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Research Article

Improvement of several indicators of physical and biological properties of soil after adding crops biomass residues and yield of upland rice

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Abstract: Returning and addition of organic material to the soil is a key to protecting the soil, plants, and the environment. A study aimed to elucidate the effect of residual biomass application on some indicators of soil physical properties, an abundance of earthworms and soil microbial activities was conducted in *Kebun Percobaan* (KP) Natar, BPTP Lampung from February to July 2017. The treatments were three types of crops biomass residues, i.e., maize stover, rice straw, and soybean stover (fresh or compost). The dosage rates were 0, 2.5, 5.0, 7.5, and 10 t/ha. The treatments were arranged in a randomized block design with three replicates. Upland rice (Inpago 9 variety) was planted after two weeks application of biomass residues treatments. The results showed that application of crops biomass residues improved bulk density and significantly increased soil water content at the high dose of biomass residues (7.5 or 10 t/ha). The amount and weight of earthworms with added of compost biomass significantly correlated with soil water content (r values 0.491 and 0.376, respectively). The dose of biomass residues had a significant effect on soil respiration that the highest soil respiration was obtained in maize compost biomass treatment (at 12 weeks observation) was 31.7 and rice straw compost (at 8 weeks observation) which was 30.19 mg/hour/m^2 C-CO_2.

Keywords: *biomass residues, bulk density, earthworms, soil respiration, soil water content*

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Introduction

The soil in the wet tropical climate usually low fertility and low in soil organic matter content (mostly <2%) (Las and Setyorini, 2010). As was known, the organic material was a key to protecting and sustainability of soil, plants, and the environment. The organic material was composed of a variety of these simple and complex carbon compounds (Fisher and Glaser, 2012), as a nutrient source for soil microbial activities and act as decomposers in the process of decomposition of organic matter (Powers et al., 2009; Kara et al., 2014). Carbon organic soil plays an important role as source and nutrient sink and as a substrate for soil microbes (Tornquist et al., 2009), so the balance in soil, environment, and biodiversity need to be maintained and sustainably. The potential of biomass residues of crops such as rice, maize, and soybeans in Indonesia reach to 10 million tons per year which can be utilized as compost or returned directly in fresh as mulch to improve soil fertility. Soil amended with plant biomass residues displayed a wide variation of decomposition such as N mineralization depending on the plant species and plant components/organs which are largely related to their biochemical composition (Abbasi et al., 2015). Returning and addition of organic material to soil improve physical properties and ensuring root growth and penetration. Riwandi et al. (2015) reported that with the application of compost mixture of cattle dung and plant biomass of 5, 10, and 20 t/ha improved the growth and biomass of roots of corn crops. Organic matter improves soil water content (Evanylo et al., 2011) and modifies the soil water dynamic as well as increases water holding capacity (Milla et al., 2013). Compost can be defined as an organic multi-nutrient fertilizer containing significant amounts of valuable plant nutrients including N, P, K, Ca, Mg and S, and a variety of essential trace elements (Smith and Collins, 2007; Quilty and Cattle, 2011; Fisher and Glaser, 2012).

Soils with sufficient organic matter provide a suitable environment for fauna and soil microbes. Organic matter as an energy source for macro and micro-fauna of the soil, it was evident with that reported by Goyal et al. (2009), that addition of 5 t/ha of rice straw compost enhanced microbial C-biomass. The addition of organic matter to the soil was caused the activities, and the microbiological population in the soil was increased, especially related to the activities of decomposition and mineralization of organic matter. Beside soil microorganisms, soil fauna also plays a role in the decomposition of organic materials, that among others belonging to protozoa, nematodes, collembola, and earthworms. Soil fauna has a critical role in accelerate decomposition of organic matter and transfers nutrients through the result of microbial activities (Xin et al., 2012). Abundance and diversity of soil fauna refer to the numbers and diversities of plant species in an ecosystem and other environmental factors. On the soil with rubber stand, the fauna dominated by Acari order at sampling 0, 2nd, and 8th week and Collembola order at 4th, 6th, 10th, and 12th week, in which both orders have an important role in the process of decomposition of organic matter (Haneda and Asti, 2014). Earthworms as early decomposers serve to eat the crumbs of organic matter and remove it in the form of faeces after digestion in the body, that making it easier for microorganisms to decompose it further.

Microbial activities in the soil can be measured from the use of O_2 or the release of CO_2 as an indicator and called the soil respiration (Paul, 2007). Soil respiration is influenced by soil temperature and humidity, and is positively correlated with the numbers of soil fauna (Zhang et al., 2015). The measures of soil respiration can use the undisturbed soil or disturbed soil samples. Measurements in the field are done by pumping soil air or by covering the soil with a vessel that the volume is known (Saraswati et al., 2007). The evolution CO_2 from the soil is a product from the decomposition of organic matter; therefore, the degree of respiration is an indicator of the degree of decomposition of organic matter which occurs at certain intervals.

Materials and Methods

A study of residual biomass application effect on the abundance of earthworms and soil respiration was conducted in Natar village, Lampung Province in 2017. The biomass residues were from three crops, i.e. maize stover, rice straw, and soybean stover. The research comprised two sub-experiments: 1) The fresh form of biomass residues (as a mulch); and 2) The compost form of biomass residues. Three types of crop biomass residues, i.e. maize stover, rice straw, and soybean stover (fresh or compost) were applied to soil (Ultisol) with the rates of 0, 2.5, 5.0, 7.5, and 10 t/ha. After two weeks of biomass application, upland rice was planted. The treatments were arranged in a randomized block design with three replicates. Chemical fertilizers for upland rice were Urea, SP-36, and KCl with doses of 200, 150, and 75 kg/ha respectively.

Water content and soil bulk density

Undisturbed soil samples taken with ring samples were oven-dried at 105°C until the constant weight. The soil with the ring was weighed and then the soil removed, and the empty ring was weighed. Calculation of soil water content (WC) was as follow:

$$WC(\%) = \frac{\text{The weight of water}}{\text{The weight of dried soil}} \text{ x } 100\%$$

Calculation of bulk density (BD) value with the following equation:

$$BD = \frac{\text{The weight of dried soil}}{\text{Volume of soil}}$$

Observation of earthworm

Observation of earthworms was done after two weeks of crop biomass residues application using the square wood monolith 50 x 50 cm^2, and soil digging to the depth of 20 cm. Soil from a monolith replace to plastic sheeting was placed on the soil and hand sorted. Then, the earthworms were counted and weighed.

Soil respiration

Soil respiration is an indicator of microbial activity in the soil. In the process of respiration, O_2 was used by microbes and CO_2 was released, Respired CO_2 can be measured by use of an alkali trap followed by titration (Paul, 2007). Soil respiration measurements in the field were done by modification of the Verstraete method (Saraswati et al., 2007). Soil respiration measurements were made three times at 2, 8, and 12 weeks after addition of crops biomass residues. Two jars on each plot (treatment) were put on the soil, where one jar as a treatment and another jar as a control. The jar was enclosed to the soil so that it covered of the surface of the soil. Inside the jar was laid a bottle of film containing 10 mL 0.1 N KOH. The same was done for control, but the soil surface was covered with plastic, so KOH could not capture CO_2 that came out from the soil. The CO_2 field capture was conducted for two hours, and then KOH in the bottle of the film was brought to the laboratory for titration to determine the quantity of C-CO_2. Determination of CO_2 was made with KOH as a CO_2 catcher, the amount of HCl required for titration is equivalent to the amount of CO_2 produced, with the following equation,

$KOH + CO_2 \rightarrow K_2CO_3 + H_2O$
$K_2CO_3 + HCl \rightarrow KCl + KHCO_3$
$KHCO_3 + HCl \rightarrow KCl + H_2O + CO_2$

CO_2 amount was calculated using the following formula:

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

where:

C-CO_2	=	mg/hour/m^2
a	=	ml HCl for soil samples, (after adding methyl orange)
b	=	ml HCl for control, (after adding methyl orange)
t	=	normality of HCl
T	=	measurement time (hours)
r	=	the radius of the jar/tube (cm)

The yield of upland rice

Observation of upland rice yield was carried out on the number of grains/panicles, and the weight of grain per plot. The dry weight of rice straw biomass was also observed.

Statistic analysis

Analysis of variance was used to test differences between the means of treatments, and Duncan's multiple comparisons were used to post hoc test. Pearson correlation coefficient (r) was used to compare soil water content with the earthworms and soil respiration data. All statistical analyses were performed using the SPSS version 20.0.

Results

Soil water content and bulk density

The application of crops biomass residues increased the soil water content compared to the control (Table 1). The increase in water content was significant at a high dose of biomass (7.5 or 10 t/ha). However, this effect on BD soil was not significant. The lowest BD value was in the application of compost biomass residues of maize 7.5 t/ha and compost of rice straw 10 t/ha, that is 1.32, while the highest BD was on the control (without application of biomass residues).

Numbers and weight of earthworms

The application of crops biomass residues either in the form of fresh or compost affected the amount and weight of earthworms (Figure 1). The most common types of earthworms were *Lumbricus sp.* which has the highest body weight compared with other earthworms. The type of biomass did not significantly affect the number and weight of worms. However, the higher doses of compost biomass significantly affected the number and weight of worms, but there was no interaction effect of type and dose of biomass (Table 2). The average weight of earthworms was higher with the application of soybean biomass residues (fresh or compost) than the application of rice or maize biomass. The results of the correlation test (Pearson) showed no significant correlation between bulk density (BD) and the numbers and weight of earthworms in both fresh and compost application. The correlation value (r) between BD and earthworm weight with added composting biomass residues was 0.233. Meanwhile, correlation of water content and the amount and weight of earthworms with added of compost biomass was significantly correlated (r values 0.491 and 0.376, respectively) (Table 3).

Soil respiration

The return of maize, rice and soybean biomass residues in both fresh and compost increased soil respiration compared to control. The dose of fresh and compost biomass residues significantly affected soil respiration (Figures 1, 2, and 3). The application of biomass residues of fresh or compost form increased respiration of soil, but the average of soil respiration was higher in compost biomass treatment compared to fresh biomass.

Table 1. The water content and soil bulk density after the application of the plant biomass residues

Treatment	Fresh Biomass		Compost Biomass	
	Water Content (%)	Bulk Density (g/cm^3)	Water Content (%)	Bulk Density (g/cm^3)
1. Maize stover				
0.0 (control)	24.34 b	1.49 a	25.54 b	1.43 a
2.5 t / ha	22.01 b	1.48 a	30.38 ab	1.35 a
5.0 t / ha	26.14 ab	1.47 a	30.82 ab	1.40 a
7.5 t / ha	31.08 a	1.43 a	34.72 a	1.32 a
10.0 t / ha	29.96 ab	1.43 a	32.64 a	1.38 a
2. Rice Straw				
0.0 (control)	28.41 ab	1.45 a	30.05 ab	1.38 a
2.5 t / ha	26.46 ab	1.44 a	32.94 a	1.33 a
5.0 t / ha	27.85 ab	1.38 a	30.96 ab	1.34 a
7.5 t / ha	30.68 a	1.42 a	30.51 ab	1.36 a
10.0 t / ha	2 6.42 ab	1.44 a	31.92 a	1.32 a
3. Soybean stover				
0.0 (control)	31.41 a	1.44 a	27.59 ab	1.43 a
2.5 t / ha	29.97 ab	1.42 a	28.79 ab	1.39 a
5.0 t / ha	32.58 a	1.38 a	30.19 ab	1.37 a
7.5 t / ha	31.09 a	1.36 a	29.74 ab	1.34 a
10.0 t / ha	28.48 ab	1.41 a	31.73 a	1.36 a
	VC - 16.63	VC = 3.57%	VC = 14.87	VC = 5.46%

Remarks: The average value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at 5%

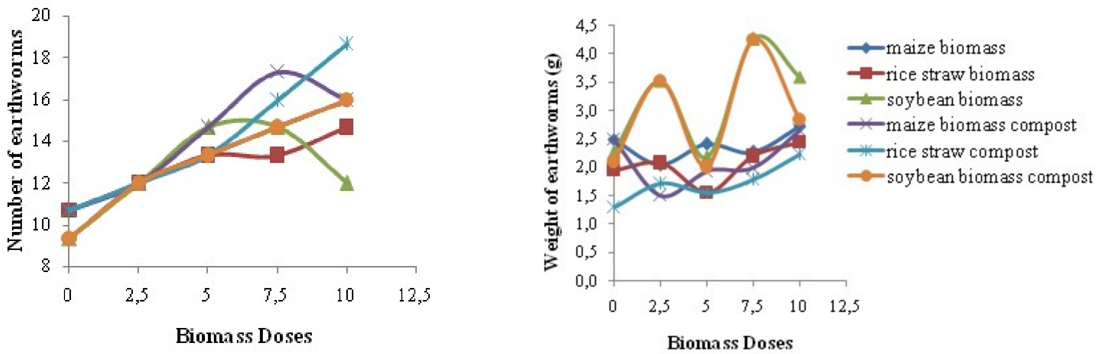

Figure 1. The number and weight of earthworm after two weeks application of biomass residues in 1 m^2 area

Table 2. Analysis of variance (tests of between-subjects effects) the number and weight of worms after added fresh and compost biomass

Source	df	F Value		P Value	
	Number of Worms	Number of Worms	Weight of Worms	Number of Worms	Weight of Worms
Corrected Model	14	0.787	0.854	0.674	0.611
Intercept	1	482.233	158.395	0.000	0.000
Fresh biomass	2	0.070	2.691	0.933	0.084
Doses	4	2.174	0.760	0.096	0.560
Fresh biomass*doses	8	0.273	0.441	0.970	0.887
Compost biomass	2	0.356	2.463	0.704	0.102
Doses	4	4.278	2.505	0.007**	0.032*
Compost biomass*doses	8	0.161	0.521	0.994	0.831

* and ** significant at $P< 0,05$ and $P< 0,01$ respectively

Table 3. Pearson correlation between soil water content with the amount and weight of earthworms on biomass residues treatment of fresh and compost form

		Fresh biomass residues		Compost biomass residues	
		Number of worms	**Weight worms (g)**	**Number of worms**	**Weight worms (g)**
Soil water content	Pearson Correlation	0.211	0.191	0.491 **	0.376 *
	Sig.(2-tailed)	0.163	0.209	0.001	0.011
	N	45	45	45	45

The type of crop biomass residues compost had a significant effect on soil respiration, but in a fresh form was not significant (Table 4). Biomass dosages also affected soil respiration but varied on each type and form of biomass, in general, the dose of biomass residues had a significant effect on soil respiration versus control. The highest soil respiration (31.7 mg/hour/m^2) was obtained in maize compost biomass treatment (at 12 weeks observation), and rice straw compost of 30.19 mg/hour/m^2 C-CO_2) at 8 weeks observation. The time after application also affected soil respiration, where at 8 and 12 weeks after the application, soil respiration was generally higher than in 2 weeks.

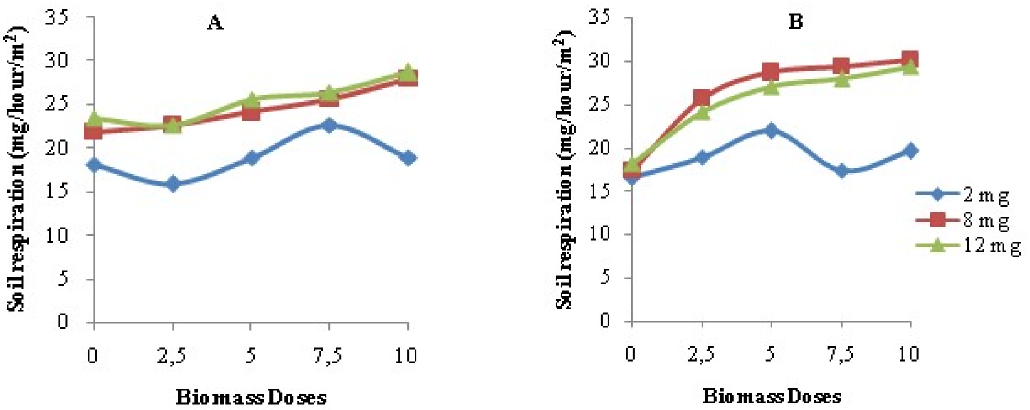

Figure 2. Soil respiration (C-CO_2) at 2, 8, and 12 weeks after application maize biomass residues (A = fresh biomass; B = compost biomass)

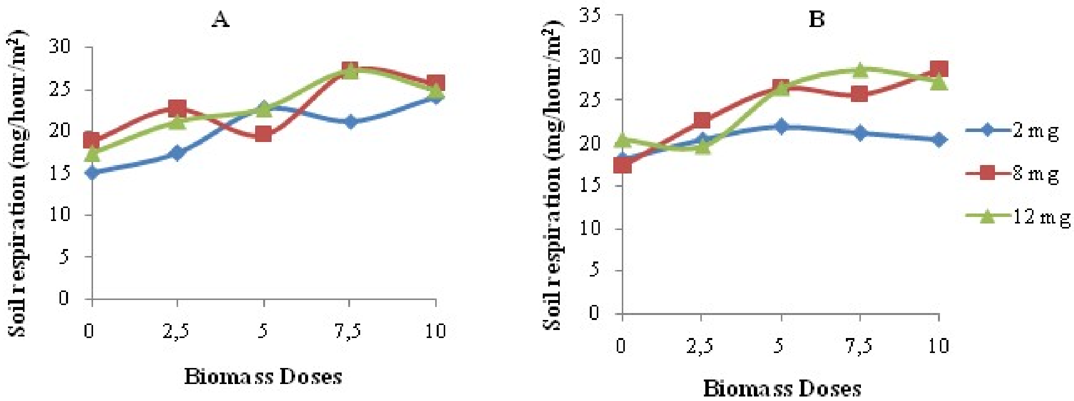

Figure 3. Soil respiration (C-CO_2) at 2, 8, and 12 weeks after application soybean biomass residues (A = fresh biomass; B = compost biomass)

Table 4. Analysis of variance (tests of between-subjects effects) of soil respiration at 2, 8, and 12 weeks after addition of fresh and compost biomass

Source	df	F Value			P Value		
Soil respiration		2 weeks	8 weeks	12 weeks	2 weeks	8 weeks	12 weeks
Fresh biomass	2	1.300	1.527	3.198	0.287	0.234	0.055
Doses	4	3.626	4.325	4.607	0.016*	0.007*	0.005*
Fresh biomass*doses	8	0.615	0.432	0.492	0.758	0.893	0.852
Compost biomass	2	0.381	4.345	0.438	0.686	0.022*	0.022*
Doses	4	1.296	22.259	11.691	0.294	0.000**	0.000**
Compost biomass*doses	8	0.109	0.323	0.576	0.999	0.951	0.951

* and ** significant at $P< 0,05$ and $P< 0,01$ respectively

The rice yield

The addition of compost of crops biomass residues had no significant effect on the yield component (the number of grains/panicles and the weight of grain), but at highest dosage (7.5 and 10 t/ha) of rice straw significantly increased the number of grains/panicles (Table 5).

The addition of rice straw compost or soybean stover compost significantly increased dry weight of rice straw at high doses (7.5 or 10 t/ha), whereas at lower doses there was no significant effect. The highest of grain weight per plot (19.3 kg) was obtained in the addition of 7.5 t/ha of rice straw compost.

Table 5. Yield component of upland rice and straw weight after application of compost of crops biomass residues

Treatment	Number of grains/panicles	Weight of grain/plot (5 x 10 m) (kg)	Dry weight straw (10 plants) (g)
1. Maize stover			
0.0 (control)	151.67 b	13.0 a	784.45 b
2.5 t / ha	164.67 b	15.0 a	804.33 b
5.0 t / ha	169.33 ab	15.8 a	717.62 b
7.5 t / ha	175.00 ab	16.5 a	803.20 b
10.0 t / ha	174.33 ab	16.5 a	1140.93 a
2. Rice Straw			
0.0 (control)	165.67 ab	14.0 a	896.78 ab
2.5 t/ ha	165.00 ab	13.5 a	860.50 ab
5.0 t / ha	174.67 ab	16.5 a	992.58 ab
7.5 ts / ha	181.67 a	19.3 a	1079.82 a
10.0 t / ha	191.00 a	17.0 a	995.43 ab
3. Soybean stover			
0.0 (control)	153.00 b	15.0 a	855.98 ab
2.5 t / ha	163.67 b	15.0 a	871.33 ab
5.0 t / ha	172.67 ab	15.5 a	905.97 ab
7.5 t / ha	176.00 ab	16.8 a	1065.58 a
10.0 t / ha	170.62ab	17.3 a	1229.12 a
St.Dev	16.36	4.37	173.0

Description: The average value followed by the same letter in the same column is not significantly different according to Duncan's multiple range test at 5%

Discussion

Addition of compost of crops biomass residues increased the soil water content especially at high doses; this was due to the increase of organic matter content, the increase of macroaggregate formation, and the increase of fast drainage pores (Barus, 2016; Fisher and Glaser, 2012). Many studies have shown that the return of organic material to the soil affects the soil properties and the presence of fauna and microbes that play a role in the decomposition of organic matter. The increase of water content under added compost of crops biomass residues implies that there would be more water available for the rice plants growth during the dry season. Zhang et al. (2009) reported that the management practice such as mulching (the air-dried wheat straw 0.8 kg/m^2) and no-till practice could increase soil water storage levels, especially in upland. Compost can effectively improve soil quality as well as soil hydraulic and pore characteristics (Eusufzai and Fujii, 2012).

The application of crops biomass residues tended to improve soil bulk density than control in this study. Soil bulk density (BD) is affected by soil organic matter content, in accordance with Busscher et al. (2011) research results that with the increase of total organic carbon by the addition of organic matter into the soil can significantly lower the BD. The study result of Barus (2016) showed that the return of organic matter from the biomass residues of the plant both in the form of compost and biochar improved the physical properties of soil such as bulk density, total porosity, and soil drainage pore. The soil physical properties improvement was due to the binding of soil organic matter and clay particles via cation bridges and through stimulation of microbial activities and root growth (Farrel and Jones, 2009).

The addition of crops biomass did not significantly affect the number and weight of worms, but doses of compost biomass were significant. The higher of compost dose added increased the amount and weight of the worm. Decomposition rates of the individual plant species depend on the initial characteristics of the biomass that plays a primary role in the process of decomposition. According to Anwar (2009), the organic material source affected the rate of decomposition by earthworms into vermicompost, where the organic material from market residues were decomposed most easily by earthworms compared to rice straw and the empty palm oil bunches. The application of biomass residues compost form increased the number and weight of earthworms compared with the application of fresh form. Composting decreases C/N, so compost is preferable than fresh matter. As stated by Ritonga et al. (2016) that worms like a high quality of organic matter (lower C/N). In contrast, earthworms also play a role in the decomposition of organic matter and play a role in biogeochemical cycles by cutting and feeding the plant litter so the material is easier to be decomposed and destroyed. The role of soil fauna in the decomposition of plant residues from macro and meso-fauna such as oligochaeta and arthropods that play a role in the early stages of decomposition (Monroy et al., 2011). Earthworms are detritivores and selective in choosing organic materials (palatability), are dependent on the value of C/N, lignin and polyphenols (Hendriksen (1990), and type of land use significantly affects the wet weight of earthworms (Hairiah et al., 2004).

The correlation of water content and the amount and weight of worms with the addition of compost biomass was significantly correlated (r values 0.491 and 0.376, respectively). Faber et al. (2017) reported that earthworm densities were correlated positively with soil moisture and negatively with soil temperature. Many studies have shown that the return of organic material to the soil affects the soil properties and the presence of fauna and microbes that play a role in the decomposition of organic matter. Barus (2016) reported that the application of 10 t/ha straw compost significantly increased the soil water available (at pF 2.54) compared to control. Earthworms prefer moist soil than dry soil, the opposite, the presence of earthworms also affects the soil water content. Earthworms usually get their food, i.e. litter on the soil, but the worm moves actively in the soil either horizontally or vertically to make many burrows in the soil, thus can increase the porosity of the soil (Hairiah et al., 2004). Soil fauna (earthworms) affects soil physical properties by forming macropores, moving through the soil by digging galleries and burrows, and digesting the casts and pellets that are often the basic components of well-developed macroaggregate structure (Lavelle et al., 1992).

The dosage of biomass residues had a significant effect on soil respiration in both fresh and compost. The type of fresh biomass residues of crops had no significant effect on soil respiration, but in the form of compost, the type of crops biomass residues had a significant effect. Plant types and forms of biomass, fresh or compost affect the quality of the organic material, including the levels of C, N, or C/N. Nguyen and Marschner (2016) reported that biomass residue added with lower C/N increased microbial biomass C, N, and P compared to higher C/N biomass. The transformation of organic matter is controlled by soil organism due to degradation of organic carbon compounds makes energy available for heterotrophic organism. The total soil respiration in relation to litter decomposition had similar patterns for the three stands of *Pinus massoniana* forests, showing a quadratic function (R^2=0.37) (Xiao et al., 2014).

The time after application also affected the soil respiration, where at 8 and 12 weeks after the application, soil respiration was generally higher than in 2 weeks. This was likely due to at 2 weeks after application; the soil condition was still affected by the impact of soil tillage that made many microbes died. Beside that, after 8 and 12 weeks, rice plants have grown and covered the soil surface, that creating an ideal environment for microbial proliferation. During the composting process, the respiration rate was initially high but decreased with time as the decrease of dissolve organic-C concentration. Goyal et al. (2009) reported that CO_2-C evolution was faster at 21 days (after incubation of 5 t compost/ha) and then decreased in the following weeks. The higher values of respiration mean more CO_2 produced by microorganisms, so it indicates that the activities of microorganisms in the soil also increases. Soil microbial responses to glucose and phosphorus addition under laboratory conditions where sugar as a carbon and energy source for soil microorganisms. Nguyen and Marschner (2016) reported that amendment of soils with residues of young kikuyu shoots, young eucalyptus leaves, and mature wheat shoots increased microbial biomass C concentration compared to control (without amended residues) at 7 days or 21 days after addition.

Land-use changes and differences in cropping patterns may affect the state of soil organic matter and the presence of soil microbes. According to Susilawati et al. (2013), carbon biomass of microorganisms (C-mic), soil respiration, and total microorganisms are related to each other and influenced by soil organic matter content. The research results of Ritonga et al. (2016) showed that changes in forest stands to various cultivated plant stands decreased the soil C-organic content, soil total-N, earthworm population, soil respiration and soil microorganism populations.

The return of compost of maize biomass residues had no significant effect on the yield component (the number of grains/panicles and the weight of grain). Generally, application of the crops biomass residues with low doses did not significantly increase the yield component and the weight of straw, this was because the nutrient content in organic materials was relatively lower than inorganic fertilizers. While the release of N from the organic material takes place through the mineralization process followed by the aminization, ammonification, and nitrification process, where all the stages of the process depend on microbial activity, Agegnehu et al. (2015) reported that addition of compost of 25 t/ha significantly increased the yield of peanut compared to control (inorganic fertilizer).

The effect of crops biomass residues on dry weight of rice straw was significant at high doses (7.5 or 10 t/ha). Barus (2016) reported that the application of rice straw compost and biochar rice husk of 10 t/ha had significantly increased the yield of upland rice, due to their multiple positive effects on physical, chemical and biological soil properties. Badiane et al. (2012) reported that water stress significantly reduced grain yields of maize. So, the addition of organic material can modify the soil water dynamic as well as increase water holding capacity (Milla et al., 2013). Management practices such as sugarcane straw removal of > 25% caused soil physical quality reduction and making it less favourable to plant development (Satiro et al., 2017). Further, Mahmoud et al. (2009) reported that addition of rice straw compost equivalent to 10 t/ha increased soil organic matter from 1.15 % to 3.42 %. Soil organic-C plays an important role as a source and sink as well as a substrate for soil microbes (Tornquist et al., 2009) so that the balance and the biodiversity in soil are maintained.

Conclusion

The application of crops biomass residues improved physical properties such as bulk density and soil water content, increased the amount and weight of earthworms, increased soil respiration, and yield of upland rice. Application of compost biomass was better than fresh biomass to improve soil properties, and at high doses, the effect was better than at low doses.

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