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Responses of soil respiration and organic carbon to organic soil amendments in upland paddy

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Carbon dioxide (CO_2) is a significant greenhouse gas (GHG) accounting for 60% of the total greenhouse effect. Soil respiration is a measure of the CO_2 released from soil. Rice was the largest contributing plant commodity of total emission by 12%. In the event of growing threats of global warming due to GHG emissions, reducing CO_2 emission by sequestering C in the soil is of supreme concernment. Improved management practices can rebuild C stocks in agricultural soils and help mitigate CO_2 emissions. A field study to assess how organic soil amendments influence soil respiration, C-organic content, and soil properties was conducted in upland paddy field. Treatments were: chemical fertilizer (F1), combination of chemical fertilizer and cow dung manure (F2), chemical fertilizer and vermicompost (F3), chemical fertilizer and liquid vermicompost powder (F4), cow dung manure+biochar (F5), vermicompost+biochar (F6) and liquid vermicompost powder+biochar (F7). All treatments tested almost had the same pattern of respiration rates starting before the application of the organic soil amendment until three months after planting. The highest respiration rate was found at 1 month after planting. Soil amendment (F4 and F7) had the lowest soil respiration rates in some measurements. The highest organic C content at three months after planting was found in the F6 and F3 treatments. The most influential factor on the respiration rate are soil moisture content and soil temperature. The results demonstrate the viability of vermicompost either in combination with chemical fertilizers or alone for soil amendment to maintain organic soil carbon for short period of time (~ 3 months).

1. Introduction

Technology advancement and to resolve problems face by mankind research is continuously progressing in various fields such as solar cell (Khadtare et al., 2014; Khadtare et al. 2019), green energy (Ahmed et al. 2022a,b) fuel cell (Ansari et al. 2019; Wu et al. 2022), semiconductor (Ansari et al., 2020; Choi et al., 2021), batteries (Ahmed et al. 2022c,d), 2D materials (Raya et. al. 2020) catalysis (Sartale et al., 2013; Ansari et al., 2016), and CO_2 reduction (Ansari et al., 2021). The carbon-based impurity viz CO_2 is one of the primary concerns in today's era. Attempt has been going on to reduce CO_2 production or its level present on earth. The earth's soils, which are located at a depth of 1 meter, hold the largest concentration of surface terrestrial carbon. When compared to the atmosphere, it retains twice as much carbon. Soil contributes significantly to the global C budget (Mielnick and Dugas, 2000; Maier and Kress, 2000). The vegetation that grows above the earth contributes carbon, and the biomass of plants stores about 500 Pg C (Eswaran et al., 1993; Janzen, 2004). In the world, crop-based agriculture covers about 1.7 billion hectares (excluding grazing land), with a soil carbon pool of about 170 Pg, or little more than 10% of the total soil carbon inventory (Paustian et al., 1997). The rate of soil respiration can be measured in order to estimate soil CO_2 outflow (Tołoczko and Niewiadomski 2015; Tołoczko and Niewiadomski 2018). Soil respiration is one of the most important components of the ecosystem C budget, which also includes root respiration, rhizosphere or faunal respiration, organic matter breakdown, and mineralization (Carlisle et al., 2006). This demonstrates the agriculture field is one of the primary sources of greenhouse gas (GHG) emission.

At a rate of around 120 Pg C each year, atmospheric CO_2 enters terrestrial biomass through photosynthesis (gross primary productivity). However, during plant respiration, around half of it is instantly emitted as CO_2, resulting in an annual net primary production (NPP) of about 60 Pg C. This amount is at least momentarily held in vegetative tissue, but as it ages, the majority of it eventually finds its way into the soil. In addition, heterotrophic respiration (mostly by soil microorganisms) and combustion provide back to the atmosphere an amount nearly equivalent to NPP (60 Pg C per year). This completes the cycle (Jansen, 2004). This C input and loss totals roughly 4 Mg C ha^{-1} year for the entire continental area (Paustian et al., 1997).

Microbial activity, which is defined by an increase in population and respiration activity, has been stimulated by agricultural practices like tillage in the practice of crop cultivation. Due to the disruption of soil aggregates and exposure to degradable materials, this stimulation takes place. As a result of this process, organic C- compounds in the soil are converted into carbon dioxide gas, which increases the amount of CO_2 emitted into the environment. If the decomposition process goes on, the soil's ability to store carbon decreases, which in turn lowers soil quality. Because of the compacted soil and problems in cultivating it, plants develop more slowly and produce less yield (Levine et al., 2011).

The production of plant-based food commodities is responsible for 29% greenhouse gas (GHG) emissions out of total Global GHG emissions from the production of food. The plant-based food namely rice is one of the main contributor to GHG emission, reaching more than 2000 TgCO2e per year, which accounts for 12% of the total carbon emissions from food production. Lowland rice emits about 30 kg of emissions to produce 1 kg of rice (Le Mer and Roger, 2001; Das and Baruah, 2008; Zschornack et al., 2018). On the other hand, most of the biomass produced is the part that is not used as food, fodder or fuel) cycles through the soil community and the resulting CO_2 is released into the atmosphere. The net difference between the photosynthetically fixed CO_2 entering the soil as plant residues and the CO_2 released from decomposition is much smaller. This difference determines the net C balance of an ecosystem, that is, whether it is a source or a sink of CO_2 (Paustian et al., 2000). In tropical climates, the rate of decomposition is faster than in sub-tropical areas. This condition accelerates the loss of carbon from the soil. This high rate of decomposition in tropical climates is supported by warmer environmental conditions that accelerate the decomposition process. This indicates that the increase in temperature has driven the release of large amounts of C into the atmosphere as CO_2 (Conant et al., 2008). Therefore, it is necessary to reduce carbon emissions in the agricultural food system, especially rice commodities by increasing energy efficiency, minimizing greenhouse gas emissions and increasing carbon absorption. This study aims to assess the effect of organic soil amendments on soil respiration, C-organic content, and soil properties and to determine the factor of soil properties that most influence the rate of soil respiration.

2. Materials and methods

2.1. Experimental site and time

This research is a field experiment carried out from June 2022 to September 2022 at Sidomulyo Village, Jabung District, Malang Regency. The fertilizers used for paddy cultivation were organic cow dung, vermicompost, vermicompost powder, rice husk biochar, Urea fertilizer, super phosphate (SP-36), and KCl. The rice seed used was Inpago 12 variety. The tools used include plastic jars, paper labels, small bottles, sickles, hoes, burettes, measuring cups, erlenmeyer, dropper, and chemical bottles. The soil respiration analyses of soil samples were carried out using 0.1 M KOH, phenolphthalin, methyl orange, 0.1 M HCl and aquades.

2.2. Experimental design

This study used a randomized block design (RBD) with 3 replications. The treatments tested included F1 = using chemical fertilizers (200 kg Urea ha^{-1}, 100 kg SP–36 ha^{-1} and 100 kg KCl ha^{-1}, F2 = a half dose of chemical fertilizer and cow dung (2.5 kg m^{-2}) , F3 = a half dose of chemical fertilizer and vermicompost (2.5 kg m^{-2}), F4 = a half dose of chemical fertilizer and liquid vermicompost powder (10 g L^{-1}), F5 = cow dung manure (5 kg m^{-2}) + rice husk Biochar (1 kg m^{-2}), F6= vermicompost (5 kg m^{-2}) + rice husk biochar (1 kg m^{-2}), and F7= liquid vermicompost powder (10 g L^{-1}) +rice husk biochar (1 kg m^{-2}).

2.3. Implementation of experiment

The preparation of experimental land consisted of several stages, namely clearing the land of weeds, manual tillage using a minimum tillage system using a hoe. The next stage is making an experimental plot with a size of 1m x 1m and arranged in a Randomized Block Design where each treatment is repeated 3 times. Organic amendment and fertilizer were applied one week before planting on each experimental plot according to the predetermined dose. Thus, the total experimental plots were 21 plots. During plant growth, spraying was carried out using biopesticides with a mixture of tobacco leaves and soursop leaves.

Soil sampling for analysis in the laboratory were taken four times, namely 1 day after application of organic fertilizers and amendments, 1 month, 2 months and 3 months after planting the seeds. Soil sampling depth for the analysis is 0–20 cm. The main variable observed in this study was soil respiration. The time for measuring soil respiration in the field is the same as when taking soil samples in the field. Other supporting data is the measurement of soil temperature in the field at a depth of 20 cm using a soil thermometer. Measurement of soil respiration was carried out twice a day for 2 hours, namely in the morning at 08.00 a.m and in the afternoon at 4.00 p.m. Soil respiration was measured using the modified Verstraete method (Anas 1989), where the soil surface was covered with a plastic jar in which a film bottle containing 10 ml of 0.1 M KOH was given. Control sample (blank) was also prepared for each treatment using 10 ml H_2O. After completing the measurement for 2 hours, each bottle containing KOH and H_2O was closed with a bottle cap, so that CO_2 could not be collected from the outside during the trip to the laboratory. The quantity of C-CO_2 produced from measurements in the field for 2 hours is determined by titration, namely 2 drops of phenolphthalein are added to an erlenmeyer flask containing 0.1 M KOH from the sample which is then titrated using 0.1 M HCl until the red color disappears. The volume of HCl used was recorded and then 2 drops of methyl orange were added and titrated again with HCl until the orange color changed to pink again. The amount of HCl used in both stages of the titration is directly related to the amount of CO_2 fixed. The same method was also carried out on film bottles whose soil surface was covered with plastic as a control treatment using H_2O. Soil respiration can be calculated using the following formula:

$$C-CO_2=\frac{(a-b)\times t\times 12}{T\times\pi\times r^2}$$

Remark: C-CO_2 = mg hr^{-1} m^{-2}, a = ml HCl for sample, b = ml HCl for blank, t = normality (N) HCl, T = time (hours), and r = tube radius jar (cm).

Supporting variables observed at the beginning and end of the study included: (1) C-organic soil (Walkley and Black method); (2) soil pH (pH meter); (3) Soil moisture content (%) using the Gravimetric method; and (3) Soil temperature (°C) using a soil thermometer.

The data collected were analyzed by F test (P < 0.05) to determine the effect of treatment on the measured variables. If the results of the F test (P < 0.05) showed a significant effect, then the difference in the average value of the data was further tested using the LSD test (P < 0.05). To find out the soil properties that have the most influence on soil respiration, multiple regression analysis was carried out by using Minitab Version 18.

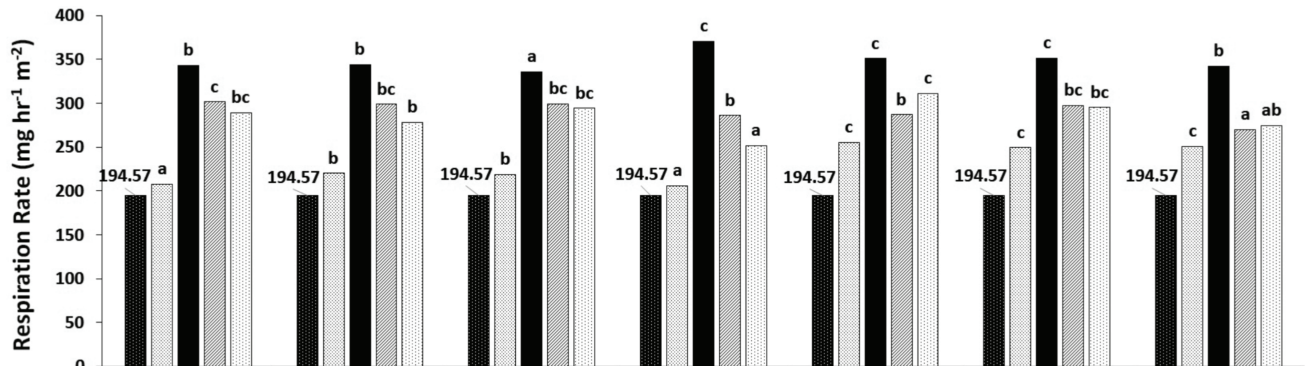
3. Results and discussion

3.1. The Effect of types of organic soil amendments on soil respiration in upland paddy

The results of the measurement of soil respiration rate in each organic soil amendment treatment showed that in general the soil respiration rate increased at 1 month after planting (1 map), the next respiration rate until 3 months after planting decreased (3 map). In measuring soil respiration rate at one day after application of soil amendment, plots using only organic amendment (F5, F6, and F7) gave the highest soil respiration rate. In measuring soil respiration rate one month after planting (1 map), plots using a combination of chemical fertilizer and liquid vermicompost powder (F4) and only organic amendments F5 and F6 (cow dung+biochar and vermicompost+biochar) statistically had the same high respiration rates. In measuring soil respiration rate at two months after planting (2 map), plots using cow dung+chemical fertilizer (F2), vermicompost+chemical fertilizer (F3) and vermicompost+biochar (F6) statistically had the same high respiration rates. In measuring soil respiration rate at three months after planting (3 map), plots using chemical fertilizers (F1), chemical fertilizer+vermicompost (F3), cow dung+biochar (F5) and vermicompost+biochar (F6) statistically had the same high soil respiration rates. The highest average respiration rate in all measurements was found in plot that used cow dung + biochar, which was 301.24 mg hr^{-1} m^{-2}, while the lowest was found in plots that used a combination of chemical fertilizer+liquid vermicompost powder (F4) and those that used liquid vermicompost powder+biochar (F7) 278.52 mg $hr^{-1}m^{-2}$ and 284.45 mg hr^{-1} m^{-2}, respectively (Fig. 1).

Organic soil amendments have a major impact on the microbial populations and activity in the soil, which in turn has an impact on soil CO_2 emission (Hu et al., 2011; Ding et al., 2001). Organic soil amendment can become a substrate for autotrophic components such as live roots and mycorrhiza and heterotrophic components (microbes) of soil respiration (Ryan and Law, 2005). The increase in CO_2 emissions due to an increase in the soil microbial population occurs because the decomposition rate of soil organic matter increases. In addition, this is also caused by increased root respiration during plant growth (Lamptey et al., 2019).

Plots with the application of organic fertilizer combined with biochar gave a high respiration rate, especially in the cow



	F1	F2	F3	F4	F5	F6	F7
iniatially	194.57	194.57	194.57	194.57	194.57	194.57	194.57
1 daf	207.88	220.19	219.07	205.64	255.65	249.30	250.80
1 map	343.35	344.30	335.89	370.85	351.07	351.16	342.62
2 map	301.65	298.83	299.38	286.06	287.00	297.57	269.70
3 map	288.86	278.41	294.13	251.54	311.26	295.21	274.68

Fig. 1. Effect of types of organic soil amendments on soil respiration in upland paddy at various measurement times (Remark: The bar chart marked with the same letter with the same measurement time on various soil amendment treatments (F1-F7) showed no significant difference in the 5% LSD test).

dung+biochar treatment for all soil respiration rate measurements. This shows that the addition of cow dung manure increases the C-organic content of the labile fraction. Labile pools of Soil Organic Matter (SOM) have a positive correlation with basal soil respiration (Benbi et al., 2015a; Benbi et al., 2015b). The application of organic fertilizers into the soil can trigger microbial growth and metabolism to become more active. Microbes use organic matter to produce CO_2, resulting in high respiration rates (Shahbaz et al., 2017; Blagodatskaya et al., 2014; Berg and McClaugherty, 2014; Condron et al., 2010). Comparatively to plots without organic amendment, the application of inorganic fertilizers along with organic fertilizers that have a low C:N ratio can promote mineralization and raise CO_2 emissions (Liu et al., 2008).

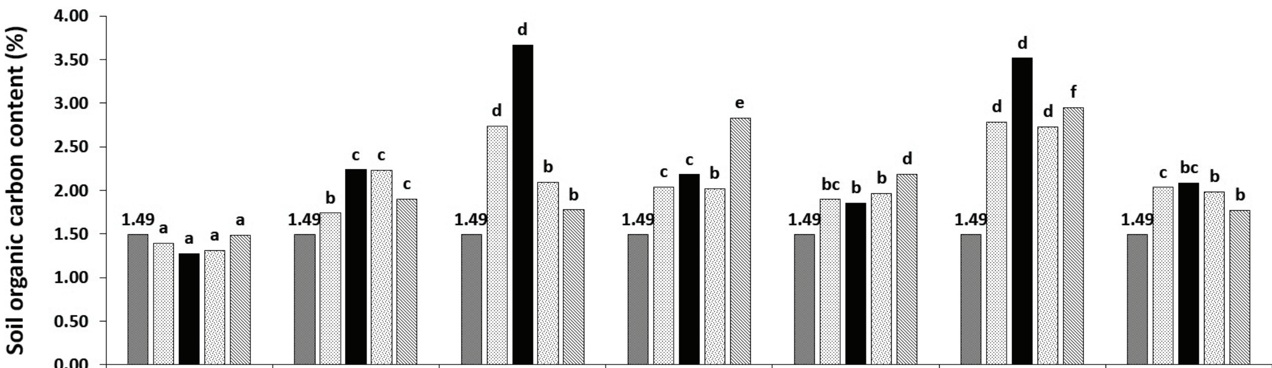
Plots using liquid vermicompost tend to have lower respiration rates, especially in the treatment combined with chemical fertilizers. The soil respiration is measures of CO_2 released from soil as a result of decomposition of SOM and plant litter by soil microbes. The lower respiration rate is due to the absence of addition of labile organic matter into the soil, which is readily and most rapid released from soil result in high soil respiration rate. Thus, the soil respiration activity occurs due to the mineralization process of soil organic matter. Soil mineralization is the process where organic nutrient available in the soil transform to useful available nutrient to the plant. This is comparatively slow respiration process than the process of labile organic matter. Further, Pan et al. (2009) reported that the replacement of 50% chemical fertilizers with organic fertilizers can reduce the rate of soil respiration. A low soil respiration rate indicates limited availability of SOM or plant litter for soil microbes. It may also signify soil conditions (temperature, moisture, aeration, porosity, and available N) that limit biological activity and decomposition. Under these conditions, nutrients are not released from SOM or plant litter for use by plants and soil organisms (USDA, 2014).

3.2. The Effect of types of organic soil amendments on content of soil organic carbon in upland paddy

The results of the analysis of variance showed that the type of organic soil management had a significant effect on the content of soil organic carbon during the measurement period of soil respiration. In all plots that received the addition of organic fertilizer, both a combination of inorganic+organic fertilizers and organic fertilizer+biochar, there was an increase in C-organic content in the measurement one month after planting (1 map) compared to initial C-organic content. There was a decrease in C-organic content in plot that only used chemical fertilizer compared to initial organic C content (Fig. 2). The results of this study indicate that the addition of organic matter to the soil can maintain the C-organic content in the agroecosystem (Bhattacharya et al., 2016). Soil properties, especially soil C-organic content, are strongly influenced by the application of organic fertilizers, amendments of organic and chemical fertilizers (Barbera et al., 2012; Srinivasarao et al., 2014).

In the measurement of C-organic one day after fertilization (1 daf) and one month after planting (1 map), the plot using a combination of chemical fertilizer + vermicompost (F3) and vermicompost + biochar (F6) had the highest organic C content. In the measurements of two and three months after planting (2 maps, 3 maps), the plots using vermicompost+biochar (F6) had the highest organic C content (Fig. 2).

Vermicompost is a slow-release organic fertilizer. The effect of vermicompost can last up to four successive mustard planting periods (Nurhidayati et al., 2018). This shows that the carbon stored by vermicompost is more stable than cow dung. The addition of biochar also increases the C-organic content of the soil. The results of this study are in line with the results of research by Sarma et al. (2018) that the application of biochar in crop cultivation significantly increased total organic Carbon and soil organic Carbon storage and reduced the lability of Soil



	F1	F2	F3	F4	F5	F6	F7
iniatially	1.49	1.49	1.49	1.49	1.49	1.49	1.49
1 daf	1.40	1.74	2.74	2.04	1.90	2.78	2.03
1 map	1.28	2.24	3.67	2.18	1.85	3.52	2.08
2 map	1.31	2.23	2.09	2.02	1.97	2.73	1.98
3 map	1.48	1.90	1.78	2.83	2.19	2.95	1.77

Fig. 2. Effect of types of organic soil amendments on C-organic content in upland paddy at various measurement times (Remark: The bar chart marked with the same letter with the same measurement time on various soil amendment treatments (F1-F7) showed no significant difference in the 5% LSD test).

Organic Carbon fractions. According to Lal (2004), reducing agricultural greenhouse gas emissions and increasing carbon storage/sequestration are urgent tasks that must be undertaken not only to mitigate climate change but also to adopt good farming practices like balanced fertilization and the addition of organic amendments. This means that the more carbon stored in the soil, the less CO_2 is released into the atmosphere.

3.3. Correlation of soil properties and soil respiration rate

This study also measures several soil properties that are considered to affect the rate of soil respiration. Several soil properties were measured, including total content of C-organic soil, soil pH, soil moisture content and soil temperature. The four soil properties were measured in each soil respiration measurement. The difference in fertilizer management used provides a significant difference between the four soil properties. To determine the soil properties that have the greatest influence on soil respiration, multiple regression analysis was performed using Minitab Version 18 as presented in the following Table 1–4.

Soil respiration rates are dependent on dynamic soil factors, including SOM content, temperature, moisture, salinity, pH, and aeration. Biological activity of soil organisms varies daily and seasonally (USDA, 2014). Based on the results of multiple regression analysis showed that soil moisture and soil temperature gave the greatest influence on the rate of respiration. This is indicated by the P–Value <0.05 in the second (one month after

Table 1
Coefficient values of several soil properties that affect soil respiration based on multiple regression analysis on soil respiration measurements of one day after fertilization (1 daf).

Term	Coef.	SE Coef.	T–Value	P–Value	VIF
Constant	–1634	1124	–1.45	0.165	
Soil Moisture (SM)	–1.28	1.57	–0.81	0.427	1.49
Soil Temperature (ST)	62.6	36.0	1.74	0.102	1.86
Soil pH (SP)	56.9	57.8	0.98	0.339	5.47
Soil Organic Carbon (SOC)	–33.8	32.1	–1.05	0.307	6.22

Regression equation of soil respiration at one day after fertilization (1 daf) :
Y = –1634 – 1.28 SM + 62.6 ST + 56.9 SP – 33.8 SOC

Table 2
Coefficient values of several soil properties that affect soil respiration based on multiple regression analysis on soil respiration measurements of one month after planting (1 map).

Term	Coef.	SE Coef.	T–Value	P–Value	VIF
Constant	139	121	1.15	0.268	
Soil Moisture (SM)	–3.040	0.703	–4.33	0.001	1.26
Soil Temperature (ST)	9.62	5.11	1.88	0.048	1.49
Soil pH (SP)	17.9	16.2	1.10	0.286	6.20
Soil Organic Carbon (SOC)	–6.79	4.90	–1.39	0.185	5.92

Regression Equation of Soil Respiration at one month after planting (1 map) :
Y = 139 – 3.040 SM + 9.62 ST + 17.9 SP – 6.79 SOC

Table 3
Coefficient values of several soil properties that affect soil respiration based on multiple regression analysis on soil respiration measurements of two months after planting (2 map)

Term	Coef.	SE Coef.	T–Value	P–Value	VIF
Constant	181	163	1.11	0.282	
Soil Moisture (SM)	–3.354	0.677	–4.96	0.001	1.28
Soil Temperature (ST)	10.97	5.08	2.16	0.046	1.03
Soil pH (SP)	–5.1	15.6	–0.33	0.746	3.25
Soil Organic Carbon (SOC)	15.88	8.75	1.82	0.088	3.61

Regression Equation of Soil Respiration at two months after planting (2 map):
Y = 181 – 3.354 SM + 10.97 ST – 5.1 SP + 15.88 SOC

Table 4
Coefficient values of several soil properties that affect soil respiration based on multiple regression analysis on soil respiration measurements of three months after planting (3 map).

Term	Coef.	SE Coef.	T–Value	P–Value	VIF
Constant	318	481	0.66	0.519	
Soil Moisture (SM)	0.97	1.26	0.76	0.456	1.52
Soil Temperature (ST)	–8.5	13.6	–0.63	0.541	1.21
Soil pH (SP)	25.2	33.3	0.76	0.461	1.11
Soil Organic Carbon (SOC)	–13.6	10.6	–1.28	0.220	1.39

Regression equation of soil respiration at three months after planting (3 map)
Y =318 + 0.97 SM – 8.5 ST + 25.2 SP – 13.6 SOC

planting) and third (two month after planting) respiration measurements. The regression coefficient for soil moisture is found to be negative measured after one day of fertilization, one month and two months after planting (Table 1–3), however, it appeared to be positive three months after planting (Table 4). This means that the higher the soil moisture, the respiration rate decreases. Soil respiration generally increases as soil moisture increases. Cook and Orchard (2008) reported that respiration rate is linearly correlated with soil water content. But on the contrary, the research results showed that the higher the soil water content, the lower the soil respiration. During rice planting of this study from June to October 2022, there were some rainy days each month, which resulted in high soil moisture. Subsequent rain events resulted in soil being too wet beyond field capacity. Luo and Zhou (2007) reported that oxygen is limited when the soil pores are filled with water, interfering with the ability of soil organisms to respire. Ideal soil moisture content is near field capacity, or when approximately 60% of the pore space is filled with water. Respiration is limited in dry soils because of the lack of moisture for microbial activity and other biological activity. The soil at the study site has a clayey texture so that the soil has a high water-holding capacity. In addition to environmental factors, differences in organic soil amendment also have a significant effect on soil moisture and soil temperature. Several researchers reported that fertilization management applied affects soil moisture conditions and soil temperature so that it affects the rate of soil respiration (Barbera et al., 2012; Srinivasarao et al., 2014).

The regression coefficient for soil temperature is found to be positive measured after one day of fertilization, one month and two months after planting (Table 1–3), however, it appeared to be negative three months after planting (Table 4). This means that the higher the soil temperature, the higher the rate of soil respiration. When normalized by soil temperature, the daily soil respiration rate is highest when soil moisture is at the field capacity and linearly declines with an increase or reduction in soil suction (pF). As soil suction increases, the soil becomes dryer and vice versa (Ito and Ishida, 2016).

When soil temperatures reach a high of 35 to 40°C, microbial respiration more than doubles for every 10°C increase. Over these temperatures, plant development, microbiological activity, and respiration are restricted. Reduced soil respiration, nitrogen loss through denitrification, and sulphur loss through volatilization occur when soils are wet or saturated (USDA, 2014). Similarly, soil respiration is not sensitive to temperature under low moisture (below 7.5% volumetrically) but is more responsive to temperature under high moisture content (10 to 25%) (Carlyle and Bathan, 1988). Since soil respiration is so large and is frequently shown to rise exponentially with temperature, predictions have been made that warming-related increases in soil CO2 emissions could speed up climate change (Cox et al., 2000; Davidson and Janssens, 2006).

4. Conclusions

Differences in soil management, especially soil management using organic soil amendment significantly affect the rate of soil respiration and soil C-organic content. In general, for all measurements of respiration from each organic soil amendment there was a tendency for an increase in the rate of soil respiration at one month after planting. The highest respiration rate was found in plots using the soil amendment combination of cow dung+biochar. Plots using a combination of liquid vermicompost powder+chemical fertilizer and a combination of liquid vermicompost powder+biochar had the lowest soil respiration rates in some measurements. The highest organic C content at three months after planting was found in the treatment of a combination of vermicompost+biochar and vermicompost+chemical fertilizer. The most influential factors on the respiration rate are soil moisture content and soil temperature. These results suggest that the viability of vermicompost and liquid vermicompost powder either in combination with chemical fertilizers or alone as a soil amendment to maintain organic soil carbon in the short term.

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