The Types and The Amounts of Organic Matter Influence Carbon Dioxide Production in The Reclaimed-Mine Tropical Soils

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Abstract. The rate of carbon (C) mineralization plays an important role in environmental system as it determines the amount of carbon dioxide emit to the atmosphere and the amount of organic carbon stabilized by soil minerals. Therefore, assessing the influence of organic matter (OM) types on the C mineralization is essential to understanding mechanisms to reduce carbon dioxide production and to improve SOC contents in the reclaimed-mine tropical soils. In this study, four different types of OM (albizia, acacia, calopo and mixed-albizia-acacia-calopo) with 4 different rates: 0, 0.5, 1.0 and 1.5 of maximum capacity of soils to adsorb OM (Qmax) were added to a 3-years reclaimed-mine soil, and the C mineralization of added OM was quantified over a 90-day of incubation period. Results of the study revealed that the addition of albizia resulted in the C mineralization of 45.2% added OM, while the C mineralization of 58.1% added OM was observed when calopo was applied to the soil. Differences in the C mineralization with different types of OM was related to differences in the chemical composition of added OM. Addition of albizia at the rate of 0.5 Qmax produced the C mineralization of 38.7% added OM, while only 50.2% and 46.6% of added OM was mineralized when albizia was added to soils at rates of 1.0 and 1.5 Qmax, respectively. This study showed that the chemical composition of OM originated from vegetation may also be considered in the selection of vegetation types for mined-land reclamation in order to reduce carbon dioxide production and to increase the OC contents of the reclaimed-mine tropical soils.

1. Introduction
The presence of organic matter (OM) is crucial for reclaimed-mine soils due its function to improve physico-chemical and biological properties of the soils [1, 2, 3]. Results of the previous study reveal that reduction of toxic and soluble Cr(VI) to Cr(III), which is insoluble and less toxic in the soils increases with increasing soil OM contents [4, 5]. These results suggest important role of OM in maintaining fertility of reclaimed-mine soils. However, several studies indicate that mining areas in the South Kalimantan Province that have been reclaimed and revegetated with acacia and albizia for 3-7 years contain only 2.70-8.40 g C kg⁻¹ soil [6] and range from 4.60 g C kg⁻¹ soil to 15.70 g C kg⁻¹ soil for the 3-11 years of reclaimed-mine soils [7]. Results of this study indicate that most OM in the reclaimed-mine soils decompose rapidly and return to the atmosphere in the forms of carbon dioxide.
and methane, which contribute to the global warming. On the other hand, only a small portion of OM in the reclaimed-mined soils is stabilized by soil minerals that eventually result in an increase in the soil OM contents.

The contents of soil OM are determined by the equilibrium between the soil organic matter input and the amount of organic matter lost from the soil through organic matter decomposition [8, 9]. Higher amount of OM inputs than amounts of decomposed OM leads to an increase in the soil OM contents, while higher rate of OM decomposition than OM deposition results in increase in the amount of carbon dioxide emit to the atmosphere [10, 11, 12]. The amount of organic carbon stabilized by soil minerals or the amount of carbon dioxide produced during OM decomposition is controlled by several factors such as the chemical composition of organic matter, clay mineralogy and the presence of iron oxide and aluminium oxide.

The chemical structure of organic carbon determines the rate of carbon mineralization [13]. Organic carbon corresponding in lignin compounds is negatively correlated with carbon mineralization in the soil, while organic carbon in the form of carbohydrate compounds has a significant positive correlation with carbon mineralization [14]. Results of this study indicate that C-organic with alkyl C structure is more resistant to microbial decomposition than organic C with O-alkyl C structure (carbohydrate). Based on the results of this study, it was hypothesized that soils with similar physico-chemical properties but planted with different types of vegetation would have different rate of carbon mineralization, which ultimately would have different amounts of carbon dioxide produced and released to the atmosphere. To examine this hypothesis in the present study, we determine the carbon mineralization of reclaimed-mine soils applied with different types of organic matter (albizia, acacia, calopo, and mixed albizia-acacia-calopo).

2. Materials and Methods

2.1. Soil and Organic Matter Sampling
Soil sample for this study was collected from reclaimed-mine soils of the PT. Arutmin Indonesia, Satui Site, Tanah Bumbu District, South Kalimantan Province. The site was reclaimed and revegetated with albizia and acacia in 2013, and calopo was grown as soil cover crop. The soils were cored at a depth of 0-20 cm using a soil auger at several different points. After removing plant debris remains, the soil samples were homogenized, air-dried and then ground to ≤ 2.0 mm. After that the soil samples were stored at 4 oC until used for the experiment.

Fresh organic matters (OM): albizia, acacia and calopo, which were collected from the reclaimed-mine soils of the PT. Arutmin Indonesia, Satui Site, Tanah Bumbu District, South Kalimantan Province were oven-dried and then ground to <2.0 mm. Chemical analyses were conducted for all OM to measure the contents of organic C, total N, hot water soluble C, cellulose, hemicellulose and lignin [15, 16, 17]. The chemical composition of OM used in this study is described in Table 1.

2.2. Incubation Study
Soil samples were combined homogenously with each OM (the amount of added OM was equal to 0, 0.5, 1.0 and 1.5 capacity of soil for adsorbing organic matter – Qmax) in the container made from the polyvinyl chloride (PVC) tube of 1.5 inch. The combinations were then compressed to a depth of 2.0 cm to acquire a bulk density (BD) of compressed soils similar to the BD measured in the field. Aquadest was then added to the container to achieve 70% water-filled pore space (WFPS). The containers were then transferred into 1000 mL jars including 5 mL distilled water in a 20 mL glass vial to keep humidity. The jars were closed with air-tight lids containing butyl septa for gas sampling from the jars and subsequently incubated in the dark at constant room temperature for 90 days. Three replicate samples were prepared and incubated for each type and amount of OM. Carbon mineralization from each treatment was measured to determine organic C stabilization by determining the headspace CO2 concentrations within each jar using a gas chromatograph (Shimadzu GC-14A). Measurement of carbon mineralization was conducted repeatedly for each sample over the 90-day of incubation period.
3. Results and Discussion

Organic matters used in this experiment had relatively equal organic carbon contents, ranging from 319 to 370 g C kg⁻¹. However, the total nitrogen content of these organic matters was different, in which the total nitrogen content of acacia and the mixed-albizia-acacia-calopo were relatively equal. The highest total nitrogen content was found in calopo. Complete analysis of the chemical composition of the OM used in this study is presented in Table 1.

| Characteristic                  | Acacia    | Albizia   | Calopo    | Mixed Acacia-Albizia-Calopo |
|--------------------------------|-----------|-----------|-----------|----------------------------|
| 1. Organic C (g kg⁻¹)          | 343.5     | 318.7     | 370.4     | 324.5                      |
| 2. Total nitrogen (g kg⁻¹)     | 18.8      | 21.5      | 28.5      | 18.9                       |
| 3. Hot water soluble C (g kg⁻¹)| 16.5      | 22.5      | 27.3      | 17.4                       |
| 4. Cellulose (g kg⁻¹)          | 31.3      | 36.5      | 37.2      | 31.3                       |
| 5. Hemicellulose (g kg⁻¹)      | 25.4      | 21.3      | 31.5      | 33.5                       |
| 6. Lignin (g kg⁻¹)             | 19.7      | 26.1      | 14.9      | 16.7                       |

Analysis of variance showed that the types and amounts of applied OM had significant effect (P < 0.001) on carbon mineralization data. Carbon mineralization of reclaimed-mine applied with different types and amounts of OM is described in Figure 1. Carbon mineralization of reclaimed-mine soils applied with albizia, acacia and mixed albizia-acacia-Calopo was not different. Regardless of the amount of applied OM, carbon mineralization applied with these three organic matters ranged from 259 to 2109 mg CO₂ C kg⁻¹ soil (Figure 1). However, the addition of calopo to the soils produced the highest carbon mineralization compared to other types of OM. This is thought to attribute to the relatively low C/N ratio of calopo so that the carbon mineralization proceeded very quickly. Thus, for the purpose of stabilizing organic matter in the reclaimed-mine soils, it is recommended that organic materials to be able to increase soil OM contents are acacia or albizia.

**Figure 1.** Effect of the types and the amounts of added OM on carbon mineralization. Vertical bars are standard deviation of mean (n=3). Similar litters above the vertical bars show no statistical difference between the treatments at P < 0.05.
The amount of added organic carbon stabilized by soil minerals was calculated using the data of the amount of soil organic carbon, the amount of organic carbon from added organic matter, and the amount of carbon mineralized from soil and added organic matter. The amount of carbon stabilized by soil minerals from different types and amounts of organic matter is shown in Figure 2. Figure 2 showed that in all types and levels of the amount of added organic matter, the amount of carbon stabilized by soil minerals ranged from 33% to 61% of added OM.

Regardless of the amount of added OM, albizia had the highest stabilization of organic matter (average 54.8%), followed by acacia (49.8%) and mixed albizia-acacia-calopo (47.4%). Calopo had the lowest organic matter stabilization (average 41.9%) compared to other types of organic matter. Differences in the stabilization of organic carbon for different types of OM are related to variation in the chemical carbon structure (chemical composition of OM). Calopo has the lowest stabilization rate among the OM applied to the soil because its lowest C/N ratio and relatively high hot water soluble organic carbon. This is in agreement with the theory of OM decomposition that suggest the water-soluble compounds such as glucose and other simple compounds are the first compound utilized by soil microorganisms during the OM decomposition [18].

Organic matter from albizia had the highest organic carbon stabilization compared to other organic matters. Table 1 shows that albizia had a relatively high lignin content. Organic matter with high lignin compounds generally have a low decomposition rate compared with OM with low lignin content [19, 20, 21, 22]. The effect of lignin on the rate of organic matter decomposition is also reported in other studies. For example, significant relationship between the lignin content of OM and the decomposition rate of OM, in which a relatively high lignin content of organic matter resulted in a decrease in the rate of organic matter decomposition [23]. A young of acacia litter with low lignin contents had faster decomposition rate than the older acacia litter with relatively high lignin contents [24]. Results of this study imply that revegetation of reclaimed-mined soils with albizia produces a higher organic carbon stabilization than revegetation with acacia. Figure 2 also shows that addition of albizia at the level of 0.5Q\text{max} (the amount of organic material added is half of the maximum capacity of soil in absorbing the organic carbon), 39% of the added organic carbon has decomposed and returned to atmosphere in the form of CO2. Non-decomposing organic matter (61% of added organic carbon) has been stabilized by soil minerals, which eventually increase soil organic matter contents. At the level of addition of 1.0\ Q\text{max} and 1.5\ Q\text{max}, 50% and 47% of the albizia added to the soil was decomposed and returned to the atmosphere in the form of CO2 gas (Figure 2). Thus, only 50% and 53% of the albizia added to the soils.

Figure 2. Effect of the types and the amounts of added OM on carbon stabilization. Vertical bars are standard deviation of mean (n=3). Similar litters above the columns show no statistical difference between the treatments at P<0.05.
were stabilized by soil minerals. Based on these calculations, it appears that the application of albizia at the 0.5 $Q_{\text{max}}$ level results in the highest stabilization of OM. Therefore, it is recommended that the amount of albizia to be applied to the reclaimed-mine soils to lead an increase in the soil OM is equivalent to 0.5 $Q_{\text{max}}$ (half the maximum capacity of soil in absorbing OM).

4. Conclusion

Results of the experiment showed that among several types of OM (albizia, acacia, calopo and mixed albizia-acacia-calopo) applied to reclaimed-mine soils, calopo yielded the highest carbon mineralization. On the other hand, albizia produced the lowest rate of carbon mineralization. The highest carbon mineralization of calopo is attributed to its chemical composition that containing easily decomposed compounds as shown by the low C/N ratio. The amount of OM applied to the reclaimed-mine soils to produce minimum carbon mineralization is equal to 0.5 $Q_{\text{max}}$ (half of the soil's capacity to absorb organic matter). Results of this study demonstrate that the chemical structure of organic carbon originated from vegetation should also be considered in the selection of vegetation types for the reclamation of mined-soils in order to reduce carbon dioxide production and to improve SOC contents in the reclaimed-mine tropical soils.

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