Estimating soil organic carbon at Takasago UNIMAS Educational Forest for forest rehabilitation

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Abstract. Soil Organic Carbon (SOC) has long been known as an indicator of soil health. This study aims to estimate the amount of SOC at Takasago-UNIMAS Educational Forest, a post-construction site, for forest rehabilitation. Since 2018, rehabilitation approaches have been conducted in the UNIMAS campus to restore these land areas via enrichment planting. The estimation of SOC was conducted at three sites; Secondary Forest (SF), Enrichment Planting site (2018) (EP18) and Enrichment Planting site (2019) (EP19). In each study plot, soil samples from different depths were collected for further analysis. Our findings showed that the soils in SF portray the highest amount of Total Carbon and Nitrogen, suggesting that this site may not have been considerably affected due to the past land use. Moreover, the estimation of SOC in all sites indicated that SF shows the highest mean at 2007.0 g/m² at the soil depth of 0-30cm, followed by EP18 and EP19. From the estimation, it can be concluded that although the period of establishment in EP18 and EP19 may have contributed to the lower SOC as compared to SF, the SOC estimation from this study could be a value-added option in determining the state of soil recovery and, possibly, the effectiveness of enrichment planting for forest rehabilitation.

Keywords: Soil organic carbon; post-construction site; forest rehabilitation; soil health.

1. Introduction
Soil Organic Carbon (SOC) acts as one of the possible indicators in estimating the area's soil health as it plays a crucial role for the forest ecosystem and agricultural lands in controlling soil fertility and plant production [1]. Factors influencing soil C loss include litter input, disturbance of woody and herbaceous plants, changes in root depth distribution, and land use change [2]. The complex interaction of climate, soils, tree species and management affect the rate of soil C sequestration and the quality of soil C stock [3].

Soil organic carbon (SOC) is one of the important indicators in determining the soil health of given land use. Sakurai et al. [4] stated that a vast amount of information on forest rehabilitation programs’ success could be indicated by assessing their soil properties. Such information is crucial when planning for proper conservation and management of the rehabilitated forest. Reforestation is fundamental to conserving our tropical rainforests, and it may be one way to mitigate these degradation processes. In the tropics, reforestation is essential in aiding biodiversity recovery by restoring forest cover [5]; ecological rehabilitation to restore high-diversity native tropical forest [6]; improving connectivity in rural landscapes [7], and increasing carbon sequestration for addressing climate change [8]. Several studies have been conducted in Sarawak, Malaysia, to understand the ecological aspects of reforestation activities in tropical rainforests on an experimental basis in relation to various factors [9,10,11]. However, less attention has been made to the effect of early establishment enrichment planting sites in restoring the forest area affected by various land uses.
Since 2018, Takasago-UNIMAS Educational Forest was established at Universiti Malaysia Sarawak (UNIMAS) campus to foster public awareness on the importance of forest for a healthy and safe environment through education. Since its establishment, more than 6000 trees from various indigenous tree species have been planted, where several planting techniques were adapted, namely, enrichment planting and the nursing tree concept. Based on the land use history, the majority of the land area was former secondary forest, but certain locations were affected by post-construction work during the construction of the campus back in the year 2003. Understanding the influence of land use change on soil carbon stock is critical for adopting land use management strategies that enhance carbon stock and, as a result, preserve soil quality. Although it is rather challenging to sum SOC as an indicator in determining the effectiveness of a forest rehabilitation program since SOC can be affected by various edaphic factors, this study was conducted to estimate and determine the amount of Soil Organic Carbon (SOC) at Takasago-UNIMAS Educational Forest, a post-construction site, for forest rehabilitation.

2. Materials and methods

2.1 Information on study site
The study was conducted in Takasago-UNIMAS Educational Forest located in UNIMAS campus, Kota Samarahan, Sarawak. The average annual rainfall in Kota Samarahan is at 3900mm, with the average temperature ranging from 23°C to 36°C with a little monthly variation [12]. In this study, study plots were established at enrichment planting sites (tree planting sites planted in 2018 and 2019) and secondary forest adjacent to the planting site. EP sites formerly served as a stockpiled area of construction materials during campus construction. After the campus was completed, all debris and construction materials were removed from the site were left abandoned, leaving a naturally formed vegetation cover. In EP18 and EP19, various indigenous tree species were planted among them; Dipterocarps (Shorea macrophylla, Shorea parvifolia, Dryobalanops beccarii), local fruit trees (Durio zibethinus, Artocarpus integer, Nephelium lappaceum) and Agarwood (Aquilaria becarriana). All trees were planted under line planting with the spacing of 5 x 2.5m, where the original vegetation in between the planting lines were left uncut during site preparation.

2.2 Method soil sampling and analyses
For soil sampling, four (4) subplots with the size of 25 x 25m$^2$ were established in each study site. Undisturbed soil samples were collected at five (5) random points from each study site at a depth of 0-10cm, 10-20cm, and 20-30cm using a 100cc soil core sampler, while soil composite was collected using soil auger at similar sampling points and soil depth. Soil samples were later analyzed for their soil physicochemical properties at Environmental Soil Science Laboratory, UNIMAS.

The method for estimating the mass of SOC (g m$^{-2}$) was adapted from [13]. In this estimation, the mass of SOC was obtained by calculating the total carbon and equivalent soil mass correction. The heaviest soil sample for a layer within each land use was used as the reference soil mass for that layer. A thickness layer adjustment ($T_{adj}$) was used to bring all samples to an equivalent soil mass:

$$T_{adj} = \frac{(SM_{ref} - SM_{ori})}{\rho_{bbe}}$$

where $SM_{ref}$ and $SM_{ori}$ were the references, and the original soil mass of the individual depth increment will be adjusted, respectively, and $\rho_{bbe}$ was the bulk density of the soil-depth increment beneath the depth increment that was adjusted. Bulk density beneath the deepest sampling layer will be assumed to be the same as the bulk density of the deepest soil depth increments. Mass of SOC ($M_{SOC}$)was calculated for each soil depth increment (0-10 cm, 10-20 cm, and 20-30 cm):

$$M_{SOC} = \text{Total Carbon content} \times \rho_b \times T_o + T_{adj}$$

where, 
$\rho_b$ is the bulk density and $T_o$ is the soil layer thickness

*Total Carbon content was analysed using loss on ignition method*
2.3 Data analysis
All soil properties in all study sites were statistically analysed using One-Way Analysis of Variance (ANOVA). The statistical tests were performed using IBM SPSS version 19.0 for windows.

3. Results and discussion

3.1 General information on the selected soil properties of the study sites.
Figure 1 shows the soil pH, electric conductivity, bulk density and soil moisture of studied sites at different depths. In general, the soils of the studied sites were strongly acidic, with soil pH (H$_2$O) less than 5.50. High soil acidity was observed in some sites in the SF site. Based on our field observation, the formation of the O horizon of the site in SF indicates a significant accumulation of organic material at forest floors compared to EP18 and EP19 sites. This observation suggested that high decomposing organic matter takes place in the top layer of the forest floor, causing high carbon dioxide production. According to [2], the higher litter input on the forest floor will increase soil carbon. As for the soil Electrical Conductivity (EC), they were varied widely among all study sites and soil depth. Overall, all study sites showed an EC value of less than 30 µS cm$^{-1}$, indicating a non-saline condition of the soil. Ho et al. [14] reported that reduction in plant growth is imminent under high saline soil where the osmotic potential of soil solution restricts water and nutrients uptake by plants.

Figure 1. Soil pH(H$_2$O), Electric conductivity, moisture and bulk density of studied sites.

The soil moisture (MC) of all study sites ranged from 1.03% to 6.46% at all soil depths. SF site shows higher soil moisture content at all depths than the other study sites. High MC in the soil could encourage microbial communities, leading to an effective decomposition process in soils [15]. For the Bulk Density (BD), all the sites showed variable values at every soil depth. EP18 showed the highest BD value, ranging from 1.35 to 1.38 g cm$^{-3}$. High BD indicates a more compacted soil and increases with depth. The soils showed low BD in the SF site, with the value ranging from 0.95 to 0.97 g cm$^{-3}$, indicating that SF has a suitable soil structure supporting plant root development. Based on field observation, the soil in SF has numerous presences of coarse roots. On the other hand, the soil BD at a 0-10cm depth in the EP18 site tended to be low but substantially increased in the deeper horizon. This could be ascribed to the past land use history, where it was formerly utilized as a stockpiled area during UNIMAS campus construction.

Figure 2 shows the total carbon and nitrogen of all study sites at different depths. The results showed that total carbon tended to decrease with increasing soil depth. Feldpausch et al. [16] reported that soil carbon and nutrient concentrations generally would decline with depth. Among all study sites, SF has significantly higher total carbon. The higher total carbon in SF was presumably due to the contribution of organic matter from the litter input on the forest floor derived from the existing vegetation [2]. As for EP18 and EP19, the lower total carbon indicated a reduction in organic matter input caused during the
tree planting process, where vegetation along the planting lines was slashed and removed. Similar trends were observed for the soil total nitrogen in all study sites, where soils in SF showed the highest total nitrogen compared to EP18 and EP19 sites. High soil total nitrogen in SF could be influenced by forest stand age, past land use history, and soil type. The soil N stocks were high, especially aboveground, and increased as the forest aged [16]. Undisturbed soils in the reforestation site would improve the trees’ growth development, causing an increase in N availability, improved aeration, soil moisture, soil structure, and develop root dynamics and increase symbiotic N fixation and mineralization [17].

**Figure 2.** Soil Total Carbon and Nitrogen of studied sites by soil depth.

### 3.2 Quantification of mass of Soil Organic Carbon (SOC) at study sites

Table 1 shows the Mass of Soil Organic Carbon (M$_{SOC}$) in all study sites at different soil depths. Overall, the M$_{SOC}$ of all study sites decreased with depths. At a depth of 0-10cm and 20-30cm, M$_{SOC}$ at SF were significantly higher than EP18 and EP19.

**Table 1.** Mass of soil organic carbon (SOC) of the study sites.

| Depth (cm)   | Secondary Forest SF | Rehabilitation Sites EP18 | Rehabilitation Sites EP19 |
|--------------|---------------------|--------------------------|--------------------------|
| 0-10         | 2504 ± 1111b        | 1082 ± 201a              | 1032 ± 348a              |
| 10-20        | 1472 ± 687ns        | 1148 ± 185ns             | 1123 ± 213ns             |
| 20-30        | 2045 ± 955b         | 841 ± 227a               | 795 ± 26a                |
| 0-30         | 2007 ± 885b         | 1024 ± 142a              | 983 ± 207a               |

Means ± deviation: values in the same row followed by a different letter(s) indicate significant differences among study sites at different soil depth P < 0.05 using Tukey's HSD test; ns: no significant difference

In all the depth, the SF site shows the highest M$_{SOC}$ ranges from 1472 g/m$^2$ to 2504 g/m$^2$ with a means of 2007 g/m$^2$. The low M$_{SOC}$ in EP18 and EP19 sites could be ascribed to the period of forest establishment after enrichment planting. According to [18], SOC often declines during the first 5 years after tree planting. It was suggested that activities related to the tree establishment, such as mounding, ripping, and cultivation during site preparation for planting may have led to soil mechanical disturbance and later reduced the SOC in the planting site. Sauer et al. [19] also suggested that post-tree plantation causes a decline in SOC because the young trees planted may not be sufficient to supply a substantial amount of biomass in their early years to restore SOC.

### 3.3 Relationship of Soil Organic Carbon (SOC) with bulk density

According to [20], SOC is an important indicator of soil health and biomass production in the forest ecosystem. Figure 3 represents the relationship between the mass of Soil Organic Carbon (M$_{SOC}$) and soil bulk density (BD) at different soil depths. Based on the graph, the correlation between M$_{SOC}$ and BD was observed where with increasing BD, the M$_{SOC}$ tended to decrease. SF site shows the lowest bulk density among all the study sites from all depths resulting in the highest in M$_{SOC}$, especially at 0-10cm.
Figure 3. The relationship between the Mass of soil organic carbon ($M_{SOC}$) and bulk density by soil depth.

Singh et al. [20] stated that about 69% of the soil carbon in the soil profile was confined to 40cm or upper soil layer. In addition, soils of the natural forest ecosystem have significantly higher C content than agricultural soils or disturbed soils in the same climate zone. On the contrary, EP19 sites showed high BD resulting in low $M_{SOC}$, especially at a depth of 10-20cm and 20-30cm. The lower $M_{SOC}$ in these depths might be ascribed to the previous land use at this site, where many construction residues were found accumulated at the deeper part of the soil. Intensification in the soil management practices would lead to a higher SOC attributed to the enhancement of soil nutrients from fertilization [21]. However, this was not the case for the soil in this study since chemical fertilizers were only applied during the transplanting of tree seedlings during site establishment. The $M_{SOC}$ in EP18 and EP19 were lower than in SF; with time, the $M_{SOC}$ at enrichment planting sites are expected to improve sufficiently enough to enable this area to support tree growth upon future land use.

4. Conclusion
In conclusion, the soils of all study sites were acidic in nature with low salinity levels. The soil bulk density and soil moisture in the SF site were generally higher than EP18 and EP19. SF has significantly higher total carbon and nitrogen concentrations among all study sites at different soil depths. In terms of mass soil organic carbon ($M_{SOC}$), the SF site shows the highest $M_{SOC}$ compared to the enrichment planting sites of EP18 and EP19. The low $M_{SOC}$ in EP18 and EP19 sites could be ascribed to the period of forest establishment after enrichment planting, where these sites may not be able to supply a substantial amount of biomass in their early years. With time, the $M_{SOC}$ at enrichment planting sites is expected to improve sufficiently enough to enable this area to support tree growth upon future land use. Since temporal sampling of SOC observation to estimate SOC decomposition rates is still typically sparse, especially at forest rehabilitation areas, continuous monitoring in the trend of SOC accumulation is necessary to better understand the plant-soil relationship under artificial planting.

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