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CO_2 emission and accumulation of soil organic matter under Sweet Corn Stand in the long term organically managed land

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Abstract It has been widely recognized that agriculture practice emits a significant amount of carbon dioxide. Long-term practice of organic agriculture accumulates organic matter in the soil; however, at the same time releases carbon dioxide. The study indicated that carbon flux from the organically managed sweet corn stand fluctuated during the growing period. However, the increasing rate of vermicompost did not influence carbon flux unless soil disturbance had occurred (tillage and heaping). When soil disturbed, high rate of vermicompost emitted carbon dioxide higher than the lower one. In addition, soil organic matter at 0-10 cm depth for 3-year accumulation increased at a higher rate of vermicompost but not at a depth of 10-20 cm. Soil organic matter accumulation brought about a reduction of exchangeable Al; accordingly, rising in soil pH. Carbon released from organically managed land in tropical highland was highly dependent on soil disturbance and crop growth stage.

Keywords: carbon emission; carbon accumulation; sweet corn; organic farming

Introduction

Soil organic matter is of importance for maintaining land productivity. Organic farming practices are suggested to increase in organic matter content in the soil continuously, consequently improvement of soil quality (Kaleem Abbasi *et al*., 2015; Muktamar *et al*., 2016; Sudjatmiko *et al*., 2018) and sweet corn productivity (Fahrurrozi *et al*., 2016; Muktamar *et al*., 2017a). Jarecki and Lal (2003) noticed that soil organic carbon sequestration was enhanced by no-tillage, surface residue mulching, continuous cropping, cover cropping, agroforestry, manure, and bio-solid application. Enhancement of soil organic matter will stimulate microbial respiration (Ferreras *et al*., 2006), which is controlled by amendment application rates (Yazdanpanah, 2016). However,

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McGee (2015) reasoned that organic farming enhanced the total amount of greenhouse gas emitted from agricultural land.

The released CO_2 from soil respiration is mainly associated with the decomposition of organic matter in the soil. Soil tillage and cropping management have a significant effect on CO_2 concentration in the soil surface and the atmosphere (Flessa *et al*., 2002; Dalgaard *et al*., 2003). A study by Reicosky *et al*. (2008) noticed that CO_2 concentration in the no-tillage system was higher than that in conventional tillage. However, another study confirms that the accumulation of soil organic matter such as no-tillage system is considered less CO_2 emissive (Utomo *et al*., 2012).

Carbon dioxide released from microbial respiration in the soil is dependent on soil temperature and moisture content. Study in the temperate zone by Chen *et al.* (2017) noticed that soil carbon flux significantly increased at soil temperature higher than 10 ^{o}C. The study also revealed that there was a linear increase in soil carbon release with soil water content up to 40%. Soil tillage also stimulates an increase in carbon release from soil (Giacomo *et al*., 2014).

Land use has also been reported to control carbon emission. Comparing carbon emission from peat soil under selected crops, Barchia (2016) found out that soil under oil palm exhibited the highest emission, followed by vegetable crop and rice. Another study shows that annual carbon emission is highest under pasture, followed by vegetables, cassava, and maize (RosenStocky *et al*., 2016). Irrigated sweet corn has higher cumulative CO2 flux that non-irrigated one as pointed out by Haile-Mariam *et al.* (2008). Current information on CO_2 flux under organic farming practice is evidently limited. The objective of this study was to evaluate CO_2 release, and soil organic matter accumulation under sweet corn stand in the long-term organically managed land.

Materials and Methods

Study site and experimental design

The study was carried out in sweet corn-cultivated cropland at Closed Agriculture Production System station located at Air Duku Village, Rejang Lebong, Indonesia, at 1054 m above sea level. The study site was established in 2009 and different sweet corn-based crop rotations were raised with fertilization of compost at a rate of 15 Mg ha^{-1} for each growing season. Since 2016, the site was designed as long-term research for evaluation of soil quality in organic cropland with organic fertilization of 5, 10, 15, 20, and 25 Mg ha^{-1}. The soil was classified as Andept and contained 20.1 g kg^{-1} total soil organic carbon (TSOC), 1.90 g kg^{-1} total soil nitrogen (TSN), 4.95 mg kg^{-1} available phosphorus (P), 74.1 mg kg^{-1} exchangeable potassium (K), 220 mg kg^{-1} calcium (Ca), 27.6 mg kg^{-1} magnesium (Mg), 31.76 cmol kg^{-1} cation exchange capacity (CEC), 11.1% clay, 34.94% silt, 53.96% sand, and soil pH of 5.50 (Muktamar *et al*. 2017b). Completely Randomized Block Design (CRBD) was assigned to allocate five treatments of vermicompost, i.e., 5, 10, 15, 20, and 25 Mg ha^{-1}. The treatment was replicated 3 times.

Crop management

The soil was plowed using hoes to 15 cm depth and cleaned from weeds. A day after soil tillage, vermicompost was incorporated into the soil according to each treatment. Sweet corn seeds were sown in corresponding plots at a spacing of 70 cm by 25 cm just after vermicompost fertilization. Thinning was performed two weeks after planting by leaving the healthier plant. Liquid organic fertilizer (LOF) was side-dressed as a supplemental nutrient for sweet corn. Each plant weekly received 150 ml LOF, starting at the second to fifth weeks after planting. Heaping was carried out at 21 days after planting for controlling weeds and strengthening sweet corn stands. Sweet corn was harvested at 78 days after planting.

Soil sampling and carbon emission measurement

At sweet corn harvesting, composite soil sample at a depth of 0-10 cm and 10-20 cm was collected using soil sampling probe. The sample was air-dried, ground, sieved using 0.5 mm screen, and analyzed for total soil organic carbon (TSOC) using Walky and Black Method and soil pH using pH meter at 1:1 ratio of soil and distilled water and exchangeable Al using titration after extraction with 1N KCl (BPT, 2009). Total soil organic carbon is reflected as an accumulation for the period of organic farming practice.

Soil carbon emission was measured using a modified method developed by Anderson (1982), where CO_2 was captured using KOH instead of NaOH (Utomo *et al*. 2012). The emission was determined at a day before and tillage, 1, 2, 3, 4, 10, 17, 28, 35, 41, 49, 56, 63, 70, and 77 days after tillage. At the same time, soil temperature at 15 cm depth was also recorded using a soil thermometer. Carbon dioxide flux was quantified twice a day (at 9.00 am and 3.00 pm) with 2 hours of incubation, respectively. The measurement was carried out by inserting upside down 12 cm diameter jar into the plot. A small plastic vial containing 20 ml 0.1N KOH was placed inside the jar. The control consisted of a vial with the alkali incubated in a completely sealed plastic jar placed in the field. The alkali solution was titrated with 0.1N HCl, and the difference between control and the treated solution was considered as the quantity of alkali that had not reacted with CO_2 to determine the C-CO_2 equivalent (Anderson, 1982).

Results

Soil organic matter accumulation

Soil organic carbon is a primary indicator of organic matter content in the soil, which has a significant role in the quality of the soil. Application of organic amendment since 2009 has led to a considerable increase in TSOC. Organic matter is mostly accumulated in the upper part of the soil profile, as shown in Figure 1. Result indicated that higher rate of vermicompost exhibited greater TSOC; consequently, soil organic matter accumulation was even higher. Total soil organic carbon was 27.2% higher for 25 Mg ha^{-1} at 0-10 cm depth while only 16.0% at 10-20 cm depth than those of 5 Mg ha^{-1}. The differences of TSOC content between the two depths was greater as the rate of vermicompost higher, indicating accumulation of organic matter was mostly at the upper portion of the soil profile.

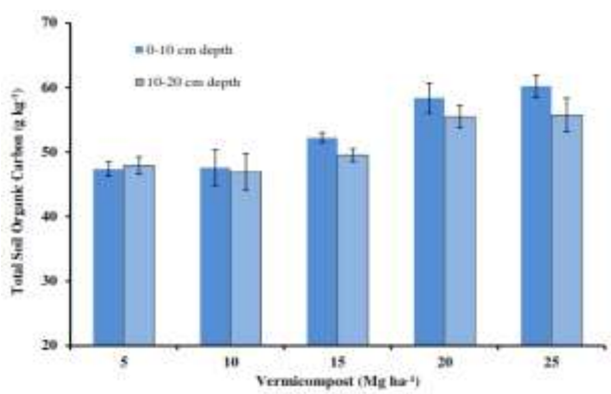

Figure 1. Total soil organic carbon at a different rate of vermicompost

Opposite fashion to TSOC is noted in exchangeable Al, as seen in Figure 2. Exchangeable Al showed drastically lower as the rate of vermicompost high. The decline was more profound at 0-10 cm depth than the deeper depth, indicating that most vermicompost is located at the upper depth of soil profile. Application of vermicompost at the rate of 25 Mg ha^{-1} reduced almost double exchangeable Al of the 0-10 cm depth, as compared to that 5 Mg ha^{-1} while at a depth of 10-20 cm, the decrease was only 70%. Reduction of exchangeable Al declined its saturation in soil solution, leading to the improvement of rhizosphere for plant growth.

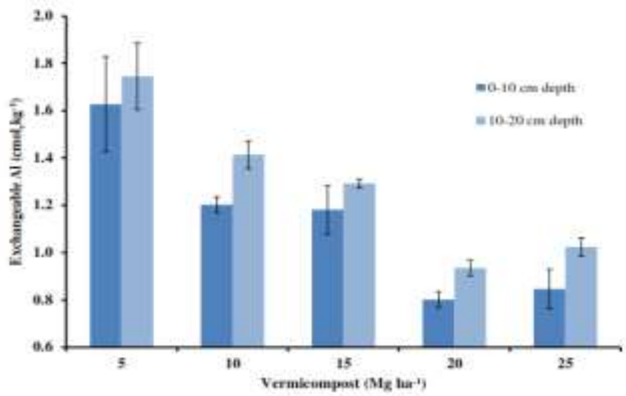

Figure 2. The influence of vermicompost on soil exchangeable aluminum

The decline in exchangeable Al led to an increase in soil pH, as shown in Figure 3. Soil pH is rised by around 11% for both depths as the application of vermicompost is enlarged from 5 to 25 Mg ha^{-1}. For both depths, soil pH at the rate of 20 Mg ha^{-1} was approximately equal to that of 25 Mg ha^{-1}, as also seen in Figure 2 where exchangeable Al was the same for both rates. A similar trend is also observed for the rates of 10 and 15 Mg ha^{-1}.

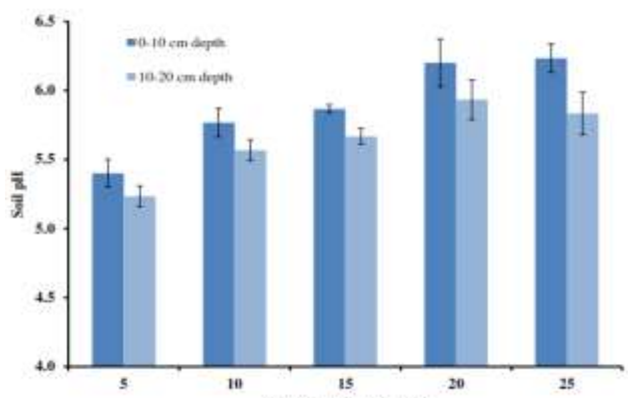

Figure 3. Soil pH as affected by the application of vermicompost

Carbon Dioxide Emission

The long-term organic farming practice has led to the accumulation of soil organic matter mainly at the upper part of the soil profile. Application organic amendment released nutrient for plant growth, and at the same time, its decomposition also emitted CO_2. Respiration also releases CO_2 to the atmosphere. Therefore, CO_2 flux is both from soil organic matter decomposition and respiration. Carbon dioxide flux fluctuated during the sweet corn growing season, as indicated in Figure 4. Release of CO_2 considerably increased at soil tillage, after heaping, and at maximum sweet corn growth stage (tasselling). At those periods, a significant increase in CO_2 release was observed as vermicompost rates were higher than it. Nonetheless, it tended to be steady when there was no soil disturbance such as at 2-20 and 50-78 days after plowing. No significant effect was detected as higher rates of vermicompost application.

Measurement of CO_2 release was carried out twice a day; 9.00 am and 3.00 pm. Average flux fluctuated during the season and was mostly low in the morning measurement (Figure 5). However, it was also observed high flux in the morning for several days during the season such as 4 and 78 days after plowing. Higher flux for those days might have been related to air temperature and heavy rain.

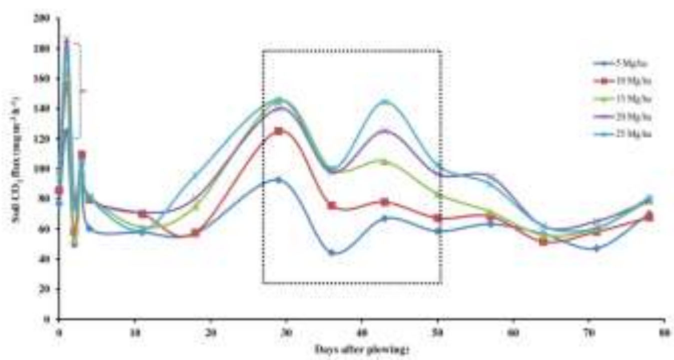

Figure 4. Soil carbon flux during sweet corn growing season

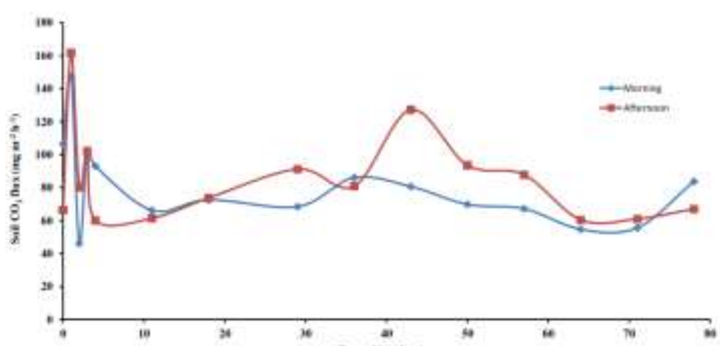

Figure 5. CO_2 flux in the morning and the afternoon

Soil temperature was recorded twice a day during the CO_2 flux measurement. Average soil temperature fluctuated throughout the growing season, ranging from 294.2 to 300.6 ^oK as indicated in Figure 6. For all treatment, the soil temperature was approximately 4 ^oK lower at 71 days after plowing than the previous week. However, the application of vermicompost to the rate of 25 Mg ha^{-1} did not affect the soil temperature throughout the study. Soil temperature in the morning was lower than the afternoon, and at both measurements, the temperature fluctuated throughout the growing season (Figure 7). The soil temperature a day before and 36 days after plowing were similar due to cloudy days.

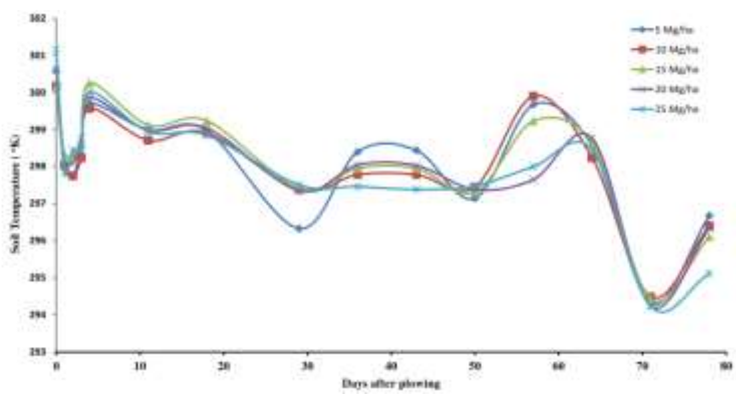

Figure 6. Soil temperature as affected by vermicompost during the growing season

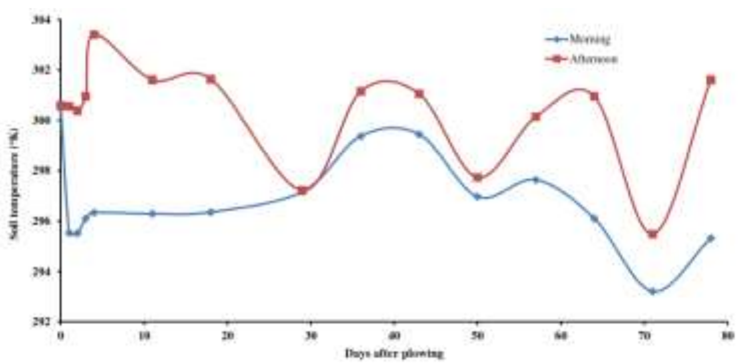

Figure 7. Soil temperature in the morning and afternoon during the growing season

Correlation analysis was carried out to determine the relationship between CO_2 flux and soil temperature. Figure 8 showed that for all treatments, there was no significant correlation between CO_2 flux and soil temperature with very small R^2, ranging from 0.001 to 0.0067. In general, higher vermicompost rate exhibited lower R^2. The insignificant correlation indicated that in the humid tropical highland, CO_2 flux was independent on soil temperature.

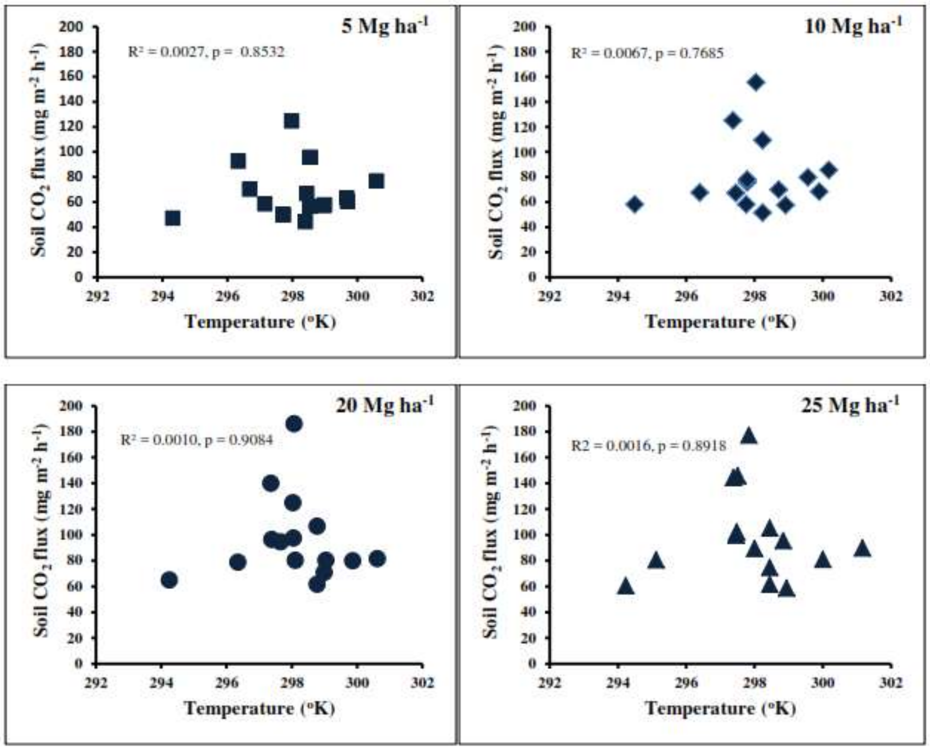

Figure 8. Correlation between soil temperature and soil CO_2 flux

Discussion

Prolong application of organic fertilizer has accumulated organic matter in the soil. The buildup has led to the improvement of soil quality indicated by greater content of TSOC, reduction of exchangeable Al, and an increase in soil pH. Previous researches concluded that addition of organic fertilizer enlarged soil organic carbon (Gong *et al*., 2009; Sudjatmiko *et al*., 2018; Muktamar *et al*., 2015). Decomposition of plant nutrients, leaving by-products are mainly humic substances such as humic and fulvic acids. The two acids are abundant in functional groups, primarily carboxyl and phenolic (Spark, 2003). Both functional groups are able to covalently bind Al to form an insoluble organo-metal complex (Sposito, 1984), leading to the decline in exchangeable Al. A study by Muktamar *et al*. (2016) also suggested that the application of organic amendment considerably reduced exchangeable Al in soil. Another result reported by Ifansyah (2013) concluded that humic acid lowered concentration of Al in soil solution.

Formation of Al-organo complex reveals lower Al hydrolysis in soil solution, reducing proton production and raising soil pH. The result was similar to Anggita *et al*. (2018) where the application of liquid organic fertilizer increased soil pH of an Ultisol. Another study conducted by Muktamar *et al*. (2016) indicated that addition of water hyacinth compost to the rate of 25 Mg ha^{-1} increased soil pH. The most prominent increment was in Udult as compared to Udept and Andept.

Soil CO_2 flux fluctuated for sweet corn growing season. Considerable increase in the flux was observed when the soil was disturbed, such as tillage and heaping and at sweet corn tasselling. An increasing rate of vermicompost significantly accelerated soil CO_2 flux; otherwise, the rate had no effect on the flux. Neogi *et al*. (2014) confirmed that minimum tillage emitted greater CO_2 than conventional tillage. Utomo *et al.* (2012) also concluded that soil CO_2 release was prominently lower in no-tillage than conventional tillage. Soil tillage and heaping lead to the enhancement of soil structure and an increase in porosity; consequently, improving oxygen supply in the soil. Sufficient supply of oxygen accelerates organic matter decomposition and respiration; accordingly, increase in CO_2 release. The previous study by Chen *et al*. (2011) revealed that oxygenation markedly enriched oxygen content and soil respiration.

Release of CO_2 measured in the morning was generally higher than in the afternoon, even though it was not dependent on soil temperature. A different result was reported by Chen *et al*. (2017), where soil temperature had a significant influence on carbon flux, mainly soil temperature over 10 ^{o}C. The different result might have been associated with the range of soil temperature throughout the experiment. Soil temperature over a period of this study ranges from 294.2 to 300.6 ^{o}K (tropical environment) while that reported by Chen *et al*. (2017) was around 253 ^{o}K to more than 300 ^{o}K (subtropical site). The slight difference between the highest and lowest soil temperature throughout this study is responsible for the insignificant effect of the temperature on CO_2 release from the soil.

The long term organic farming practice has enhanced soil organic matter, leading to the reduction of aluminum saturation in the soil, accordingly raising soil pH. In the tropical environment, CO_2 release from the soil is independent on soil temperature but highly dependent on soil disturbance such as tillage and reaping. Unless the soil is disturbed, the increase in vermicompost application to the rate of 25 Mg ha^{-1} had not influenced on the flux of CO_2 from the soil.

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