainly controls soil respiration (Wang *et al*., 2013).

Long term research on the effect of organic farming system on SOC, labile carbon (SLC), SOCS and soil quality have been conducted in a number of countries (Fließbach *et al.*, 2007). However, similar research particularly on SOCS under organic and conventional vegetable farming systems during different time of system application have not been done in Indonesia, particularly in Bali. Therefore a study on those components of soil quality and their influence on Chinese cabbage production under the two farming systems during five years of organic system application needs to be conducted.

2. Materials and Method

The research was conducted at the area of vegetable farming in Baturiti village, Tabanan Regency, Bali Province, Indonesia, located between $08^0$32'93"SA and 115017'64", 975 m above sea level. The average daily maximum and minimum temperatures during September were 31^0C and 21^0C respectively. The average annual rainfall was 3165.11 mm. Soils at this site are Typic Tropudan, coarse-loamy, mixed, isohyperthermic (USDA soils taxonomy), equivalent respectively, to Andosol in FAO soil classification. Geografic location is presented in Figure 1.

The field study was conducted in March 2012 by interviewing 20 farmers who practicing organic (received organic certificate from the authority in 2011) and conventional systems respectively on their Chinese cabbage crops. Besides those interviews, samples of soil under both farming systems were taken to study the SOC, SLC, SOCS, soil N, soil bulk density and soil microbial respiration.

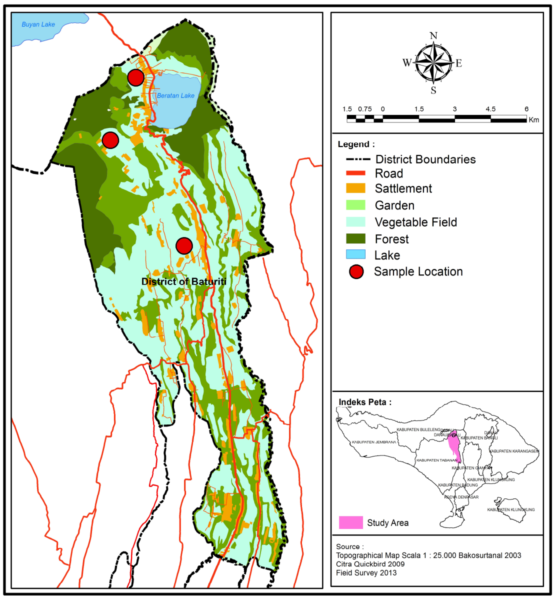


Figure 1. Geografic location of the area of vegetable farming in Baturiti district, Tabanan Regency, Bali Province, Indonesia

2.1 Yield data

Chinese cabbage yield data were obtained from interviewing 20 conventional and organic farmers respectively and their yield records for five years (2009-2012). Besides yield data, the kind of fertilizers they used, the source of the organic fertilizers were also asked. The conventional farmers usually apply 84 kg N ha^{-1}, 72 kg P ha^{-1} and 30 kg K ha^{-1} for their crops, while the organic farmers apply 40 t ha^{-1} of self-produced composted cattle manures which contains 17.36% C, 1.16% N, 0.53% P and 0.14% K

2.2 Soil data

Soil sampels were taken from the land of organic system at one, three and five years application, and from the land of conventional system accordingly in the neighboring area. A core sampler of 35.8 cm diameter was used to take the soil samples for bulk density measurement. An auger was used to take samples from 0-20 cm soil depths. The soil samples were mixed and then analyzed in the Soil Laboratory of Lembang Vegetable Research Institution (2012) and in the Soil Laboratory of Faculty of Agriculture, Udayana University, Denpasar, Bali, Indonesia (2012) to measure soil organic carbon, labile carbon, total nitrogen and soil respiration. Sample of top soils at different depths of 0-10 cm, 10-20 cm and 20-30 cm were taken from the two farming systems using a post hole auger at harvest time of the crop (May 2012) to calculate distribution of SOCS.

2.3.Analysis of samples

The analysis of soil characteristics were conducted using the standard procedure of soil analysis in the laboratory.

2.3.1 Soil bulk density, soil organic carbon and nitrogen

The method of potentiometry, Walkley and Black Method and Macro Kejldal (Sulaeman *et al*., 2005) were used to measure soil bulk density, soil organic carbon and nitrogen respectively. The method of soil organic carbon oxidization with 333 mM $KMnO_4$ (Blair *et al*., 1995) was used to analyze the labile carbon. The unlabile carbon will not oxidized by the solution. The total soil respiration was measured using the method of Isemeyer (Alef & Nannipieri, 1995). As much as 50 g of soil samples (at field capacity), 25 ml of 0.05 M NaOH and 5 ml of water were incubated in a separate air free plastic containers. CO_2 produced from the respiration process of soil microbes will be bound with NaOH solution and then it was titrated with 0.05 M HCL solution. Soil microbial respiration was recorded in mg C kg^{-1}.

2.3.2 Soil organic carbon storage

The soil organic carbon storage was calculated using the equation (Komatsuzaki & Syaib, 2010):

$$SCS\ (Mg\ ha^{-1}) = BD \times SOC \times DP \times 100 \quad \text{……………………………………..(1)}$$

where BD = soil bulk density (g cm^{-3}); SOC= soil organic content (%); DP= soil depth (m).

2.3.3 Yield data

The yield of Chinese cabbage (t ha^{-1}) was obtained from the conversion of 1 m x 2 m yield harvested in May 2012.

2.3.4 Analyses of data

The differences in soil organic carbon and other soil characteristics measured under both organic and conventional farming systems were tested using paired t-test (Gomez & Gomez, 2007). The correlation among dependent variables of organic carbon, labile carbon, soil nitrogen and Chinese cabbage yields with independent variables (farming systems) were examined using correlation, regression and path analysis. By using the analysis, the correlation matrix, the contribution percentage of independent variables and their direct influences to the dependent ones would be determined. The whole analysis were performed using 17.0 SPSS computer software.

3. Results

3.1 Soil Organic Carbon (SOC) and Soil Labile Carbon (SLC)

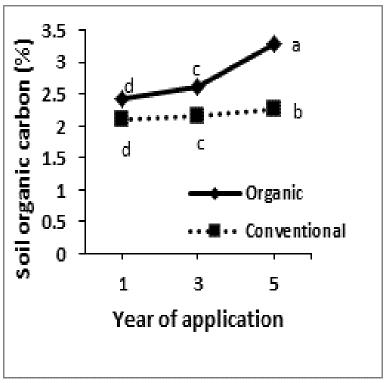
Soil organic carbon significantly increased from one to five years of organic system application under both organic and conventional systems but the values were not different between the two systems (Figure 2a) until five years of application, in which the SOC under organic system was significantly (P<0.01) 68.6% higher than that under conventional system. The SOC was consistently higher at different soil depths (0-10 cm, 10-20 cm and 20-30 cm) but the highest was found at 10-20 cm depth (Figure 4).

Soil labile carbon under both systems did not increase during one to three years of organic application, but began to increase until five years. The value increased sharply under organic system, which resulted in significantly (P<0.01) 49.01% higher SLC compared to that under conventional system (Figure 2b).

3.2 Soil Organic Carbon Storage (SOCS)

Under both organic and conventional farming systems SOCS increased significantly from one to five years of organic system application, however the differences in SOCS between organic and conventional system was only significant after five years (Figure 3a). After five years of system application, the organic system had significantly 27.42% higher SOCS than its conventional counterpart.

a) **b)**



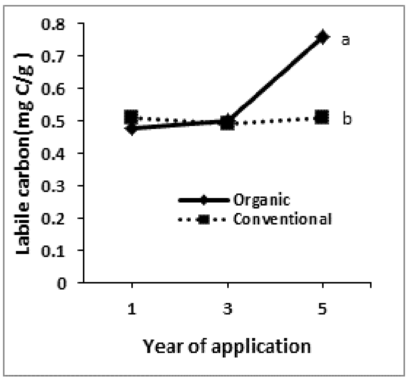
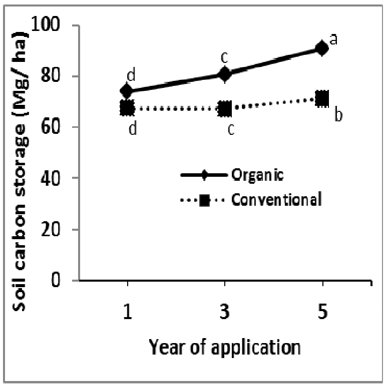


Figure 2. Soil organic carbon (a) and labile carbon (b) under organic and conventional farming systems during five years of system application

a)



b)

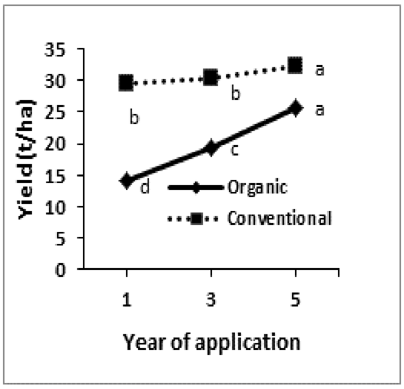


Figure 3. Soil organic carbon storage (a) and yield of Chinese cabbage (b) under organic and conventional farming systems during five years of system application

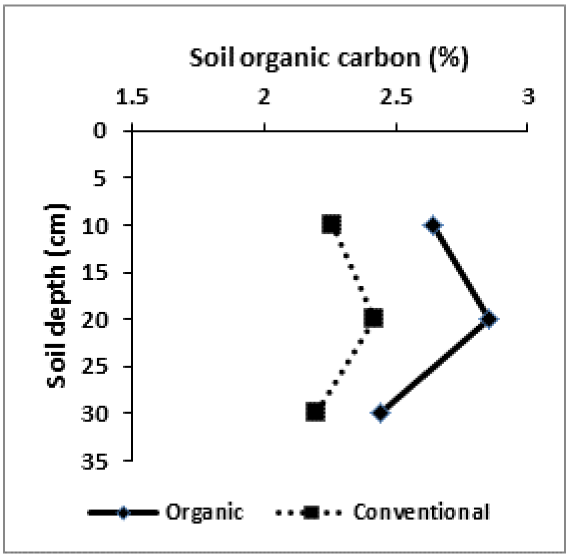


Figure 4. Soil organic carbon profiles in the top 30 cm soil depth under organic and conventional farming systems during five years of system application

3.3 Soil Bulk Density

The soil bulk density under organic systems from one to five years of organic system application were not significantly ($P<0.05$) different from those under conventional system, although under organic system they were tended to be consistently lower. The average bulk density was in the range of 0.92 -1.04 g cm^{-3} (Table 1).

Table 1. Soil bulk density, nitrogen, and microbial respiration rate under organic and conventional farming systems during 5 years of system application

Treatment	Soil bulk density	Nitrogen (N)	Soil microbial respiration
	g cm^{-3}	%	mg C kg^{-1}
5 years application			
Organic	0.92^a	0.33^a	7.49^a
Conventional	1.02^a	0.33^a	5.41^b
3 years application			
Organic	0.97^a	0.28^a	6.63^a
Conventional	1.04^a	0.32^a	5.94^a
1 years application			
Organic	0.93^a	0.23^b	6.40^a
Conventional	1.02^a	0.30^a	5.16^a

Notes: Values followed by the same letter in the same treatment of application and in the same column are not significantly different at 5% paired-t Test.

3.4 Soil Nitrogen

Soil nitrogen content under organic system was significantly (P<0.05) 30.43% lower than under conventional system only after one year of organic system application (Table 1). After three to five years of system application the soil N (0.33%) under both system were not different.

3.5 Soil Microbial Respiration

After five years of organic application, the organic farming system showed soil microbial respiration of 7.49 mg C kg^{-1}, which was significantly (P<0.05) 38.44% higher than that under its conventional counterpart (Table 1). The values between the two farming systems were not different during one to three years of organic system application.

3.6 Yield of Chinese Cabbage

The yield of Chinese cabbage under organic system increased significantly (P>0.05) from one to five years of organic system application, meanwhile the yield under conventional system only increased significantly after five years (Figure 3b). These resulted in no different yield was found between the two systems (25.78 and 32.21 t ha^{-1} under organic and conventional systems respectively) after five years of organic system application. The differences in yields between the two farming systems were only significant during one to three years of organic system application.

3.7 Correlation between organic system and SOC, SLC, soil N and yield of Chinese Cabbage

The organic system was highly correlated (r= 0.836**, r=0.846**) with levels of SOC and SLC respectively (Table 2). Meanwhile, the system was correlated (r= 0.753*, r=0.739*) with soil N and crop yields. On the other hand, highly but not significant correlation ($r=0.820^{ns}$) was found between the organic system and SOCS.

4. Discussion

Organic farming system had significantly higher soil organic carbon compared to conventional one after five year of organic system application (Figure 2a). That high organic carbon content resulted in higher soil organic carbon storage after five year (Figure 3a). This result was in line with that of Komatsuzaki & Syuaib (2010) showing higher soil organic carbon in rice organic farming after five years. Reganol *et al*. (1993) reported that soil organic carbon significantly higher in organic than in conventional farming system after four years period. Meanwhile Scow *et al*. (1994) stated that three to five years were needed to stabilize soil characteristics after converting the conventional to organic system.

Soil carbon dynamic could be measured in the form of active or labile carbon or easily respired carbon or oxidized carbon, which indicates easiness of organic materials to decompose in the soil. Stock of labile carbon is important food and nutrition for the growth of plants and microbes, while non-labile or resistant carbon is important for soil structure and buffer (Blair *et al*., 1995). In this present study, the labile carbon under organic system was significantly 49.01% higher than that in conventional farming system (Figure 2b). This result was also supported by Binoka (2008) who applied the same method of analysis for oxidizing organic carbon using $KMnO_4^-$ and found that increased labile carbon was resulted from the growth and decomposition of organic materials. Plant roots could break down the carbon compound into labile carbon (Conteh *et al*., 1997). Labile carbon function as the source of energy for the growth of soil microbes that is important for development of soil microbes population and influence the rate of organic material decomposition. This condition was supported by the average microbial respiration which increased significantly under the organic farming system (Table 1).

Soil microbial respiration rate indicates the activities of microbes in the soil (Cong-Tu *et al*., 2006). Soil organic carbon is positively correlated with labile carbon and soil respiration rates. In fact labile SOC, not total SOC, mainly controls soil respiration (Wang *et al*., 2013). These correlations occurred due to the labile carbon is part of total soil organic carbon (Binoka, 2008). Moreover, the labile carbon is active, therefore it is easily driven down to the deepen part of soil profile. Result of this present study also showed that SOC was consistently higher at different soil depths (0-10 cm, 10-20 cm and 20-30 cm) but the highest (2.85%) was found at 10-20 cm depth (Figure 4). Komatsuzaki & Syuaib (2010) reported the highest (2.89%) SOC in the top 10 cm soil depth of organic compared to conventional rice field. Soil bulk density under organic system was not significantly different from that under its conventional counterpart. This was due to organic fertilizers that are usually applied by vegetable farmers in the conventional system although only in small amounts.

Data obtained in the present study could describe C sequestration under organic and conventional farming systems. Under organic system of Chinese cabbage the soil C storage increased as much as 3.37 Mg C ha^{-1} annualy compared to that under conventional system. Komatsuzaki & Syuaib (2010) found an increase of 1.85 Mg C ha^{-1} anually under organic system of rice field compared to conventional counterpart in West Java Indonesia. Lal (2004) stated that increases in organic C storage resulted from changes in land use and the application of organic farming system has been following a sigmoid curve that achieved the maximum point after five to twenty years.

The yield of Chinese cabbage in organic system was lower only during one and three years of system application but after five years the yields under both systems are not significantly different. The yield was positively correlated with the labile C and soil N. The labile C in the soil becomes the source of important nutrition for plants and soil microbes. Increasing activities of soil microbes enhances the decomposition process of organic matter that releases important nutrients beneficial for plant growth. Scow *et al*. (1994) reported that N deficiency often inhibits plant growth during early periods of conversion from conventional into organic farming. Therefore the crop yield usually lower in organic than the previous conventional system, particularly during the conversion period.

5. Conclusion

Based on the results of this present study it can be concluded that organic farming system significantly increases soil organic C storage from one to five years application. The soil organic C storage increased as much as 3.37 Mg C ha^{-1} annualy under organic system of Chinese cabbage compared to that under conventional system. Soil organic C content and soil microbial respiration (indicating the microbial activity) significantly higher (68.6% and 38.5% respectively) under organic farming system during five years of system application, but soil nitrogen did not increase. Organic farming system had significantly 49.01% higher labile carbon after five years, but it was lower in one year of application. There was no significant difference in soil bulk density between the two farming systems. The yield of Chinese cabbage in organic system was lower during one and three years of application but at five years the yield (25.78 t ha^{-1}) was not significantly different from that in conventional farming system. This could explain that significant yield increases in organic farming system could only be expected after five years of system application.

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