The variation of carbon content and bulk density on different time period post fire and peat depth

Muhammad Abdul Qirom, Tri Wira Yuwati, Dony Rachmanadi, and Wawan Halwany

Banjarbaru Environment and Forestry Research and Development Institute (BEFORDI), Jl. Ahmad Yani Km 28.7 Banjarbaru Kalimantan Selatan

Email: qirom.litbanglhk@gmail.com

Abstract. Peatland plays the biggest carbon sink and the biggest carbon stock is in the soil. The main factors determining the number of carbon stock are bulk density and soil carbon content. Fire has caused the changes in the soil biophysical condition however limited study has been performed. The aim of this study is to obtain the number of carbon content and bulk density on post burning sites and various peat depth. The study was conducted on post burning peatland sites after 22 years, 16 years, 5 years and one site that has never been burnt. Two hundred and eighteen soil samples were collected up to the 5 m depth. Laboratorium analysis was carried out using Loss of Ignition method. The result showed that the average carbon content was 52.65% with the biggest carbon content was 53.98% from the site that has never been burnt. Nevertheless, the carbon content was not effected by the fire scenes. Peat depth had effect on the carbon content adjacent to the peat sub-stratum. Generally, the carbon content was lower following the distance to peat sub-stratum however the number of carbon content varied on the upper layer of peat sub-stratum. The carbon content value was different with the conversion factor of 46% or 50%, respectively. It was shown by the diversity analysis that the conversion value different with the value of carbon obtained in this research (P-value < 0.05). The peat bulk density was not effected by the period of fire. Generally, the bulk density was bigger following the distance to peat sub-stratum and it showed no pattern on the upper layer of the peat sub-stratum. The implication of this study emphasized that the conversion factor for peatland should be more than 50% to prevent underestimate carbon stock prediction.

1. Introduction

Tropical peat swamp forest plays important roles in the global warming mitigation as the biggest carbon sequester and carbon storage. The important role will be disturbed whenever there is a disturbance on peatland ecosystem and will effect on the higher GHG emission. The world’s peatland covers 3% of the total world’s area or approximately 400 million hectares while tropical peatland covers 11% of the total world’s peatland area [1]. The current data showed that Indonesia owns 13.43 million hectares of tropical peatland [2]. The area showed the importance of peatland roles in the efforts of GHG mitigation in Indonesia. The disturbance or destruction of peat ecosystem was started with the timber utilization more than its capacity to regrowth. The low access in the peat ecosystem had driven the establishment of canals and railways for logs transportation. A study case at Central Kalimantan showed that based on GIS analysis the accumulation of railways on peatland reached more than 11,000 km and the canal establishment had altered soil water table and increased subsidence processes [3].
The destruction process has continued with various activities such as land conversion and efforts to lower the soil water table so that the peatland can be used for agriculture, such as the case of The 1 Million Hectare of Ex-Mega Rice project; where massive canals were built and had successfully altered the peat hidrological condition that led to drainage of peatland [4]. As an expanse of dry organic material, the peatland is very prone to fire and proven to be easily burnt continuously especially in dry seasons [5]. Fire has become the peak of peatland destruction process because it was formed of high organic material with irreversible drying properties after burnt [6,7].

A disturbed ecosystem has ability to recover forming the initial ecosystem or a different ecosystem [8]. The difference in the recovery process is determined by the frequency, intensity of disturbance and actions to support the recovery process. Peatland as a place to store carbon is predicted to have lower ability to store carbon due to the disturbances. There are still limited research that study whether disturbance could cause the differences in the carbon stock of peatland. Peatland is formed by layers of organic material from imperfect decomposed plant remnants due to inundation or anaerobic condition. Various peatland location is enriched with sediment from rivers or sea so that peatland varied based on the process of peat formation. Peatland is differentiated based on sub-stratum: clay or quartz sand [9]. In general, the peatland properties are consistent based on peat layer such as bulk density which will increase the deeper peat layer [10]. The disturbance process is predicted to effect the peat material properties such as bulk density and will lead to the different peat soil carbon content. The aim of this study is to obtain the number of carbon content and bulk density on post burning sites and various peat depth.

2. Material and methods

2.1. Field works

This research was conducted at Tumbang Nusa Research Forest Central Kalimantan. The research forest is peat swamp forest with various peat depth of 2-8 m. Geographically, it lies on 02°18’37”-02°22’34” SL and 114°02’48” -” – 114°06’46” EL and the latitude of 0-5 m asl and elevation of 0-18% [11]. This area was formerly over-logged area with continue fire incidents. The fire had caused fragmentation of this area into various covers such as area burnt in1997 (1 time burnt), area burnt in 2015 (more than 2 times burnt) and over logged area without fire (Figure 1).

The data collection was carried out for three vegetation covers. Based on those conditions, soil samples were collected in several locations: area with 1 time burnt and 16 years without fire; area burnt 1 time and 22 years without fire; area with > 1 time burnt and 5 years without fire and unburnt secondary forest. Auger eijkelkamp with 500ml volume was used in the soil samples collection. The soil samples were taken at each depth with 50 cm intervals: 0-50 cm, 50-100 cm, 100-150 cm, 150-200 cm, 200-250 cm, 250-300 cm, 300-350 cm and so on until reaching sub-stratum layer. The samples were weighed for fresh weight in the field for each layer. Soil samples for lab analysis were collected with peat auger with the length of 10 cm (volume 50 ml) and freshly weighed. These samples were the samples with the perfect wholeness that were used for bulk density and carbon content analysis.

2.2. Laboratory analysis

Bulk density and carbon content analysis were carried out at the laboratory of Banjarbaru Environment and Forestry R&D Institute. Bulk density was determined based on ratio between dry weight and volume. Soil samples of 100-200g were oven-dried (103°C ± 2°C, 24 hours) to obtain dry weight data. Dry weight was calculated with the formula:
With KAs: water content (%), BBs: fresh weight (g); BKs: dry weight; BKT: total dry weight (g); BB: total fresh weight [12]. Bulk density was determined by dry weight after oven-dried. The formula of bulk density is:

$$BD_(g/cm^3) = \frac{BK_(g)}{V_{total}(g)}$$

with BD: bulk density (g/cm$^3$); BK: total dry weight (g); and $V_{total}$: soil volume (cm$^3$) [13].

The carbon content was determined with Loss of Ignition method by burning 2-5 g of soil samples until 600°C for 3 hours [13,14]. The weight is the dry weight after putting in the oven. For the first step, cups and soil samples were weighed before putting them into the furnace. After heating in the furnace, the samples were cooled for approximately 24 hours before being weighed. The weighed data was remnant ashes. Organic material content can be calculated with the formula:

$$BO(g) = \left[\frac{(b-a) - (c-a)}{(b-a)}\right] \times 100\%$$

and

$$C(%) = \frac{BO}{1.724}$$

with BO: soil organic matter (%); b: cup weight + sample weight (g); a: sample weight (g); c: ashes weight + cup weight; C: carbon content(%); 1.724: organic material constant [13].

2.3. Data analysis

The data analysis aimed to determine the effect of land cover condition (fire frequency and period with no fire) on the bulk density and carbon content. The analysis used analysis of variance with land cover condition (fire frequency and period with no fire) as treatments. The hypothesis formulated was:

H$_0$: bulk density and carbon content is not affected by land cover condition after fire.

H$_1$: bulk density and carbon content is affected by land cover condition after fire.

Moreover, the analysis was conducted on the carbon content obtained compared with conversion factors of 50% or 46% [15,16]. The hypothesis formulated was that the carbon content is the same with 50% or different carbon content.

3. Result and discussion

3.1. Bulk density

The changes of soil water content due to the disturbed land hidrological function has altered soil physical condition such as bulk density or ensuring soil degradation [17]. The analysis on bulk density in this research supported the statement mentioned above and generally the bulk density varied between peat depth. The bulk density tended to raise when the peat depth was adjacent to sub-stratum layer. The variation of bulk density was found in the 1997 area (no fire within 16 years), it was shown by the big standard deviation (Figure 1). The average of BD for all land types and soil depth was 0.18 – 0.20 g/cm$^3$ with the highest BD on soil depth adjacent to sub-stratum, highest BD value could also be found on upper layer when oxidation and compaction happens [7].

The BD value was the same as research [18] that was conducted at peat swamp forest of Malaysia, Peru, and Indonesia. The BD value ranged from 0.013 – 0.53 g/cm$^3$ [18] and the research [7] at Sebangau National Park with BD value of 0.02 – 0.21 g cm$^{-3}$. It was also supported by the research of [14] who used range of BD value in correlating between carbon content and BD as independent variable. However, BD value was bigger than BD from the research of [10]. The condition was
suspected due to the differences in the methods of BD calculation. This BD was determined with ring samples [10] while our research used auger eijkelchamp in the peat soil sample collection. The study of [19] showed bigger BD trend on drained areas compared with those undrained. It showed that drainage was highly affecting the changes of soil physical condition.

![Figure 1. Bulk density on different site and peat depth.](image)

The result of analysis of variance showed that BD was strongly affected by peat depth ($F_{cal}=2.15$; $P_{value}=0.05$), nevertheless this BD was not affected by peatland condition ($F_{cal}=0.36$; $P_{value}=0.78$). Soil depth between 300-350 cm had different BD value compared with other soil depth for all land types (Table 1).

**Table 1.** Multiple duncan analysis of bulk density and carbon content on different type and peat depth.

| Parameter       | Criteria                        | Mean of BD (g/cm^3) | Mean of Carbon content (%) |
|-----------------|---------------------------------|---------------------|----------------------------|
| Site condition  | Not burnt                       | 0.19a               | 54.11a                     |
|                 | Burnt in 1997 and 22 years after fire | 0.20a             | 53.45a                     |
|                 | Burnt in 1997 and 16 years after fire | 0.20a             | 54.32a                     |
|                 | Burnt in 2015 and 4 years after fire | 0.18a             | 53.12a                     |
| Peat depth      | 0-50 cm                         | 0.18a               | 55.10a                     |
| (cm)            | 50-100 cm                       | 0.16a               | 56.23a                     |
|                 | 100-150 cm                      | 0.16a               | 56.37a                     |
|                 | 150-200 cm                      | 0.20a               | 56.14a                     |
|                 | 200-250 cm                      | 0.19a               | 56.37a                     |
|                 | 250-300 cm                      | 0.17a               | 54.18a                     |
|                 | 300-350 cm                      | 0.28b               | 43.38b                     |

This condition was different with the research of [10] who showed that fire and canals caused the increase of BD or the research of [20] and [7] who mentioned that land utilization with drainage would
cause the differences in the BD value. The increase of BD due to drainage and peat surface warm up because the loss of canopy cover. This could cause decreasing of peat organic fibers [21]. It could be a cause of differences on the scale of measurement. Measuring BD by [10] was carried out with the scale of 10 cm. This condition showed that degradation could be very sensitive or happened on the peat depth less than 60cm [10]. The BD value could be used in the prediction of burnt organic matter depth [22]. The prediction used the combination of vegetation cover, BD and moisture content.

3.2. Carbon content
The carbon content obtained in this research was relatively equal for each peat depth (Figure 2). The mean of carbon content was more than 50% up to the 300 cm peat depth, nevertheless the carbon content was continuously decreasing following the distance to sub-stratum. This pattern was different with BD value for each peat depth (Figure 1). In that peat depth, the carbon content was less than 50% with variation of %C bigger than other peat depth. The value of %C was the same with various tropical peat land use [14,18]. The value of %C was more than 50% [14,18,23].

![Figure 2. Carbon content on different site and peat depth.](image)

The result of analysis of variance showed that peat depth was strongly affected the value of carbon content ($F_{cal}$: 10.07; $P_{value}$ = 0.00), however, the %C value was not significantly effected by the land condition ($F_{cal}$ : 0.34; $P_{value}$ = 0.80). Based on post hoc analysis, the value of carbon content for peat depth more than 300 cm was different with other peat depth (Table 1). The value of %C depends on the methods that are being used. The study of [14] showed that the Lost of Ignition (LOI) method resulted in underestimate value of 4.9 ± 0.8% compared with the analysis elemental method so corrections are needed on the methods that are being used. The use of conversion factor of 1.878 for conversion from organic material into carbon content is highly recommended to increase the accuration from this method [14].

The %C value significantly effects the carbon stock potential of peatland. The use of un proper conversion factor has led to inaccurate carbon stock potential or carbon emission prediction. The t-test($T_{cal}$: 7.046; $P_{value}$= 0.00) showed that the value of %C in this research was different with the value of %C of 50%. The t-test result can be used as a base to declare that the value of %C for biomass conversion into carbon should be more than 50%. The value of %C suggested for peat soil from this study was 52.85%. Moreover, the study of [23] suggested the use of BD and %C correlation as one effective method to save costs in the determination for peat organic material carbon stock. Several
studies showed that there was strong relationship between BD and %C or C \([14,23]\). This study estimated the C density value (kg C m\(^{-3}\)) based on the value of BD. The result of [14] showed that %C/ C density could be predicted using BD, however this equation should be used with limitation range of BD. The equation can be used in the estimation of carbon stock or emission because of fire [24]. Nevertheless, the use of such equation is not always resulted in a good prediction. The study of [18] showed that there was no strong relationship between bulk density and %C. It showed that the equation should be validated to be used in different areas.

4. Conclusion
The BD value and %C was not significantly affected by the period of fire, however, both physical parameters were strongly affected by the peat depth. The mean of %C was 52.65 % bigger than common conversion factor of 50% or 46%. The result of this research showed that %C for peat soil should be adjusted so that the carbon stock/ carbon emission prediction can be more accurate. The conversion factor of 52.85% can be used especially on the surface peat layer or upper the sub-stratum.

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