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# Effects of forest reclamation methods on soil physicochemical properties in North-Central Vietnam

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## ABSTRACT

Globally, forest loss is happening because of timber harvesting, agricultural expansion, wildfires, mining extraction and service transportation networks via roads. This study was conducted during 2016 to 2019 at Ngoc Lam Commune, Thanh Chuong District, Nghe An Province, Vietnam on the effect of forest reclamation methods (FRMs), including the slash-and-burn method (SBM), the clear-cutting method (CCM), and agricultural cultivation methods on the interaction of soil physicochemical properties across the study area. To conduct this study, soil samples were collected in natural forest areas in the study area. The results indicated that the bulk density (BD) of the natural forest soils across the study area ranged from 0.86 to 1.12 g/cm$^3$ at depths varying from 0 to 60 cm from the surface. The concentrations of total carbon (T-C), exchangeable potassium (Exch. K$^+$), and exchangeable magnesium (Exch. Mg$^{2+}$) in the deeper layer were normally lower than in the upper layer. Forest reclamation using the CCM influenced the increase of the BD at depths varying from 0–20 cm, but the soil texture remained same, while forest reclamation applying the CCM showed an increase in the BD in the plots depending on the land-use management (LUM). Based on these findings, LUM has a significant influence on the concentration of Exch. Ca$^{2+}$, Exch. K$^+$, Exch. Mg$^{2+}$, and T-C compared to FRMs across the North-Central Vietnam.

**Key words :** Bulldozer, forest land, forest reclamation, slash-and-burn, surface soil

## INTRODUCTION

Globally, timber harvesting, agricultural expansion, wildfires, mining/resource extraction, and the expansion of transportation networks via roads are five major factors that cause forest loss (Potapov *et al.*, 2017; Bensemann *et al.*, 2018). Specifically, agricultural expansion is accompanied by approximately 27.7% of global intact forest landscape (IFL) area reduction (Tabi *et al.*, 2013; Thomaz *et al.*, 2014). In the same way, in Southeast Asia, timber harvesting and agricultural or pasture expansion were the dominant drivers of IFL losses, causing 75.45 and 22.55% of the total loss of IFL area, respectively (Francisco *et al.*, 2021). From 2000 to 2013, the IFL area reduction in Southeast Asia and Vietnam accounted for 13.9 and 25.5% of the total IFL of each area, respectively (Potapov *et al.*, 2017).

Depending on the economic and social conditions of each region, the natural forests were reclaimed by applying FRMs (de Souza *et al.*, 2016). These activities affect the distribution and interaction among soil physicochemical properties (Thomaz *et al.*, 2014; Fachin *et al.*, 2021; Genrietta *et al.*, 2021). The FRMs for farmland expansion influence the nutrient uptake of the crops (Tabi *et al.*, 2013; de Souza *et al.*, 2016). In addition, FRMs and LUM affected not only the soil nutrient content but also the vertical distribution of soil physicochemical properties and the interaction among soil physicochemical properties (Marty *et al.*, 2017; Chaudhari *et al.*, 2018; Masowa *et al.*, 2018).

Rosolem (2011) conducted a study on the effects of N fertilization and residues of pearl millet, black oats, and oilseed radish on pH, Exch.Ca$^{2+}$, and NH$^{4+}$ distribution within the profile of a Distroferric Red Latosol as a

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greenhouse experiment. His results pointed out that the contents of pH and Exch.$Ca^{2+}$ were decreased when using pearl millet residue, while the contents of pH and Exch.$Ca^{2+}$ increased in when using black oat and oilseed radish. A study on the impacts of two long-term (30 years old) cacao agroforestry systems on soil physicochemical properties in the primeval forest area in the Peruvian Amazon by Arévalo-Gardini *et al.* (2015) stated that the reduction of Exch. $Mg^{2+}$ and Exch. $K^{+}$ in cacao plants were more evident in the 0–20 cm depth from the soil surface. According to FAO (2006), the primary forests of Southeast Asia are very diverse in variety and play a very important role in ecological function as well as economic development. However, most of the forests are over-exploited and face high degradation due to indiscriminate exploitation (Asia-Pacific Forestry Commission, 2006) as well as exploitation without a scientific basis (Fig. 1).

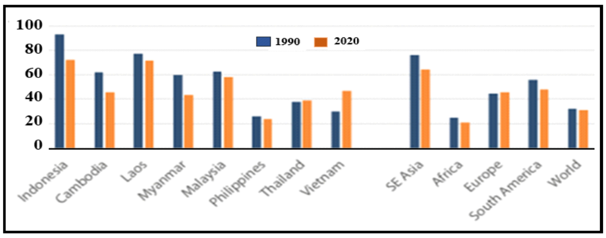

Fig. 1. Changes in forest cover in some countries around the world (Food and Agriculture Organization, 2006).

Therefore, this study aimed to evaluate the effect of FRMs and agricultural cultivation methods on the distribution and interaction of soil physicochemical properties across forest areas in North-Central Vietnam.

## MATERIALS AND METHODS

### Study Area

The study was located in North-Central Vietnam, including the Ngoc Lam Commune and the Thanh Chuong District, Nghe An Province, Vietnam (18°34’42” N–18°53’33” N and 104°56’07” E–105°36’06” E), as shown in Fig. 2. The annual mean temperature is 24.4°C and the maximum temperature is about 41.0°C. The average annual rainfall is 1832.1 mm; heavy rainfalls occur during August and October, and the dry season lasts from December until April (Tue *et al.*, 2015).

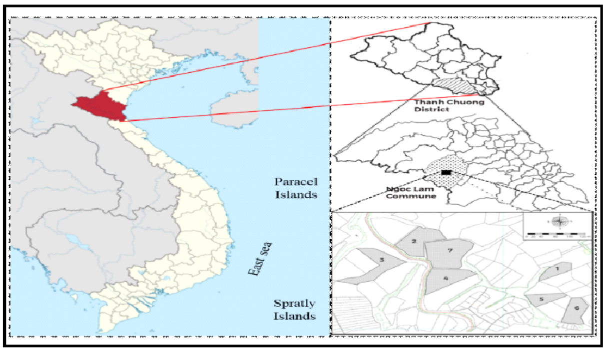

Fig. 2. Map of the study area with surveyed locations marked from 1 to 7.

In Nghe An Province, these two main FRMs, including (1) the slash-and-burn method by human power (SAM) and (2) the clear-cutting method and site preparation using heavy machinery (CCM) were mainly applied. Specifically, for the SAM, the farmer cut and burned the plants (Edivaldo and Rosell, 2020), while for the CCM, with the heavy machinery, bulldozers were used not only to remove the forest trees but also to shape the hill surface, design the hillslope gradient, change the terrain, and construct flat fields for growing rice from the valley (Thomaz, 2014). According to Thomaz (2014), the CCM was mainly applied for the soil areas where there were topographical changes. Therefore, there was a non-homogenous change in the surface soil removed in these areas (Edivaldo and Rosell, 2020). Furthermore, the different soil forest disturbance levels on each position could be affected by reclamation and LUM (Callesen *et al.*, 2007).

### Soil Samples Collection

To conduct this study, 109 soil samples were collected at seven study locations within two different areas where the land use types of representation for natural forest land and *Acacia* planted land (Fig. 3). Soil samples were collected on nine plots, at three slope positions (upper, middle, and lower) on the hills. In each position, the soil samples were collected on five or six different layers varying from 0 to 60 cm.

In Nghe An Province, farmers have reclaimed the forest and then, *Acacia mangium* cuttings were sowed in sloping terrain areas, while green tea cuttings and rice-growing paddies were sowed in the gently sloped land areas (Table 1). From 2006 until recently, depending on the geographical condition and economic situation, each farmer who

Fig. 3. Illustrations of several locations where soil samples were collected in the field.

immigrated to the area has sown based on the various cultivation managements.

**Laboratory Analysis**

After being collected in the field, the soil samples were dried and stored in plastic bags for laboratory analysis. In the laboratory, soil physicochemical properties were analyzed for the following parameters: the BD was measured by the cylinder method (Carter and Gregorich, 2007); soil texture was determined with the centrifuge method, an analysis by sieving in combination with hydrometer analysis (Tan, 1996); Exch. $Ca^{2+}$, Exch. $Mg^{2+}$ and Exch. $K^{+}$ were extracted by 1M ammonium

**Table 1.** Soil samples collected across at several locations across the study area

| Site | | Method and time of land reclamation | Plot No. | Land-use history after reclamation | Use status in 2017 |
|---|---|---|---|---|---|
| 1 | | Manual 2007 | 1M | Acacia was planted with cassava starting in 2007 and harvested at four-year intervals. | 1-year old Acacia plantation. Scattered grass growing. |
| 2 | | Manual 2007 | 2M | *Acacia* was planted starting in 2007. Farmers harvested Acacia in 2014 and planted it again with cassava | 3-year-old Acacia plantation. Grass grew richly in the understory of the Acacia Forest and was used for grazing. |
| 3 | Upper one third of the slope | Heavy machinery 2006 | 3M | Cassava was planted in 2010; the land was left fallow until Acacia was planted in 2013. | 4-year-old Acacia plantation. Mainly ferns, with scattered grass and bushes growing in the understory of the Acacia Forest. |
| | Lower two-thirds of the slope | Manual 2010 | 3H/M | | 4-year-old Acacia plantation. Grass mainly grew in the understory of the Acacia Forest and was used for grazing. |
| 4 | | Heavy machinery 2006 | 4H | Cassava was planted in 2008 and 2009. In 2010, Acacia was planted with cassava. Farmers harvested Acacia in 2015 and planted it again with cassava. | 2-year-old Acacia plantation. Grass and bushes grew richly in the understory of the Acacia Forest. Barriers were built to prevent grazing. |
| 5 | Upper half of the slope | Heavy machinery 2006 | 5H/M | Cassava was planted annually from 2010. Acacia was planted with cassava in 2013. | 4-year-old Acacia plantation. Grass and bushes grew richly in the understory of the Acacia Forest and were used for grazing. |
| | Lower half of the slope | Manual 2007 | 5M | Cassava was planted annually from 2007. Acacia was planted with cassava in 2013. | |
| 6 | | Heavy<br>Heavy<br>2006 | 6H | Acacia was planted in 2010. It was harvested and replanted in 2015. | 2-year-old Acacia plantation. Grass grew richly in the understory of the Acacia Forest and was used for grazing. |
| 7 | | Undisturbed area | FL | This area has been left over a long period without using | Natural forest |

Land use history information was established by farmer interviews. In all Acacia plantation areas, plant residues were burned one week after the harvest. Cassava is always harvested one year after being planted.

acetate (rate 1:5 of soil: $CH_3COONH_4$) and measured by atomic absorption spectrophotometer (AA-6800) (Tan, 1996); T-C and total nitrogen (T-N) were determined by dry combustion using C-N analyzer (CORDER MT–700, Yanaco, Japan).

### Statistical Analysis

To determine the effect of FRMs on the distribution of soil physicochemical properties corresponding to different depth layers from the surface, the collected samples were analyzed based on the LUM as shown in Table 2. The differences in the physicochemical properties of soils at various depth layers as well as LUM methods were analyzed using one-way ANOVA and Tukey HSD tests. The function “rcorr” from package “Hmisc” and the linear model function of the statistical software R version R3.4.2 were used to indicate the relationship between all LUMs (Harrell and Hmisc, 2006).

## RESULTS AND DISCUSSION

### Effects of FRMs and LUM on Bulk Density

The analyzed results of the change in bulk density (BD) at various depth layers under FRMs and LUM were shown in Fig. 4a. The results showed that the BD of natural forest was 0.86 ± 0.05 Mg/m$^3$ at the surface soil layer varying from 0–2.5 cm and slightly increased in the deeper soil layer. The BD of the plots that were cleared by CCM reached approximately 3H/M, 4H, 5H/M, and 6H, except the surface soil layer of the plot 4H, while the BD values of the plots cleared by SBM only reached 1M, 2M, 3M, and 5M. It seems that the influence of the disturbance from applying the SBM on the surface structure was not strong. However, the BD values of these plots increased around 0–5 cm from the surface but decreased around the 10–20 cm depth. Sites 2 (2M) and 4 (4H) were contiguous with site 7

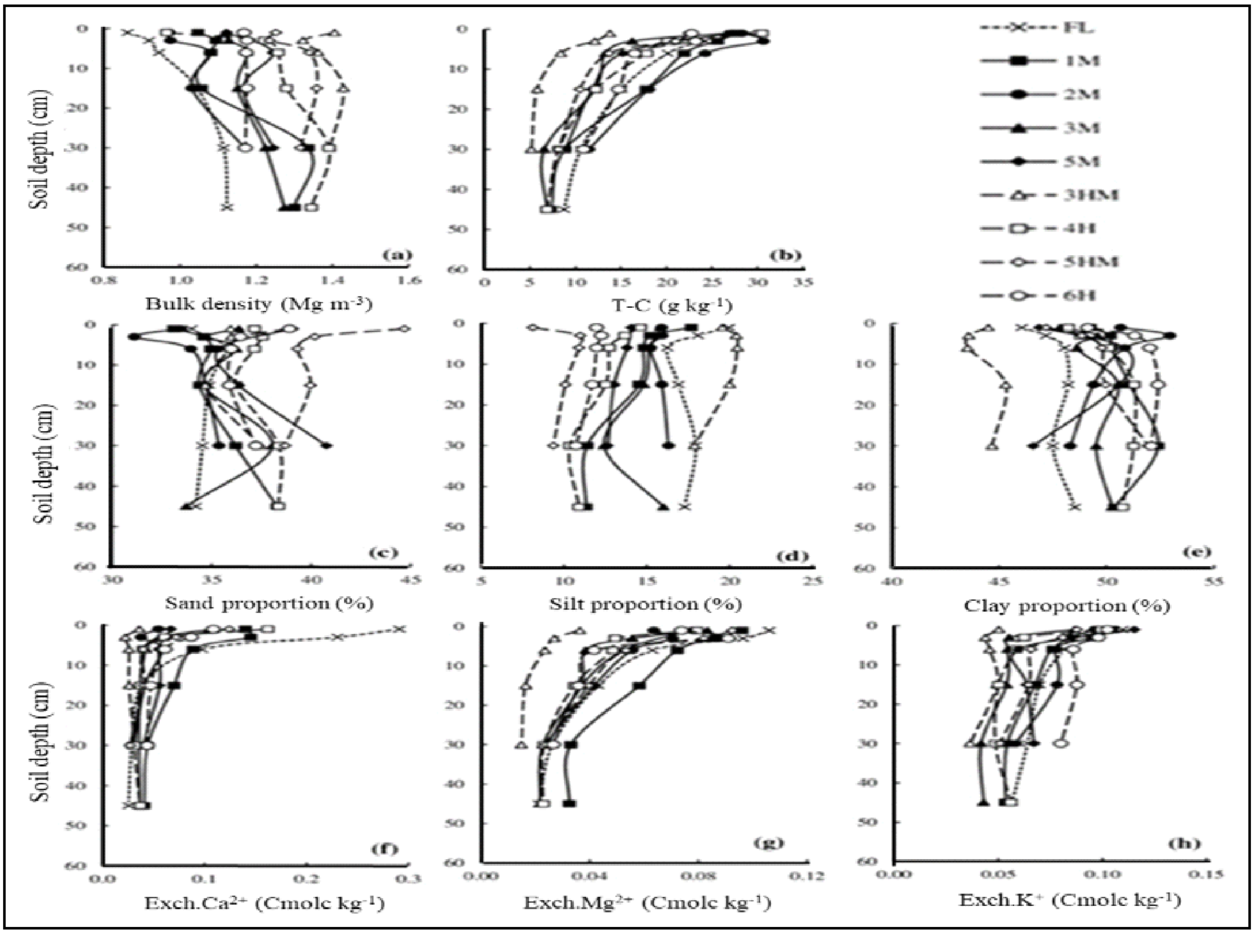

Fig. 4. Vertical distribution of bulk density (a), total carbon (b), soil texture (c, d and e), and exchangeable base cations (f, g and h) in natural forest soil and plantation forest soils on cleared land.

(FL), but they used FRMs (Fig. 4a). There were no differences in the BD values of the surface soil layers of these plots with the FL. However, there was a significant difference in the BD of plot 4H with FL and plot 2M at 5–60 cm depths (Fig. 4a).

From 2008, plot 4H was protected from cow grazing and trampling by barriers. Grass and bushes, therefore, grew thickly in the understory of the *Acacia* plantation. Therefore, the soil compaction was not affected by cows grazing and trampling in this plot (Mohseni *et al.*, 2015). Besides, the natural growth of grass and shrubs may be related to the increase of pore spaces formed by their fibrous root systems and organic matter in the soil (Fachin *et al.*, 2021). Thus, the protection from grazing and the recovery after 10 years could efficiently reduce the soil BD at 0–2.5 cm depths especially.

In addition, the results suggest that SBM and plantation activities as sources of soil disturbance or confounding of the soil layer order, could change BD in the soil profile, especially at depths 0 to 20 cm. At 1 m, soil samples were collected 9 months after harvest activities. In this period, the synthetic impact of agricultural activities (harvest, transport, burning, and planting, among others) on soil compaction remained on the surface of this study site. This means that farmer management clearly affected BD in the early period. According to Portella *et al.* (2012), the content of organic matter probably plays a role in forming a rich network of pores by aggregate stacking. At depths of 0–20 cm, biological material, the organic matter decomposition process, soil fauna activities, and plant root penetration directly affect BD by relating to organic matter dynamics, pore spaces, or porosity formation of the soil.

## Effects of FRMs and LUM on Total Carbon and C/N Ratio

The change in total carbon (T-C) in the soil layers under FRMs at LUM is shown in Fig. 4b. The significant positive correlation between T-C and T-N in all soil samples is shown in Fig. 4a. At the surface layer (0–2.5 cm), the accumulation of T-C was the lowest at 3HM (13.80 g C/kg) and the highest accumulations of T-C were at 4H (30.50 ± 4.88 g C/kg) as well as FL (29.15 ± 1.38 g C/kg). However, the T-C was not appreciably different among all plots on respective intervals of depth. Under FRMs, Fig. 4b shows the remarkable disparities of T-C at respective depth intervals in plots 3HM and 3M of site 3. In contrast, the T-C was not significantly different between 5HM and 5M at the respective depth layers. At site 5, cassava had been sown annually in plot 5M from 2007, in plot 5HM from 2010; and from 2013 *Acacia* was planted in site 5. Grass and bushes grew thickly in the understory of the *Acacia* Forest. However, at site 3, plot 3HM has been fallow from 2006 to 2013, and cassava was planted only once in 2010. Since 2013, *Acacia* was planted and mainly ferns grew, with grass and bushes scattered in the understory of the *Acacia* Forest. In the lower part of the hill (plot 3M), *Acacia* was planted in 2013, and mainly grass grew in the understory of the *Acacia* Forest. This indicated that *Acacia*-cassava plantation and grasses cover could contribute to the increase of T-C concentration in the soil.

The average T-C of natural forest estimated for the depth of 100 cm was 11.934 kg C/m$^2$. This result is in line with the amount of carbon density in the tropical moist forests that had been reported by Post (1985). However, the amounts of T-C at plots 1M, 2M, 5M, 5HM, and 6H were higher than at FL (0–100 cm) (Table 2). According to Post (1985), the amount of T-C in the surface soil layer is strongly dominated by vegetation and climate conditions. The variation of the C/N ratio is directly affected by carbon or nitrogen storage or decomposition in the soil. Nghe An, in Vietnam, is located in a tropical climate zone with high temperatures, high rainfall, and humidity, which was an advantage for the organic matter decay process. Thus, natural forest land in Northern Central Vietnam had low C/N ratios varying from 6.56 to 9.13.

Fig. 5b implied that BD had a significant negative correlation with T-C. The content of organic matter probably plays a role in forming a rich network of pores by aggregate stacking. According to Soane (1990), in the natural soil, the strongly negative correlation between BD and organic matter and the removal of surface soil using the CCM influenced the change in BD, thereby forming the interactions between BD and T-C.

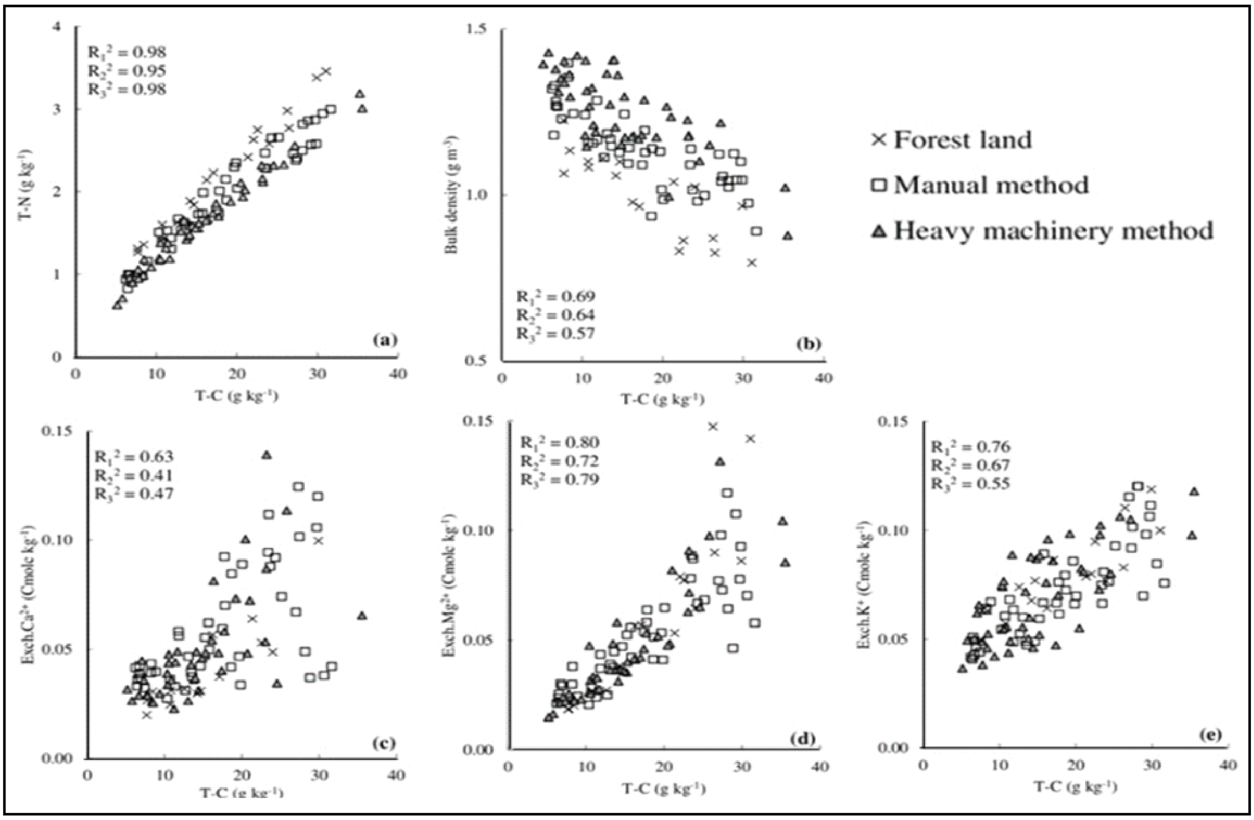

Fig. 5. The interaction of among Total Carbon and Total Nitrogen (a), Bulk density (b), and Exchange basic cations (c, d and e) in soil under different forest reclamation methods at 0-60 cm depth. (R12, R22 and R32 display R-square value in natural forest land, manual method and heavy machinery method area, respectively).

**Effects of FRMs and LUM on Exchangeable Base Cations (EBCs)**

The changes in Exch. Ca$^{2+}$, Exch. Mg$^{2+}$ and Exch. K$^{+}$ in the soil layers under FRMs and LUM were presented in Figs. 5f, g and h, respectively. They showed the downward trend of EBCs in the soil vertical profile of all plots. Admittedly, each EBC was not significantly different among all plots on the respective depth intervals. In general, Exch. Ca$^{2+}$ had a wide fluctuation in the upper depths (0–2.5 and 2.5–5 cm), but it had a minimal fluctuation in the deeper layer (10–60 cm) (Fig. 5f). Exch.Ca$^{2+}$ of natural forest widely fluctuated at 0.291±0.125 Cmolc/kg in the surface layer (0–2.5 cm depth) but it steeply decreased and minimally fluctuated between 0.026 ± 0.003 and 0.039 ± 0.009 Cmolc/kg in the depth layer varying from 10 to 60 cm. Besides, the reduction was rapid at 2.5–5 cm to 5–10 cm depths in FL (Fig. 5f). The concentration of EBCs in plot 3HM was lower than in plot 3M, and it was the lowest of all plots (Fig. 5f, g and h). The strong positive correlation between T-C and EBCs is shown in Fig. 5c, d and e, while the negative correlation between BD and EBCs was also seen in all plots.

However, the statistical results were insignificant for the plots that had been reclaimed by the CCM, as seen in the plots 6H (BD-Exch. Ca$^{2+}$ ($r = -0.04$, $p > 0.1$), BD-Exch. Mg$^{2+}$ ($r = -0.2$, $p > 0.1$)) and 3HM (BD-Exch. Mg$^{2+}$ ($r = -0.24$, $p > 0.1$)). In addition, the interactions of BD-Exch. K$^{+}$ ($r = 0.02$, $p > 0.1$) at 6H as well as BD-Exch.Ca$^{2+}$ ($r = 0.58$, $p > 0.1$) and BD-Exch. K$^{+}$ ($r = 0.31$, $p > 0.1$) at 3HM had positive correlations (Table 3).

Calcium is a structural component of plant tissue; the release of calcium during decomposition is more dependent on biological ruins and biotic activities (Adugna and Abegaz, 2015). In addition, Ca$^{2+}$ strongly relates to the surface attraction of clay particles; hence, the leaching of Ca$^{2+}$ through the soil is normally negligible. Thus, the concentration of Exch. Ca$^{2+}$ in the surface layer was higher than in the lower soil layers. Even though the forest

**Table 2.** Variation in C/N ratio and silt fraction with soil depth at all plots

| Soil layer (cm) | Plot No. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | FL | 1M | 2M | 3M | 5M | 3HM | 4H | 5HM | 6H |
| Variation in C/N ratio with soil depth | | | | | | | | | |
| 0-2.5 | 9.13aC | 11.37aA | 9.99aBC | 9.94aAC | 10.97AC | 9.68AC | 11.19aAB | 10.5aAC | 10.74aA |
| 2.5-5 | 8.77aB | 11.03aA | 10.38AB | 8.53abB | - | 9.19AB | 10.01abAB | 10.41aAB | 10.75AB |
| 5-10 | 8.30abA | 10.15aA | 9.27abA | 8.39abA | 8.81A | 8.49A | 9.29bcA | 8.85aA | 9.80abA |
| 10-20 | 7.70abB | 9.59abA | 8.34bcAB | 8.09abAB | 8.20AB | 8.17AB | 8.38bcAB | 8.27aAB | 9.52bA |
| 20-40 | 6.87bA | 7.98bcA | 7.28cA | 7.23bA | 7.64A | 8.17A | 7.89cA | 7.67aA | 9.14bA |
| 40-60 | 6.56bA | 7.61cA | - | 7.12bA | - | - | 7.50cA | - | - |
| The estimated average for the 0 to 100 cm depth of T-C (kg C/m$^2$) | | | | | | | | | |
| 0-100 | 11.934 | 12.533 | 15.229 | 10.205 | 12.697 | 8.049 | 11.841 | 12.217 | 13.082 |
| Variation in Silt fraction with soil depth | | | | | | | | | |
| 0-2.5 | 19.9aA | 17.7aA | 15.9aAC | 15.8aAC | 14.1AC | 19.5AB | 14.6aBC | 8.1aD | 11.9aCD |
| 2.5-5 | 18.1abA | 15.2aA | 15.9aAC | 15.6aA | _ | 20.4A | 13.7abA | 11.0aA | 12.3aA |
| 5-10 | 16.2bAB | 14.8abA | 15.2aA | 15.1aA | 13.8A | 20.5A | 12.7abBC | 10.9aC | 12.0aBC |
| 10-20 | 16.9bAB | 14.5abBC | 15.9aAC | 14.8aBC | 13.0BC | 20.0A | 12.5abD | 10.1aD | 11.7aD |
| 20-40 | 17.9abAC | 11.4bBC | 16.3aAB | 12.4aAC | 12.6AC | 17.9AC | 10.4bAC | 9.4aC | 10.7aBC |
| 40-60 | 17.3bA | 11.3bB | - | 16.0aA | - | - | 10.9abB | - | - |

Different lower-case letters indicate significant differences among depths. Different capital letters in the row indicate significant differences among study sites on the respective same soil layer.

clearing methods did not significantly affect the variation of Exch. Ca$^{2+}$, LUM relating to biological ruins contributed to the transformation of the Exch. Ca$^{2+}$ concentration, especially in the surface layer.

According to Tan (1996), magnesium and potassium immediately increased after the burning trees and plant residue. However, in the tropical climate zone, the ratio of Exch. K$^+$ to Total K is often high. Thus, LUM and SBM affected the concentration of Exch. K$^+$ and Exch. Mg$^{2+}$.

**Table 3.** Pearson's correlation coefficients for relationships between BD and EBCs, T-C and the C/N ratio in all plots

| Plot No. | Index | | | | |
|---|---|---|---|---|---|
| | Exch. Ca$^{2+}$ | Exch. K$^+$ | Exch.Mg$^{2+}$ | T-C | C/N |
| FL | -0.70b | -0.74a | -0.86a | -0.83a | -0.72a |
| 1M | -0.67b | -0.69b | -0.82a | -0.88a | -0.81a |
| 2M | -0.39 | -0.36 | -0.68c | -0.7b | -0.72b |
| 3M | -0.50d | -0.61c | -0.72b | -0.75b | -0.84a |
| 5M | -0.86d | -0.85d | -0.76 | -0.82d | -0.82. |
| 3HM | 0.74 | 0.57 | -0.07 | -0.28 | -0.24 |
| 4H | -0.43d | -0.88a | -0.83a | -0.86a | -0.85a |
| 5HM | -0.64d | -0.56 | -0.53 | -0.66d | -0.32 |
| 6H | -0.04 | 0.02 | -0.20 | -0.14 | -0.01 |

Letters a, b, c and d on the right of Pearson's correlation coefficient indicate significance at 0.1, 1, 5 and 10%, respectively. No letter indicates no significant difference.

## Effects of FRMs and LUM on Soil Texture

The change in the sand, silt, and clay proportions in the soil layers under FRMs and LUM are represented in Figs. 5c, d and e. For natural forest, the sand proportion had negligible fluctuation at 34.0 to 35.7%, the silt proportion accounted for 16.2 to 19.9%, and the clay proportion accounted for 46.1 to 48.5% at depths of 0–60 cm. The soil properties collected at the surveyed locations from the field were analyzed using United States Department of Agriculture software (Oyeogbe and Oluwasemire, 2013). The analyzed results from the standard laboratory procedures for soil samples were classified, including clay and heavy-textured soil.

The silt proportion of the plots which were reclaimed using the CCM (4H, 5H/M, and 6H) were significantly lower than that of FL on the respective depth layers, except for the plot 3HM (Table 3). The clay proportion at 3HM was lower than plot 3M, and it was the lowest of all plots (Fig. 5e). However, the silt fraction of plot 3HM was highest of all plots (Fig. 5d). In general, the clay proportion showed a slight increasing trend at 0 to 10 cm depths in all plots. Especially at plots 6H and 5HM, clay fraction drastically increased (Fig. 5e). This result indicated that the leaching of clay might have occurred from the surface to the 10 cm depth at the plots that were reclaimed using the CCM.

Admittedly, under FRMs, remarkable disparities of silt proportion at respective depth intervals of site 3 (plot 3HM and 3M) and site 5 (plot 5HM and 5M) are illustrated in Fig. 5d. However, at the plots where the SBM was applied, the proportions of sand, silt, and clay were not significantly different (Figs. 5c, d and e). This means that the SBM, *Acacia*-cassava plantation, or grass cover did not affect the change in soil texture.

## CONCLUSIONS

The physicochemical properties were determined in the first 60 cm of the forest soils across the study area. Bulk density significantly increased from 20 cm to deeper depths. The concentration of T-C, Exch. K+, and Exch. $Mg^2$+ in the deeper depth normally was lower than the upper depth. The SBM and Acacia/cassava plantation influenced the increase of BD at depths of 0–20 cm, while for the CCM, the increase of BD varied in several plots, depending on the LUM. The concentrations of EBCs and T-C were more affected by land plantation history than the land clearing method. Otherwise, the soil texture was more affected by the land clearing method than land plantation history.

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