Organic vegetable farming system enhancing soil carbon sequestration in Bali, Indonesia

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Abstract. Climate change as an implication of global warming due to the influence of increasing concentrations of greenhouse gases in the atmosphere has become an important issue in recent decades. Organic farming plays an important role in mitigating climate change by reducing atmospheric greenhouse gas emissions through increased soil carbon sequestration. This study was designed to compare soil carbon sequestration levels between conventional and organic vegetable farming fields in Bali, Indonesia. Soil samples were taken from organic fields and conventional fields in pairs. Variables of soil organic carbon, soil labile carbon, and soil bulk density are measured. Vegetable yields were estimated by fresh weights from a quadrant of 45 plants (1.12 m²) in each farming system, which is then converted to the fresh weight per hectare. The results from soil analysis indicate that organic farming leads to soil with significantly higher soil carbon storage capacity than conventional farming. The labile C fraction shows a more significant increase compared to total C. Organic farming can increase by 1.13 tons C per hectare per year compared with the conventional farming system. The use of manure compost as an alternative in vegetable fields of Bali has resulted in increased soil organic carbon storage and gross benefits for farming. Although more research is needed on the actual emissions of CO₂ gas from organic and conventional farming, this research can be used as an early indication that organic vegetable farming system can increase the mitigation of global warming, and build sustainable agriculture in Bali, Indonesia.

1. Introduction
Climate change as a result of increased concentrations of greenhouse gases in the atmosphere has become an important issue in recent decades, with carbon dioxide (CO₂) being the main greenhouse gas responsible [1]. Agriculture plays an important role in mitigating climate change by reducing atmospheric greenhouse gas emissions, through carbon sequestration in soils and plants. For example, the carbon sink capacity of agriculture and degraded soil is 50-66% of the total global carbon drop to 42-72 Pg [2]. However, returning organic C to degraded soils can take years or even decades, and the amount of stored C in the soil is largely determined by land management practices or cultivation techniques.

Conventional vegetable farming has been shown to turn down the levels of soil organic carbon [3]. The characteristics of this agricultural system include high-intensity tillage, exposed soil, and the high usage of chemical fertilizers, pesticides, and water for irrigation. This damages the soil structure causes a loss of soil organic carbon decreases soil fertility and results in the loss of natural fertilizers and other chemical elements due to erosion and leaching [3] [4] [5]. The loss of organic C in the soil due to tillage is mainly as a result of a decrease in the labile C fraction, which plays an important role as a nutrient supplier for plants [6]. Furthermore, conventional farming’s over-dependence on chemical
fertilizers decreases the amount of organic matter and reduces soil quality.

In the past, farmer’s awareness toward organic farming, and the consumer demand for pesticide-free crops, are considered very low in Indonesia. In general, the benefits of organic farming are only acknowledged by those who has concerned about environmental-friendly food products in regards to their personal health or lifestyle. Nowadays, however, through intensive efforts of the government together with NGO’s, some vegetable farmers in Bali have converted to organic farming systems. Organic farming is an agricultural system that uses natural inputs to increase soil fertility, without using chemical fertilizers or pesticides [7]. This system allows numerous advantages to farmland in Indonesia because it can raise the soil and food grade and can increase the capacity for carbon sequestration. Additionally, organic farming systems can accelerate soil carbon by recycling organic matter. Therefore, this type of soil management strategy has a prominent prospect for global environmental conservation. Indonesia, at the moment, has 261,383 total hectares of land which is under organic cultivation, with an average increase of 5.5% per year in the period of 2012-2016 [8].

Evaluation of soil organic carbon in organic and conventional farming systems is a key step in understanding the impact agriculture has on carbon sequestration [9][4]. The impact of soil management practices on soil C is best observed in regards to the active or labile C fraction, which plays an important role in providing nutrients for plants [6]. Assessing the organic C levels in the soil are key to studying carbon sequestration because the distribution of the labile C fraction in the lower regions of the soil has implications for carbon storage.

Various researches on the influence of agricultural systems on carbon sequestration have been carried out in many countries [10]. However, few studies have been done which specifically assess the labile C fraction in soils of organic and conventional farming systems. This study was designed to show differences in the carbon sequestration capacity of organic and conventional vegetable farm management systems in Bali, Indonesia.

2. Materials and methods

2.1. Study area
The area of this study was in the regency of Tabanan, specifically in the Yeh Empas watershed in Bali - Indonesia. The Yeh Empas River flows through rural areas from Penebel and Tabanan and is a major vegetable production area. The type of soil in this area is predominantly Andisol. Farmer groups included within this study were selected from the Bangli Village district of Baturiti. Figure 1 illustrates the geographical area of the study.

The research area was located at 08°32’93”SL and 115°17’64”EL, 975 m above sea level. The average annual rainfall during the last 10 years (2008-2018) in this region was 3,165.11 mm/year, with an average number of rainy days of 154.00 days/year. The minimum daily average air temperature was 21°C, with a maximum of 31°C [11].

2.2. Field investigations
Field research was managed in September 2017-2018, with information on farming practices such as application of fertilizer were derived from interviews with both conventional and organic vegetable farmers. In organic farm management, the research found that cow manure compost were used. The dry matter nutrient composition of this organic fertilizer was 17.36% carbon, 1.16% nitrogen, 0.53% phosphorus, and 0.14% potassium. It was applied in the village of Bangli with a dosage of 10 tons ha⁻¹. Grounded on interview data, the costs associated with the cultivation and required employment were also calculated.

2.3. Soil and crop yield analysis
Transformation into organic farm management were conducted in July 2011 and were assessed during the 15th vegetable crop grown after the changes. The fields received an organic certificate and were recognized by the LeSos Organic Institute. On the other part of the farm, conventional farm management
was continued to be conducted with the application of chemical input and small doses of organic fertilizer. Both vegetable production farms were located in the same area.

![Figure 1. Area of study.](image)

The research step continued with the collection of topsoil samples of each type of system from a depth of 0–10 cm were taken from five conventional fields and five organic fields in September 2018, using a 55.8 mm diameter soil core sampler. Soil core volume was registered and water content was determined gravimetrically using sample aliquots, to calculate the bulk density (BD). The samples then were dried at 50°C, then ground to pass Ø 2 mm size, and to be stored until analysis. The amount of soil organic carbon content was examined using the Walkley-Black Procedure. Changes in soil carbon can be measured in terms of the active or labile carbon fraction, which indicates the ease of decomposition of organic matter in the soil. Labile carbon levels were determined through the oxidation of organic C using 333 mM of potassium permanganate (KMnO₄) \[^4\][12]. Labile carbon is easily oxidised, whereas non-labile carbon is not, which means that this method could be used to determine the quantity of labile C in the soil. The carbon sequestration (SCS) capacity was evaluated as follows \[^13\].

\[
\text{SCS (Mg ha}^{-1}) = \text{BD} \times \text{SOC} \times \text{DP} \times 100
\]

Note. BD: bulk density (g mL\(^{-1}\)), SOC: soil organic carbon content (%) and DP: soil depth (m).

In order to understand the soil carbon distribution in both farm management type, soil samples from five fields of each system were collected using a post hole auger in the following deep, include 0–5 cm, 5–10 cm, 10–20 cm, and 20–30 cm, during the vegetable harvest in September 2018. The data gathered then examined for organic carbon content by the above-mentioned methods.

The types of vegetable plants used as indicators in this study are carrots (Daucus carota L.). Fresh tuber weights are determined from a quadrant of 45 plants (1.12 m\(^2\)) in each farming system, which is then converted to the fresh weight per hectare. Additionally, an independent sample t-test was used to
compare the average of the two farming systems.

### 3. Results and discussion

Research suggests that higher carbon content and significantly greater carbon storage were found in the soil of organic farming systems compared to a conventional system. Result also suggest that there were no significant differences in soil bulk density between organic and conventional farming systems (Table 1).

**Table 1. Comparison of soil carbon sequestration between organic and conventional vegetable farming system**

| Farming system | BD (g/cm³) | SOC (%) | Labile C (mg C g⁻¹) | SOCS (Mg ha⁻¹) |
|----------------|------------|---------|---------------------|-----------------|
| Organic        | 0.93       | 3.05    | 0.72                | 28.365          |
| Conventional   | 1.03       | 2.18    | 0.52                | 22.454          |

Note. **,** * and ns indicate significance at levels of 1%, 5% and no significance, respectively. BD: bulk density, SOC: soil organic carbon, SOCS: soil organic carbon sequestration.

Table 1 shows that organic farm management results in higher levels of carbon sequestration compared to conventional agriculture, with carbon storage in the soil being 24.52% higher in organic fields. This was as expected because an increase in carbon sequestration is associated with a rise in levels of organic C in the soil. It can also be influenced by the continuous provision of organic matter as fertilizer in organic farming, which increases the amount of biomass in the soil. According to Stevenson [14], organic material undergoes decomposition in the soil, resulting in mineralization and the formation of a relatively thick material called humus. Humus is composed of cellulose, lignin, and protein, and generally has an organic C content of 58 percent. Therefore, applying organic fertilizer increases the amount of humus in the soil, which also improves levels of carbon.

Changes in carbon sequestration due to differences between organic and conventional farming management appear to be greater for the labile soil C fraction (Table 1). This was found to be 49.02% higher in organic fields than in conventional fields, a significant result (p <0.01). The labile carbon fraction in the soil represents the ease with which organic material decomposes. It, therefore, plays a very important role in maintaining soil fertility, by acting as a key nutritious source for plant growth. Labile carbon is also a prominent source of nutrients for microbial growth, while stable carbon is important in the formation of biological structures and soil buffering capacity [4].

The results of this study are supported by Binoka's research [15], who showed that the increase in labile C levels in the soil is associated with the increase in plant growth, characterized by improved root formation. Plant roots also release labile carbon back into the soil in return [16]. Furthermore, this type of carbon functions as an energy source for soil microbes, which influences the rate of decomposition of organic matter. Therefore, organic farming can provide greater volatile C levels in the soil. These results also indicate that labile carbon is more sensitive to changes in agricultural systems when compared to total carbon levels [17]. This makes it suitable for use as an indicator of changes in soil properties due to different cultivation practices [4] [6]. In this study, labile C made up about 20 % of the total soil C, which was as expected, since labile C makes up a smaller pool of the total soil carbon content.

Labile carbon in the soil is very active, so it is easily transported down the soil profile, accumulating in the root zone [14][18]. It, therefore, plays an important role in increasing carbon storage within the soil. This was shown in the soil carbon content profile, with significantly higher carbon content appeared in organic fields than conventional fields, especially in the top 10 cm of the soil (Figure 2).
Figure 2. Comparison of soil carbon content profile between conventional and organic vegetable fields in the top 30 cm soil depth.

From Figure 2, it can be seen that the lowest organic C content in the soil was found at 0-5 cm depth. This value was found to increase with increasing soil depth, reaching its highest value at a depth of 15-20 cm under the surface, then decreasing again in deeper layers. Despite this, there was no significant difference found in organic C values between the soil layers. This was presumably because the organic carbon content was approaching a stable phase, indicating the rate of decomposition of organic matter in the soil was equivalent to the amount of organic material being added [19]. Also, activities such as plowing or hoeing pull the lower layers of soil to the surface, which can be a trigger for differing organic C between soil levels.

Using the data in Table 1, it was possible to estimate the ability of soils to sequester carbon and to compare between conventional farming and organic farming systems. At a soil depth of 10 cm, organic vegetable farming can increase carbon sequestration by as much as 1.18 Mg ha⁻¹ per year, when compared to conventional farming systems. Similarly, Jackman [19] reported that organic rice farming in West Java was able to increase carbon sequestration levels by 1.85 Mg ha⁻¹ per year, at a soil depth of 10 cm. Therefore, these results indicate that organic agriculture increases organic C sequestration, meaning this farming system has the potential to play a major part in mitigating greenhouse gas emissions in Indonesia [13].

The overall yield from organic farming systems is lower than from conventional land. However, the rate of organic carrots is 97% higher than a conventional system which leads to gross profits that are almost double overall (Table 2).

Table 2. Comparison of yields and gross profit between conventional and organic farm management.

| Management   | Yield (kg) | Price (IDR kg⁻¹) | Gross Profit (IDR ha⁻¹) | Wages (IDR ha⁻¹) |
|--------------|------------|------------------|-------------------------|------------------|
| Organic     | 3,996      | 15,000           | 52,758,233.33           | 2,946,787.50     |
| Conventional| 4,394      | 7,600            | 25,707,398.88           | 1,963,747.62     |

Note. Yields were obtained by sampling in September 2018.

Furthermore, the organic farm management system helped to diminish the price of vegetable production (Figure 3). For example, conventional farm management had to allocate IDR 624,226,26 for chemical-based fertilizers and pesticides, meanwhile, organic farmers spent IDR 230,416,67 for the cow manure compost. Hence, organic farm management system could trim down the cost of production by 75%.
Organic farming requires higher tillage costs than conventional farming. The dilemma for organic farmers is that these approaches for increasing soil organic matter also require tillage. Specifically, tillage is required to eliminate cover crops and control weeds; to incorporate manure or compost to avoid nitrogen runoff and volatilization losses; and to facilitate more rapid mineralization and release of nutrients to the crop. The organic system required more labor to apply organic fertilizer and weeding. The amount of organic fertilizer applied was 10 Mg ha$^{-1}$ for each vegetable growing season, which was four times greater than conventional farming, due to the lack of appropriate technology for the application of the organic fertilizer. Weeding in Indonesia is mainly done by hand, and requires a lot of manual labor.

Based on the soil analysis, significantly higher carbon storage of organic farming systems may help to mitigate global warming as well as establishing sustainable food production in Indonesia. Organic vegetable farming also has the potential to increase soil quality, minimize the cost spent on fertilizers, and lead to increase farmers’ incomes. However, a disadvantage of organic farming is that it needs intensive employment activities such as weeding and put in manure compost.

To further develop renewable agriculture and enhance sustainability, an approach needs to combine biophysical aspects with socio-economic aspects, in regards to agricultural systems. Although more research is still needed on the actual emissions of CO$_2$ gas from organic and conventional farm management, the results of this study can be used as an early indication that organic vegetable farming plays a role in mitigating global warming by increasing carbon sequestration in soils and supporting sustainable agriculture.

### 4. Conclusion

Soil carbon sequestration in organic farm management systems was found to be significantly higher when compared with conventional farming. The higher organic carbon levels in the soil were particularly in the form of labile carbon, which has the potential to increase farm profitability by improving soil fertility and nutrient availability. Furthermore, the use of manure compost as an alternative to chemical fertilizer affect the rise of organic carbon storage and increase financial benefits for farmers. To conclude, organic farming is a method of vegetable production to assist reduce global warming by improving carbon sequestration and encourages sustainability of the agricultural sector in Indonesia.

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