INTRODUCTION

Tropical forests play an important role on ecosystem functions including maintaining temperature, oxygen, water and soil resources. Various plant species present in the forest can absorb CO₂ and solar radiation through photosynthesis and release oxygen for humans and animals. In addition, forest functions are generally associated with watersheds that receive, process, and distribute water, including precipitation, water reserves, and water flow (Black, 2004). Finally, forests maintain soil fertility and nutrient balance through litter input, as well as low nutrient losses through leaching and evaporation (Allen, Corre, Kurniawan, Utami, & Veldkamp, 2016; Kurniawan et al., 2018a; Kurniawan, Corre, Utami, & Veldkamp, 2018b). However, these forest functions have declined in the past three decades due to changes in forest function and land cover.

Tropical forests, with an area of 1,760 million ha, have undergone rapid changes in cover since 1970, where is mostly occurred in developing countries. In the period 1976-1980, land cover change from tropical forests was estimated to be 3.4 million ha per year, mainly due to its conversion to agricultural land. Furthermore, tropical forest cover continued to decline from 154.4 million ha in the 1980s to 13 million ha per year in the 2000s (FAO, 2003; 2012). Within the period of 1985 – 1997, the cover forest area in Indonesia has changed of approximately 20 million ha (Barber et al., 2002), and one of forest area that has changes in cover is forest area with special purpose. Forest area with special purpose defined as an area of forest for research and development, education and training, as well as forest for religion and culture without changing its function. Since 2015, Universitas Brawijaya received a mandate from the Indonesian Ministry of Forestry to manage

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ABSTRACT

Differences in land use systems may resulted in different soil cover, litter input, and soil management practices, and consequently affect to soil nutrient stock. The study aimed to assess soil carbon (C) and nitrogen (N) storages on various soil depths from difference land use systems within UB forest. The research was conducted in UB forest, Malang – Indonesia, from April to November 2017. Soil sample was collected from four soil depths (0-0.1, 0.1-0.3, 0.3-0.5, and 0.5-1.0 m) within five land use systems, including (1) protected area; (2) pine + coffee; (3) pine + crops; (4) mahogany + coffee and (5) mahogany + crops, each with three replicate plots. Soil C and N concentrations, soil texture, and bulk density, were measured. The study showed significant difference in soil C and N storages among land use systems. In 0.5 m depth of soil, soil C and N storages was higher in protected area (64% and 53%, respectively) as compared to other land use systems. The result support clay content controls soil C and N stock, whereas vegetation determines soil N stocks. Therefore, proper management in vegetation and soil were needed to conserve soil C and N storages.

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Syahrul Kurniawan et al.: Land Use Systems in the Forest Soil of UB Forest, Indonesia

544 ha of forest area for special purpose especially for education. The forest is located at the foot slopes of Mount Arjuna where is bordered by Batu City and Malang Regency (Karangploso and Singosari districts). Before managed by Universitas Brawijaya, the forest area was managed by a State Owned Enterprise called as Perum Perhutani, consisted of production and conservation forests. For more than 4 decades, farmers have planted cash crops (e.g. coffee, taro, cabbage, etc.) under the tree (pine and mahogany) in the forest through joint community forest management program. As consequently, UB forest has various land use system with different soil management practices.

Differences in land use systems will affect canopy cover, understorey, litter input (Hairiah et al., 2006), and root system both fine and coarse roots (Pransiska, Triadiati, Tjitrosoedirjo, Hertel, & Kotowska, 2016), resulted in decrease soil carbon stocks (de Blécourt, Brumme, Xu, Corre, & Veldkamp, 2013). Dechert, Veldkamp, & Anas (2004) reported that soil nutrient stock in the annual crops was lower than tropical forest in Sulawesi, Indonesia. In addition, the stock of carbon and nutrient in the rooting system of monoculture plantations decreased over 50% as compared to forest (Pransiska, Triadiati, Tjitrosoedirjo, Hertel, & Kotowska, 2016). Differences in land use systems is also changing land management practices such as soil tillage, fertilization, and pest and disease controls that potentially affect soil characteristics. As reported by Syswerda, Corbin, Mokma, Kravchenko, & Robertson (2011), soil management practices in annual cropping system (i.e. no-tillage and organic fertilization) and land use system (i.e. early successional, never-till mid-successional, and deciduous forest) had higher total C stock in the soil surface as compared to conventionally managed agricultural cropping systems.

Changes in soil nutrient stocks (e.g. C and N) is not only affected by land use system (including soil management practices) but also related to soil properties (e.g. soil texture) which may determined by parent material. The differences of soil nutrient and carbon storages among different land-use systems in Indonesia have been studied by van Straaten et al. (2015) especially in highly weathered soil from lowland forests converted to rubber and oil palm plantations. Saha, Nair, Nair, & Kumar (2010) also studied soil carbon storages in different land-use system in Kerala-India, and their result showed that tree-based land-use systems had higher C storage in soils as compared to the treeless systems. To our knowledge, there is limited study of soil C and N storages in different land use systems that have different soil management in the forest area with special purpose. Therefore, this study aimed to answer the questions: 1) what are the effect of land use systems on the changes of soil carbon and nitrogen storages in UB forest? and 2) what factors (vegetation characteristics such as i.e. basal area, standing litter mass, canopy cover, and soil properties such as soil texture) are controlling soil carbon and nitrogen storages? The hypothesis of this study were: 1) differences in land use systems within UB forest impact on soil C and N storages, and 2) the level of carbon and nitrogen in the soil closely related to vegetation and soil particle size distribution (e.g. clay content).

MATERIALS AND METHODS

The study was conducted in the forest area with Special Purpose UB forest from May to December 2017. The forest area consists of 15 blocks and geographically lies in the coordinates 7°49’300” – 7°51’363” S and 112°34’378” – 112°36’526” E. UB forest has mean annual air temperature of 21.9°C and mean annual precipitation of 4,725 mm (2016-2017; data from Meteorological, Climatological and Geophysical Agency Karangploso climatology station, ± 15 km away from the site), with dominant slope 15 – 25% (Fig. 1). The existing conditions indicates that the land cover within UB Forest varies from low to high canopy cover, that is due to differences in land management including tree species and their age, planting patterns and fertilization (dosage and period of application) done by farmers.

There are differences in the application of fertilizer for coffee and seasonal crops which may affect to the amount of nutrient availability. For seasonal crops, chicken manure is applied with doses 6 tons/ha/year and inorganic fertilizer (i.e. NPK) with rates ranged from 200–400 kg/ha. While for coffee tree, farmer gave chicken manure in the first two year after planting with doses 6 tons/ha/year. Then in the mahogany systems, farmer applied cow manure approximately 3.2 tons/ha/year in the young coffee (first two year after planting) and 0.4 tons/ha in the crops (taro).
Soil samples were collected at five land use systems including protected area (PA) and agroforestry systems such as pine + coffee (PC), pine + crops (e.g. carrot, cabbage and cauliflower; PS), mahogany + coffee (MC), and mahogany + crops (e.g. taro; MS) within the area of UB forest, Malang Regency, Indonesia. The pine is ranged from 26-40 years old, whereas the mahogany is more than 40 years old. Coffee (5 years old) and seasonal crops (i.e. cabbage, cauliflower, carrot, and taro) were planted under the pine and mahogany.

The five land use systems studied was set up using main plot with the size of 20 m x 20 m each, with three replicates. The minimum distance between plots were arranged at least 200 m. Observation of vegetation characteristics (e.g. basal area, tree density, and canopy cover) conducted in expanded 5 times of the main plot (20 m x 20 m) become 40 m x 50 m (2,000 m$^2$). The standing litter mass was collected using a frame with the size of 0.5 m x 0.5 m from three subplot (5 m x 5 m) which were determined randomly inside the core plot (Fig. 2).
Soil carbon and nitrogen storages, as well as soil texture were measured by collecting soil samples using soil auger at 0.0-0.1, 0.1-0.3, 0.3-0.5, and 0.5-1.0 m depths from three subplots (5 m x 5 m in size each) in every main plot (Fig. 2). In addition, measurement of soil bulk density was done by collecting undisturbed soil sample using soil core at the same depth. Prior to laboratory analysis, all soil sample was air dried for along 7 days, then grounded and passed through 2 mm sieve. Then, the soil sample from each soil depth in three subplots within each replicate plot was composited for laboratory analysis. Therefore, soil carbon and nitrogen storages was measured from one composite soil sample from each soil depth and each replicate plot, totaling 60 soil samples (5 land uses x 3 replications x 4 soil depth). Soil organic C and total N content was measured using Walkey and Black, and Kjeldahl methods, while soil texture (% clay, silt, and sand) was measured by using pipette method. Soil C and N storages were calculated for each soil depth (0-0.1, 0.1-0.3, 0.3-0.5, and 0.5-1.0 m) by multiplying total C or N concentration with soil dry weight.

All data was tested for normality (Shapiro-Wilk’s test) before statistical analysis. Logarithmic or square-root was used to transform the non-normal data. The study used linear mixed effects (LME) models (Crawley, 2007) to test differences in soil carbon and nitrogen storages among land use systems in each soil depth. Fixed effect were considered significant based on analysis of variance at P ≤ 0.05, and differences between land use were assessed using Fisher’s least significant difference test P ≤ 0.05. The research also considered marginal significance at P ≤ 0.09, due to the experimental design encompassed the inherent spatial variability in the study area. Pearson correlation analysis was conducted to analyze the relationships of soil C and N storages with vegetation characteristics (i.e. basal area, standing litter mass, canopy cover) and soil properties (e.g. soil fraction such as sand, silt, and clay content), by averaged replicate plot in each land use systems to minimize the spatial effect (replication).

RESULTS AND DISCUSSION

Vegetation Characteristics Among Different Land Use Systems in UB Forest Malang, Indonesia

Vegetation characteristics (i.e. tree density, canopy cover, and standing litter mass) among land use systems in UB forest was presented in Table 1. The agroforestry systems of pine [e.g. pine with coffee (PC) and pine with crops (PS)] had higher (P ≤ 0.01) tree density and lower standing leaf litter mass (e.g pine + crops) than protected area (PA), however, their basal area and canopy cover are not significantly different (P ≥ 0.05). This is due to the existence of big trees (DBH 30 cm) which are still pronounce in the protected area (29-38%). The protected area (PA) is dominated by shrubs and not being used for agriculture due to the area is very steep slope (> 40%), while in PC there is plant weeding conducted by farmer resulted a lower standing leaf litter mass as compared to PA. Beside, the pine density in UB Forest East Java (277 – 322 trees/ha) was lower than pine density in production forest West Java – Indonesia that had 50% thinning (400 trees/ha) as studied by Heriansyah, Bustomi, & Kanazawa (2008).

In the agroforestry systems of mahogany [e.g. mahogany + coffee (MC) and mahogany + taro (MS)], the tree density, basal area, and leaf litter mass were higher (P ≤ 0.01) than those in the protected area (PA). This was due to the majority (81-87%) of tree in the mahogany plot is categorized as big tree (has more than 40 years old with DBH 30 cm). In addition, the owner (Perum Perhutani as the previous manager or Universitas Brawijaya as the current owner) have not conducted thinning for mahogany (e.g. MC and MS), resulting in higher tree density and litter mass as compared to protected areas (PA) and pine land use systems (e.g. PC and PS). Although the number of big trees between mahogany (81-87%) and pine (80-89%) plots is comparable, the basal area and standing leaf litter mass in the mahogany land (both mahogany + coffee and mahogany + taro) was higher as compared to the pine (both pine + coffee and pine + crops) due to a better growth of mahogany tree, and hence producing more litter.
Table 1. Tree density, basal area, canopy cover, and standing litter mass among land use systems in UB forest, Malang, Indonesia

| No. | Land cover | Tree species | Old (years) | Tree density (trees/ha) | Basal area (m²/ha) | Canopy cover (%) | Leaf litter mass (Mg/ha) |
|-----|------------|--------------|-------------|-------------------------|-------------------|-----------------|-------------------------|
| 1   | Protected area (PA) | *Ficus ariegate, Erythrina ariegate, Quercus sundaica, Toona sureni Merr, Bischofia javanica, Ficus ampelas* | - | *102 ± 42 a | 30.8 ± 7.5 a | 87 ± 2 b | 3.7 ± 0.7 bc |
| 2   | Pine + Coffee (PC) | *Pinus merkusii* | 30 | 277 ± 52 b | 30.2 ± 0.6 a | 70 ± 12 b | 3.4 ± 0.6 b |
| 3   | Pine + Crop (PS) | *Pinus merkusii* | 30 | 322 ± 39 b | 36.4 ± 2.2 a | 48 ± 5.3 a | 0.4 ± 0.2 a |
| 4   | Mahogany + Coffee (MC) | *Swietenia mahagony* | 35 | 345 ± 3 b | 80.0 ± 3.1 c | 89 ± 3.5 b | 5.0 ± 0.6 cd |
| 5   | Mahogany + Taro (MS) | *Colocasia esculenta* | 35 | 380 ± 10 b | 62.2 ± 8.7 b | 86 ± 2.9 b | 5.5 ± 1.0 d |

Remarks: * = mean ± s.e.d (n = 3), followed by different lower case letter in the same column showed significantly different based on Fisher LSD test at 5%

Soil Physical Properties in Different Land Use Systems Within UB Forest Malang, Indonesia

The measurements of soil physical properties were carried out to study the conditions of soil texture, bulk density, carbon content and nitrogen storage. Soil particle in UB Forest was dominated by silt particles (Fig. 2) with soil texture class is silty clay (55% plots at 0-0.5 m depth, and 40% plots in depth 0.5-1.0 m). Fig. 3 shows a slight increase of clay particles in the sub surface layer (indicating eluviation process) in the three land use systems including pine + crop (PS), mahogany + coffee (MC), and mahogany + taro (MS). The soil order in the UB Forest is classified as Inceptisol (indicated young soil), characterized by Cambic horizon with the dominant sub group of Andic humudepts (74% of the entire UB forest). Almost all of the research plots are located in the sub-group of Andic humudepts, except for 2 plots of protected areas located in the Typic humudepts subgroup. Soils that was formed from andic materials or volcanic ash generally have high silt content with abundant organic C.

Furthermore, soil that was formed from volcanic ash is characterized by low soil bulk density (< 1 g/cm³). This is consistent with the measurements which is showed the low soil bulk density (< 1 g/cm³ in the upper 0.3 m soil depth; Fig. 3). There is only a plot (i.e mahogany + crop) having soil bulk density > 1 g/cm³ at deeper layer (> 0.5 m). The low soil bulk density (0.6–0.9 g/cm³) in all land use systems in UB Forest is comparable to the measurement in natural forest in Andisols – Chile (Valle, Dörner, Zúñiga, & Dec, 2018). Soil bulk density at 0-0.1 and 0.5-1.0 m depth was significantly different (P ≤ 0.05) among land uses. At the depth of 0-0.1 m, the soil bulk density in the protected area (PA) and mahogany + coffee (MC) were lower than those in the pine + coffee (PC) and pine + seasonal crop (PS). While at a deeper layer (0.5 - 1.0 m depth of soil), the soil bulk density in mahogany + seasonal crops (MS) was larger than the three other land uses (i.e protected areas, mahogany + coffee, mahogany + seasonal crops). In the upper layer (0-0.1 m), the low soil bulk density in the protected areas (PA) and mahogany + coffee (MC) is probably due to a less intensive soil tillage (protected areas) and the high leaf litter inputs. High litter input is supposed to produce high soil organic matter (mahogany with coffee) as an agent for soil aggregation, hence resulting lower bulk density. Valle, Dörner, Zúñiga, & Dec (2018) reported similar results, that forest conversion to agriculture practices (e.g. pasture and crops) changes soil bulk density.
Soil Organic C and Soil Carbon Storages from Different Land Uses Within UB Forest

Differences in vegetation (i.e. tree density, basal area, canopy cover, and standing leaf litter mass) and soil characteristics (i.e. particle size distribution) resulted differences in soil organic C and soil C storage (P ≤ 0.05) at all depths (0-0.1, 0.1-0.3, 0.3-0.5, and 0.5-1.0 m). Protected area (PA) had the highest (P ≤ 0.05) soil organic carbon (SOC) and soil carbon storage at 0-0.5 m depths (0-0.1, 0.1-0.3, and 0.3-0.5 m) as compared to agroforestry systems both pine (e.g. pine + coffee and pine + crops) and mahogany (e.g. mahogany + coffee and mahogany + taro) (Fig. 4A and 4B). This was due to less disturbance in the protected area as compared to the pine and mahogany systems. Saha, Nair, Nair, & Kumar (2010) reported that less soil disturbance and higher tree density contributed to the larger soil C storage. In addition, the high SOC in protected area as compared to agroforestry system of pine and mahogany is also controlled by litter diversity which is resulted from high tree diversity in the protected area (Table 1).

Fig. 3. Soil particle size distribution (A: Pine + coffee (PC), B: Pine + crops (PS), C: Mahogany + coffee (MC), D: Mahogany + crops (MS), E: Protected areas (PA)), and F: soil bulk density from different land use systems in UB Forest, Malang, Indonesia.
In the lower layer (0.5-1.0 m), the total C concentration and soil C storage in pine + coffee and protected areas were higher than the other land use systems (e.g. pine + crops, mahogany + coffee, and mahogany + crops). The soil organic C concentration shows a decreasing trend with increasing soil depth in all land use systems within UB Forest, supported by higher soil organic C in a depth of 0-0.1 m as compared to in a depth of 0.3-0.5 m and 0.5-1.0 m. This trend is similar with the finding of Saha, Nair, Nair, & Kumar (2010) where carbon concentration in the soil profiles decreased following with soil depth.

In total 0.5-m depth of soil, all land use systems in UB forest stored C ranged from 152 to 323.5 Mg/ha with 20% of its was found in the top soil (0-0.1 m depth of soil). This result was higher than C stock measurement in the mountainous agroforestry systems within Central Sulawesi, Indonesia (28–45.5 Mg/ha) (Dechert, Veldkamp, & Anas, 2004). This study detected positive correlation, but insignificant between vegetation characteristics (e.g. tree density, canopy, and standing leaf litter mass) with soil carbon storages ($r \geq 0.05$). It is assumed that the quality of litter on all land use systems and organic fertilizer input plays an important role in affecting soil carbon storages. The main trees (pine and mahogany) in UB forest has organic composition which does not support the rapid decomposition process. Pine and mahogany have low litter quality, which is shown by high lignin content (29% and 20%). This result consistent with Hairiah et al., (2006) that reported leaf litter of non-legume trees with high lignin concentration (>20%) is expected to decomposed slower than the litter with low lignin content (e.g. leguminous tree). The soil organic C content from different land use was not only influenced by litter input, but also influenced by the input of manure in all land uses, except for protected area (PA). The land cover of PC and PS is applied chicken manure, while the land use systems of MC and MS was applied cow manure. The dosage of chicken manure in PC and PS (6 Mg/ha) was higher than those of cow manure in MC (3.2 Mg/ha) and MS (0.4 Mg/ha). In addition, chicken manure is faster decomposed than cow manure due to the lower C/N ratio (14.4) of chicken manure (Ravindran & Mnkeni, 2017) than cow manure (19.9; Guarino et al., 2016). Application of manure and litter input (both from pine and coffee) altogether resulted a higher concentration and stocks of C in PC as compared to MC. This result supported all hypothesis that land use systems and soil management practices controlled soil organic C and soil C stock.

The study support the second hypothesis that clay content control soil C storage especially in the sub surface layer (0.1-0.3 m and 0.3-0.5 m depth of soil; Fig. 5), shown by positive correlation between clay content and soil C storages ($r = 0.86$ and $0.97$; $P = 0.06$ and $< 0.01$). This result is comparable with the study in lowland Amazonian forest ecosystems where total C were significantly positive correlated with clay content (Silver et al., 2000). van Straaten...
et al. (2015) also recorded that clay content strongly determine soil organic C in the sub soil within the forest. The increases of soil carbon storages in accordance to clay content, indicated that the low losses of C in the soil with higher clay content probably due to physicochemical protection of soil organic C through organo-mineral complexation (Silver et al., 2000; Sollins, Homann, & Caldwell, 1996), and/or clay content regulate decaying rate of organic C (Barré et al., 2017). Another report by Plante, Conant, Stewart, Paustian, & Six (2006) stated that the increment of clay content increased biochemical protection of C (nonhydrolyzable C). While, Matus, Rumpel, Neculman, Panichini, & Mora (2014) reviewed that priming and destabilization of adsorbed soil organic matter are critical mechanism influencing soil C sequestration in deeper layer of Andisols.

Fig. 5. The relationship between clay content (%) and soil carbon storage (kg/m²) in: 0-0.1 m depth (A), 0.1-0.3 m depth (B), and 0.3-0.5 m depth (C) of soil under different land use systems in UB forest.
Table 2. Total nitrogen and soil nitrogen storage in various soil depth from different land use systems in the UB Forest, Malang, Indonesia

| Land use system       | Soil depth (m) | Total nitrogen (g N/kg) | Soil nitrogen storage (kg N/m²) |
|-----------------------|---------------|-------------------------|--------------------------------|
|                       | 0.0-0.1       | 0.1-0.3                 | 0.3-0.5                        | 0.5-1.0                        |
|                       |               |                         |                                |                                |
| Protected area (PA)   | *7.0 ± 1.3 c  | 6.7 ± 0.7               | 7.3 ± 1.3 b                    | 4.6 ± 0.5                      |
| Pine + coffee (PC)    | 5.6 ± 0.1 bc  | 5.3 ± 0.2               | 4.9 ± 0.4 ab                   | 4.2 ± 0.4                      |
| Pine + cropS (PS)     | 4.7 ± 0.1 ab  | 4.2 ± 0.6               | 4.6 ± 0.6 a                    | 2.1 ± 0.9                      |
| Mahogany + coffee (MC)| 3.5 ± 0.2 a   | 4.3 ± 0.8               | 3.5 ± 0.8 a                    | 3.3 ± 1.5                      |
| Mahogany + crops (MS) | 3.9 ± 0.3 ab  | 4.1 ± 0.6               | 2.7 ± 0.3 a                    | 4.2 ± 1.2                      |

Remarks: * = mean followed by different lower case letter showed significantly different of total N and soil N storage among land use systems at each depth of soil with Fisher LSD test at 5%

Fig. 6. The relationship between clay content (%) and soil nitrogen storage (kg/m²) in: 0-0.1 m depth (A), 0.1-0.3 m depth (B), and 0.3-0.5 m depth (C) of soil under different land use systems within UB forest
Soil Nitrogen Storages Among Land Uses in the UB Forest

Nitrogen in the soil is derived from the decomposition of organic matter of plant and animal remains, fertilization and bulk precipitation. Plants mainly absorb N through roots, also through leaf stomata during rain or spraying of leaf fertilizers. Total N among different land use systems in UB forest was significantly different (P ≤ 0.05), especially at 0-0.1 m and 0.3-0.5 m soil depth (Table 2). In 0-0.1 m depth of soil, the highest total N concentration was found in the protected area (PA), while the lowest was recorded in mahogany + coffee (MC; Table 2). Then, at a depth of 0.3-0.5 m, the protected area has a higher total N in the soil than the three other land use systems (e.g. pine + seasonal crop, mahogany + coffee, and mahogany + taro), whereas the total N in the land use systems of pine + coffee (PC) was comparable with all the other land uses. In general, the total N in the depth of 0.3-0.5 m and 0-0.1 m tends to higher than those in the depth of 0.1-0.3 and 0.5-1.0 m.

In total 0.5-m depth of soil, all land use systems in UB forest store N ranging from 15.5 to 28.4 Mg/ha, with the highest N stocks was found in protected areas (PA) and the lowest in mahogany + crops (MS). The top soil contributed to 15 to 20% of N stocks in all land use systems within UB forest. The N stocks in UB forest (2.3–4.2 tons/ha) was comparable to the N storage in the mountainous agroforestry systems in Central Sulawesi, Indonesia (2.4–3.5 tons/ha) (Dechert, Veldkamp, & Anas, 2004). Similar to soil carbon storage, clay content also controls soil N stocks in deeper layer (0.3–0.5 m depth of soil), reflected by positive correlation between clay content and soil N storage (r = 0.51, P < 0.01; Fig. 6). In contrast, vegetation characteristics has negatively impact on soil N storages, shown by the negative correlation of soil N storage with basal area (r = -0.97, P < 0.01) at top soil (0–0.1 m depth of soil), and tree density (r = -0.99, P < 0.01) at sub soil (0.3–0.5 m depth of soil). The negative correlation between vegetation characteristics (e.g. basal area and tree density) and soil N storage indicated the high N loss from the soil due to uptake by vegetation.

CONCLUSION AND SUGGESTION

Land use systems within the UB forest has diverse characteristics such as basal area, canopy cover, tree density, and leaf dry mass, consequently have vary soil C and N stocks in 0-1.0 m depth ranged from 29.09 to 53.16 kg C/m² and 3.3-5.1 kg N/m². The vegetation characteristics and land use management, altogether with soil physical properties (especially clay content) control soil C and N storages in UB forest. The results suggest a proper management in all land use systems within UB forest for minimizing soil loss (e.g. clay) through soil erosion for maintaining soil C and N storages and sustainable production of coffee and crops.

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