Measuring of leaf litter decomposition rate and flux of carbon dioxide in various land cover in Gunung Bromo Education Forest, Karanganyar

A A Darmawan¹, D P Ariyanto²*, T M Basuki³ and J Syamsiyah²

¹Student of Magister Program of Soil Science, Graduate School of Sebelas Maret University, Jl. Ir. Sutami 36 A, Kentingan, Surakarta 57126, Central Java, Indonesia.
²Soil Science Department, Faculty of Agriculture, Sebelas Maret University, Jl. Ir. Sutami 36 A, Kentingan, Surakarta 57126, Central Java, Indonesia.
³Watershed Management Technology Center, PO BOX 295, Jl. A. Yani-Pabelan, Surakarta, Central Java, Indonesia.

*Correspondence: dp_ariyanto@staff.uns.ac.id

Abstract. The process of leaf litter decomposition on the soil surface as a source of nutrition and food for soil fauna. Leaf litter decomposition rate is influenced by the activity of soil fauna, which is thought to increase the emission of carbon dioxide from the soil. The aim of this research was to investigate the leaf decomposition rate and flux of carbon dioxide in various land cover. The research was conducted from July to November 2020 in Gunung Bromo Education Forest, Karanganyar, Central Java. This research used purposive sampling with nine land covers and three replications. The leaf decomposition rate was measured using the litterbag method, and flux of carbon dioxide was measured using the closed chamber method. The results suggested that the leaf decomposition rate was the fastest in Pine 2016 at 6.17 g/week, and the highest flux of carbon dioxide in Indonesian rosewood (Dalbergia sissoo) rejuvenation was 9,860 mg/CO₂/day. The leaf decomposition rate was influenced by air temperature (p = 0.535) compared to humidity (p = -0.257). Flux carbondioxide is influenced by air temperature (p = 0.854) compared to humidity (p = -0.677), and the leaf decomposition rate affects the level of flux of carbon dioxide (p = 0.631).

1. Introduction

Forests are one of the semi-natural habitats providing important ecosystem services such as air storage, climate regulation, improved air quality, carbon and nitrogen sequestration [1]. One of them is the Education Forest where several activities have been carried out as part of natural science, environmental education and continuing education, outdoor education, and vocational education [2]. Gunung Bromo Educational Forest has been done a lot for research activities where there are 3 main land covers, namely pine trees, mahogany trees and sonokeling or rosewood (Dalbergia sissoo) trees. In pine land cover, there are secondary trees in the form of mahogany plants as litter production plants. Leaf litter is an important carbon source in the decomposition process [3].

The decomposition of organic matter is an important ecological process in forest ecosystems. The decomposition process starts from the crushing process carried out by small insects on parts of plants and organic matter into smaller sizes. Then proceed with the biological process carried out by bacteria and fungi assisted by enzymes that can break down organic materials such as proteins, carbohydrates
and others. This litter decomposition is an important step in the nutrient cycle and can provide nutrients for plants and feed soil fauna [4].

Several factors can influence the rate of leaf litter decomposition such as physicochemical properties of litter (leaf toughness, nitrogen and lignin concentrations), regional climate (e.g. temperature, precipitation), soil properties (e.g. soil moisture, pH and soil nutrient concentration) and composition and decomposers activity [5, 6, 3]. Increased temperature and low humidity can affect the rate of decomposition of leaf litter and change the associated invertebrate fauna [7]. The high biomass of leaf litter indicated a potential source of high nutrient cycling if it is maintained to undergo decomposition at the bottom of the ecosystem but also a lot of carbon dioxide (CO₂) emissions [8]. Increased aerobic decomposition activity can increase the emission of CO₂ into the atmosphere [9]. Land cover also implies an increase in CO₂, this is because the organic C stored in leaf litter, decomposes and releases stored C into the atmosphere [10].

The relationship between environmental factors on decomposition rate and flux of CO₂ emissions, which has never been conducted at Gunung Bromo Education Forest, Karanganyar. In the Gunung Bromo Education Forest, there is land management by forest farmers as agroforestry, namely on pine 2016 and Indonesian rosewood rejuvenation, presumably due to this cultivation activity can affect the rate of decomposition and flux of CO₂. Therefore, this underlies researchers to conduct research aimed at the purpose of this study is to determine the rate of decomposition and flux of CO₂ in various land cover in Gunung Bromo Educational Forest Karanganyar, given the importance of the decomposition or mineralization process in the soil nutrient cycle and its role in CO₂ emissions.

2. Materials and method

2.1. Site description and experimental design
The research was conducted from July-November 2020 in Gunung Bromo Education Forest, Karanganyar. Analysis of decomposition rate was conducted in the Soil Science Laboratory at the Faculty of Agriculture, Sebelas Maret University. CO₂ gas analysis was conducted in the GHG Laboratory of the IAERI, Pati. This research used purposive sampling with nine land covers and three replications: Pine 1973, 1994, 1996, 2000, 2003, 2007, 2016, Mahogany 1949 and Indonesian rosewood rejuvenation.

2.2. Air Temperature and humidity
We measured of temperature and humidity for each air uses a thermohygrometer attached to each plot. Measurements were taken every 3 days in the morning (06.00-07.00), afternoon (12.00-13.00) and evening (16.00-17-00).

2.3. Precipitation
Precipitation data from Nasa Power 2020 which can be obtained can be downloaded at the address https://power.larc.nasa.gov/data-access-viewer/ at coordinates -7.5833329,110.980546 (location of Gunung Bromo Education Forest, Karanganyar).

2.4. Collected of leaf litter
Collected of leaf litter is taken from the surface of the forest on various land cover. The leaf litter used is mahogany leaves because a mahogany tree as a secondary tree as a litter production plant. The leaf litter used to measure the decomposition rate is 50 g, planted using a litter bag made of wire mesh measuring 50 mm x 50 mm with dimensions of 50 cm x 50 cm x 5 cm. Litter bags are placed on surface of the ground on various land cover of 4 pcs / plot. The litter bag is left for 2 months, where it will be destructed 4 times every 2 weeks.
The litter is taken from each plot and then washed first to remove the soil adhering to the litter. Furthermore, the clean and dry litter is wrapped in aluminum foil and oven for 48 hours at a temperature of 75º-80º C. Then weigh the dry weight of the litter with a digital scale.

2.5. Collected of CO₂ gas
Gas samples were collected at 2\textsuperscript{nd}, 4\textsuperscript{th}, 6\textsuperscript{th}, and 8\textsuperscript{th} week. The GHGs taken were CO₂ using closed chamber technique with dimensions of 40 cm x 20 cm x 30 cm. Samples were taken with 10 ml syringes attached to a three-way stopcock at 3, 6, 12 min for CO₂, respectively, and then injected into 5 ml evacuated vaccutainer. The GHG concentrations in the samples were analyzed in the laboratory using a gas chromatograph GHG 450 Varian type, with equipped Thermal Chapter Detector (TCD) for CO₂. Gas sampling was consistently conducted between 06:00 and 08:00 A.M. to minimize the effect of diurnal variations.

2.6. Mass loss of litter and decomposition rate
The calculated of the mass loss of litter in the same way as the following formula [4]:

\[
L \text{ (%) } = \left( 100 \frac{(W_o - W_t)}{W_o} \right)
\]

where L is mass loss of litter (%), W₀ is litter weight before the study started (gr), Wₜ is dry weight of litter left after time t (gr).

The litter decomposition rate is calculated using the following formula [4]:

\[
R = \frac{(W_o - W_t)}{T}
\]

Where R is decomposition rate (g/week), T is time of observation (weeks), W₀ is initial dry weight of litter (gr), Wₜ is final dry weight of litter (g) per time period.

2.7. Flux of CO₂ analyzed
CO₂ emission was calculated as described by IAEA [11]:

\[
E = \frac{dc}{dt} \times \frac{V_{ch}}{A_{ch}} \times \frac{m_{W}}{m_{V}} \times \frac{273.2}{(273.2 + T)}
\]

where E is the gas emission (mg m\textsuperscript{-2} day\textsuperscript{-1}), dc/dt is difference in concentrations per times (ppm minute\textsuperscript{-1}), V_{ch} is box volume (m\textsuperscript{3}), A_{ch} is box width (m\textsuperscript{2}), m_{W} is molecule weight (g), m_{V} is molecule volume (22.41 l) and T is the mean air temperature inside the chamber during sampling (ºC).

3. Result and discussion

3.1. Environmental factor
Environmental properties are taken in the field and include air temperature and humidity, and precipitation is obtained from Power Nasa Data Access. The air temperature during the study was a minimum temperature of 16.8ºC and a maximum temperature of 39.8ºC (Figure 2). The minimum relative humidity is 57.9% and the maximum air is 81.4% (Figure 3). The field conditions during the study were classified as dry months with rain intensity less than 100 mm/day (Figure 1).

Precipitation can determine the level of temperature, humidity and that can affect various biological activities. Precipitation can also be used to calculate the estimated soil moisture using the Standardized
Precipitation Index (SPI) [12]. Precipitation can also control physical litter washing, where when the precipitation is high it can accelerate the breakdown of litter. One of them in pine 2016 and Indonesian rosewood rejuvenation has a low canopy density.

**Figure 1.** The average precipitation in Gunung Bromo Education Forest in September-November 2020.

**Figure 2.** The temperature in September-November 2020 in various land covers.

**Figure 3.** The relative humidity in September-November 2020 in various land covers.

### 3.2. Decomposition and flux of CO₂

**Table 1.** Condition, mass loss, decomposition rate and flux of CO₂ in various land cover.

| Land Cover          | Condition     | Mass Loss (%) | Decomposition Rate (gr week⁻¹) | Flux of CO₂ (mg m⁻² day⁻¹) |
|---------------------|---------------|---------------|-------------------------------|---------------------------|
| Pine 1973           | Moist         | 37.75         | 3.82                          | 7437.92                   |
| Pine 1994           | Moist         | 21.20         | 1.85                          | 7036.49                   |
| Pine 1996           | Moist         | 29.39         | 2.46                          | 7948.49                   |
| Pine 2000           | Moist         | 31.78         | 2.57                          | 7303.84                   |
| Pine 2003           | Moist         | 35.63         | 2.39                          | 7948.49                   |
| Pine 2007           | Moist         | 41.25         | 3.96                          | 8377.60                   |
| Pine 2016 (agroforestry) | Dry       | 57.75         | 6.18                          | 8422.05                   |
| Mahogany 1949       | Moist         | 27.92         | 2.63                          | 6998.82                   |
| Indonesian rosewood (rejuvenation) | Dry | 44.10         | 4.40                          | 9860.95                   |
The lower mass loss was reached with Pine 1994 by 21.20%, then the higher mass loss for Pine 2016 by 57.75%. On the other hand, the lower decomposition rate was reached with Pine 1994 by 1.85 gr week\(^{-1}\), than the higher Pine 2016 by 57.75 gr week\(^{-1}\). Flux of CO\(_2\) were lowest for the Pine 1994 by 7036.49 mg CO\(_2\) m\(^{-2}\) day\(^{-1}\), then the higher flux of CO\(_2\) in Indonesian rosewood (rejuvenation) by 9860.95 mg CO\(_2\) m\(^{-2}\) day\(^{-1}\) (Table 1).

### 3.3. Relationship decomposition and flux of CO\(_2\)

**Table 2.** Correlation of the parameters in this research.

| Correlation          | Temperature | RH  | Mass Loss | Decomposition Rate |
|----------------------|-------------|-----|-----------|--------------------|
| Relative Humidity    | -0.656      |     |           |                    |
| Mass Loss            | 0.539*      | -0.288 |           |                    |
| Decomposition Rate   | 0.536       | -0.258 | 0.990**   |                    |
| Flux of CO\(_2\)     | 0.855*      | -0.677 | 0.664     | 0.632*             |

Significant * (0.05) and ** (0.01)

Relationship between environmental parameters such as temperature and relative humidity to mass loss, decomposition rate and flux of CO\(_2\) (Table 2; Figure 4-10). This study showed that there is a positive significance between temperature-mass loss, temperature-flux of CO\(_2\), and decomposition rate-flux of CO\(_2\), so there is a very positive significance on mass loss-decomposition rate. The relationship between these parameters can be used as an experimental model (Figure 11).

![Figure 4](image1.png) **Figure 4.** Relation mass loss and various temperature.

![Figure 5](image2.png) **Figure 5.** Relation mass loss and various relative humidity.

![Figure 6](image3.png) **Figure 6.** Relation decomposition rate and various temperature.

![Figure 7](image4.png) **Figure 7.** Relation decomposition rate and various relative humidity.
Figure 8. Relation flux of CO$_2$ and various temperature.

Figure 9. Relation flux of CO$_2$ and various relative humidity.

Figure 10. Relation flux of CO$_2$ and decomposition rate.

Figure 11. Modeling relationship between temperature, relative humidity, mass loss, decomposition rate and flux of CO$_2$. 
Temperature directly affects the mass loss rate of 51.9%, affects the decomposition rate of 2.7%, and affects the CO$_2$ flux of 52.5%. Temperature indirectly affects the decomposition rate through the mass loss path by 51.1% and affects the flux of CO$_2$ through the decomposition rate path of 0.88%. Air temperature has the highest effect on soil temperature, interaction between air temperature and soil temperature can result in changes in weather and climate, especially in open land [13]. It can be seen that temperature affects the activity of soil fauna as a litter comminutor in physically decomposing litter into smaller sizes, which are then distributed into the soil. The decomposition process is continued biologically and chemically by soil microorganisms such as fungi and bacteria. The rate of litter decomposition, driven primarily by microbial activity, is largely temperature dependent [14], [15] suggested that dry soil has greater litter loss than moist soil. Therefore, the rate of decomposition increased due to the effect of increasing temperature on microbial activity and soil fauna [16]. Furthermore, moist soil showed lower mass loss, so that the decomposition rate in moist soil is slower.

Decomposition processes in ecosystems have been implicated as enriching the atmosphere with CO$_2$. During leaf litter decomposition, the decomposing litter is accompanied with losses of carbon. The increase in CO$_2$ resulted from the activity of soil microorganisms and fauna. CO$_2$ produced from the decomposition of organic matter is affected by changes in temperature. At high temperatures, large amounts of CO$_2$ gas are formed. The content of organic matter in the soil was obtained from the mass loss process and the rate of decomposition so that it had a positive correlation of $p = 0.631$ and had an effect of 32.3% and 32.8% with the flux of CO$_2$ emitted from the soil [17]. Organic matter is a source of energy for microorganism activity in the respiration process which produces CO$_2$. The temperature and humidity of both air and soil in the tropics are strongly influenced by the type and density of vegetation that covers them. Indeed, changes in forest cover have been implicated in the rising levels of CO$_2$, the main greenhouse gas (GHG), in the atmosphere [10].

Relative humidity and mass loss, decomposition rate and flux of CO$_2$ show negative significance. It can be concluded that every time there is an increased in relative humidity, there is no significant increase in the decomposition rate, mass loss or flux of CO$_2$. Relative humidity directly affects the mass loss rate by 8.3%, affecting the decomposition rate by 2.9%. Relative humidity indirectly affects the decomposition rate through the mass loss path by 8.1% and affects the CO$_2$ flux through the decomposition rate path of 0.95%.

4. Conclusions
Our study showed that the leaf decomposition rate and flux of CO$_2$ varies widely. leaf decomposition rate was the fastest in Pine 2016 at 6.17 g/week, and the highest flux of carbon dioxide in Indonesian rosewood rejuvenation was 9,860 mg/m$^2$/day. Our results confirmed findings of other studies that the response of leaf litter decomposition and flux of CO$_2$ depends on land cover type, the associated local micro-climatic conditions include precipitation, temperature, and relative humidity.

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