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# Changes in Carbon and Nutrient Stocks of Secondary Forest Transformations Under Ultisol in Leyte Island, Philippines

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## Abstract

*Ultisols are old soils, inferior and acidic. However, tropical secondary forests (SF) under this soil are transformed into grasslands (GL) and forest plantations (FP) which could profoundly affect the carbon and nutrient stocks. To support efforts in conserving tropical forest, estimates of these are essential, especially in addressing climate change and carbon sequestering. This study aimed to quantify soil organic carbon (SOC), total aboveground biomass (TAGB) and nutrient stocks of SF transformations using three adjacent land-use types, namely SF, GL and FP with comparable climate, parent material, soil type and geology. Results showed that land-use mean of organic carbon, TAGB, potential cation exchange capacity, effective cation exchange capacity, exchangeable acidity, hydrogen ion, aluminum, magnesium, calcium, potassium, sodium and the base saturation decreased when SF was converted into GL and then into FP. Additionally, there was a slight increase in SOC stocks, total nitrogen, available phosphorus and pH in $H_2O$ when SF was converted into GL and then into FP. This study indicates that SF conversion into GL and FL did not affect SOC stocks and has no significant relationship with TAGB.*

***Keywords**: Ultisol, secondary forest, grassland, soil organic carbon stocks, total aboveground biomass*

## 1. Introduction

Global warming and climate change are two major environmental problems that humans face today (Lai *et al*., 2016). Majority would agree that something must be done to address these issues. Soil carbon sequestration has gained considerable interest in mitigating the problem. Fixed carbon (C), as soil organic matter, could be stored by capturing atmospheric $CO_2$ by plants called soil carbon sequestration (Houghton *et al*., 2012; Lawler *et al*., 2014). C sequestration is considered the most effective way to lessen atmospheric carbon (Houghton *et al*., 2012; Thompson, 2018); thus, understanding its dynamics and role on different ecotypes would be essential (Gebeyehu *et al*., 2019). Assessing tropical forest, holding 50% of the aboveground C in its vegetation (Hunter *et al*., 2013), plays an essential role in the global C cycle and $CO_2$ sequestration in climate change mitigation.

The estimated world's forest carbon stock is 861 Gt of C; 383 Gt are stored in soil (up to 1 m); and 363 Gt are stored in vegetation (Pan *et al*., 2011) indicating the large potential for temporary and long-term C storage. Yet, global forest C storage differs in its within-system distribution and magnitude influenced by management and conservation strategies (Chen *et al*., 2014). Deforestation and alteration of this ecosystem could induce negative effects on its C storage (Harris *et al*., 2012; Goetz *et al*., 2015; Gautam and Mandal, 2016). Tropical montane forest in Ethiopia rendered 149.32 and 191.6 Mg C/ha on its mean soil organic C (SOC) stocks and aboveground biomass C stocks, respectively, with a positive correlation of SOC and total nitrogen (N) stocks suggesting that biomass could be a predictor of SOCs (Gebeyehu *et al*., 2019). Thus, assessment of nutrients stocks is essential in studying forest SOC stocks. A study conducted in Leyte Island under Andisol soils obtained a negative effect when secondary forest (SF) was converted into grassland (GL) and forest planation (FP) where SOC stocks, TAGB and fertility status significantly declined (Carnice and Lina, 2017). Drawing upon this, the present study was carried out to determine how it would turn out if the same conversion is applied on old soil, particularly Ultisol.

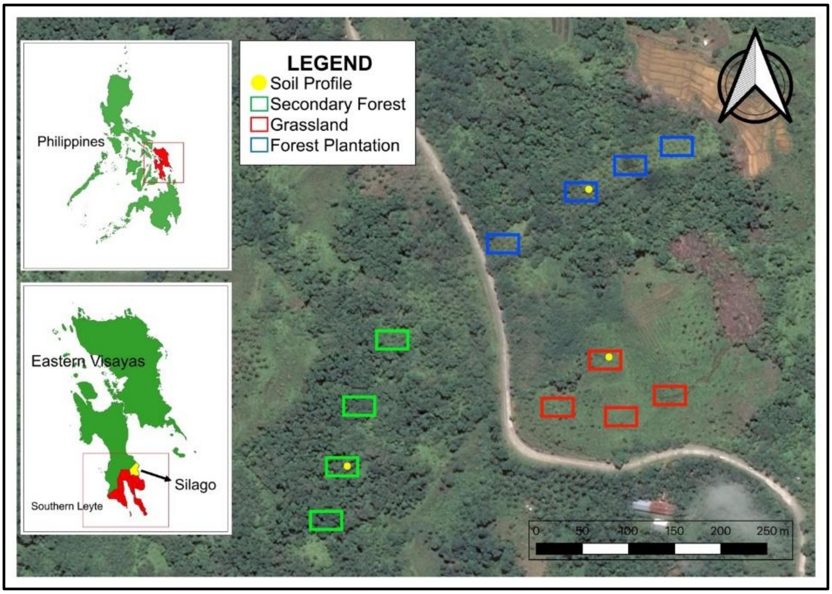
This study could contribute to the Philippines' databank on C stock assessments of different land-uses that could help in creating better policy agenda related to greenhouse gas mitigations inclined with the United Nations Framework Convention on Climate Change (UNFCCC) advocacies (UNFCCC, 2011). Moreover, determining Ultisol SOC stocks of SF transformations in Silago, Southern Leyte could help in understanding its potential in C sequestration. The said municipality has allowed high-quality timber and furniture production that paved the way for inland clearing and conversion threatening ecosystem services (Cedamon *et al*., 2011) and biodiversity (Ceniza *et al*., 2011; Deborde *et al*., 2016). The SF in the area is among the last forested regions in Leyte Island (Narisma *et al*., 2011; Aureo and Bande, 2017), where you can find sites that have been converted into GL and FP, which are highly suitable to the study's methodology. Hence, this study quantified SOC stocks, TAGB and nutrient stocks of these SF transformations and further related SOC stocks with TAGB.

## 2. Methodology

The sampling methodology used in the study was described in detail by Carnice and Lina (2017). A paired area or space-for-time substitution approach (Luo *et al*., 2013; Xiao *et al*., 2017; Faber *et al*., 2018; Huang *et al*., 2019) were used wherein three adjacent land-use types, namely SF (as the reference site), GL and FP were previously forests or SF with comparable climate, parent material, soil type and geology. Sampling was carried out in January 2013. The research site was located in Silago, Southern Leyte, Philippines (Figure 1), where an SF with an adjacent GL and FP could be found in this area; hence, this study site was selected.

In each site, four plots as replications in 20 m x 20 m size was laid out where five sub-sampling points were randomly selected and soil samples with uniform depths (0-20, 20-40, and 40-60 cm) were collected using an auger. All samples were brought and prepared in the screen house of the Department of Soil Science, Visayas State University, Baybay City, Leyte. All standard laboratory analysis methods (bulk density, porosity, organic C, pH $H_2O$, pH HCl, Δ pH, total nitrogen (N), available phosphorus (P), exchangeable Ca, magnesium (Mg), potassium (K), sodium (Na), acidity, $Al^{3+}$, $H^+$, effective cation exchange capacity ($CEC_{eff}$), cation exchange capacity ($CEC_{pot}$) and base saturation) were carried out. The formula used in calculating were described in detail by Carnice and Lina (2017). To emphasize, total SOC contents were calculated for the specified three depths from each land-use using Equation 1.

$$Total\ SOC\ (Mg\ C\ ha^{-1}) = \frac{\%\ SOC}{100} \times soil\ depth\ (m) \times bulk\ density\ (Mg\ m^{-3}) \times 1000\ m^{-2}\ ha^{-1} \quad (1)$$




Rectangles (20 m x 20 m) represents four replications of each land-use type and five individual sampling points are scattered inside each replication.

Figure 1. Study sites in Barangay Tubod, Silago, Southern Leyte, Philippines

In SF and FP, 10 m x 10 m representative sampling plots were laid out. All trees inside the plots with a diameter at breast height (DBH) of at least 10 cm were identified and recorded. The TAGB for trees were calculated using the allometric equation (Equation 2) (Brown and Lugo, 1990).

$$\%Y = exp\ [-2.134 + 2.530^{*} ln\ (DBH)] \tag{2}$$

where:

$Y$ = biomass per tree (kg)

For the amount of stored C in TAGB, Equation 3 was used.

$$C\ storage\ (t\ ha^{-1}) = Total\ biomass/ha \times 0.45 \tag{3}$$

where:

$0.45$ = average C content for tropical trees (Lasco and Pulhin, 2003)

For aboveground and root biomass, grasses found at each grassland site within 1 m x 1 m plot were collected, appropriately washed with distilled water and air blot-dried. The fresh weight was determined and representative samples were oven-dried at 65 °C until a constant weight was achieved. The carbon stock of the grass biomass was calculated using Equation 4.

$$WC = WO \times 0.5 \tag{4}$$

where:

> *WC* = weight of carbon in grass biomass (g)
> *WO* = oven-dry weight of aboveground biomass
> *0.5* = estimated C percentage in plant biomass
> (Sarmiento *et al.*, 2005; Redondo-Brenes, 2007)

Land-use effects on SOC and nutrients stocks in each site and soil depth were evaluated through one-way analysis of variance (ANOVA) and multivariate analysis using the SF (reference) as the baseline values to compare with GL and FP. Multiple regression analyses and correlation coefficients were employed to evaluate SOC and nutrient stocks' relationship in different land-uses and soil depths.

## 3. Results and Discussion

### *3.1 Environmental Setting*

One of the forest biodiversity hotspots in the Philippines is the Silago forest in Southern Leyte. Slash-and-burn agriculture has been practiced in some parts of the forest area. After a few seasons of farming, leading to less production, farmers tend to leave it and move to different sites. Farmers also ventured on planting fast-growing trees, mostly *Acacia mangium* and *Gmelina arborea*, on areas dominated by *Imprerata cylindrica* after slash-and-burn cultivation. This adjacent land-use (SF, GL, and FP) is less than 1 km apart. The soil was classified as Hapludults (Soil Survey Staff, 2010; Piamonte *et al.*, 2014); additional shreds of evidence are presented in Table 1. Its soil is generally highly weathered (Ultisol) developed from basaltic-andesitic volcanic rocks (Piamonte *et al*., 2014). The land-use information is crucial since it influences the direction and rate of soil formation, and soil fertility (Clemens *et al.*, 2010), which C in vegetation and soil could be affected (Huang *et al*., 2019). The study area, originally vegetated with rainforest, and SF were dominated by dipterocarp species. The GL ecosystem is estimated to have been cultivated 15 to 20 years ago and probably a *kaingin* (slash-and-burn) abandoned farm, resulting in the domination of cogon grass (*I. cylindrica*). FP ecosystem is planted with *A. mangium* usually harvested when DBH reaches more than 30 cm. Southern Leyte belongs to the Type II climate in the Coronas classification system (Philippine Atmospheric, Geophysical and Astronomical Services Administration [PAGASA], 2014).

Table 1. Site characteristics of Silago Forest, Southern Leyte, Philippines

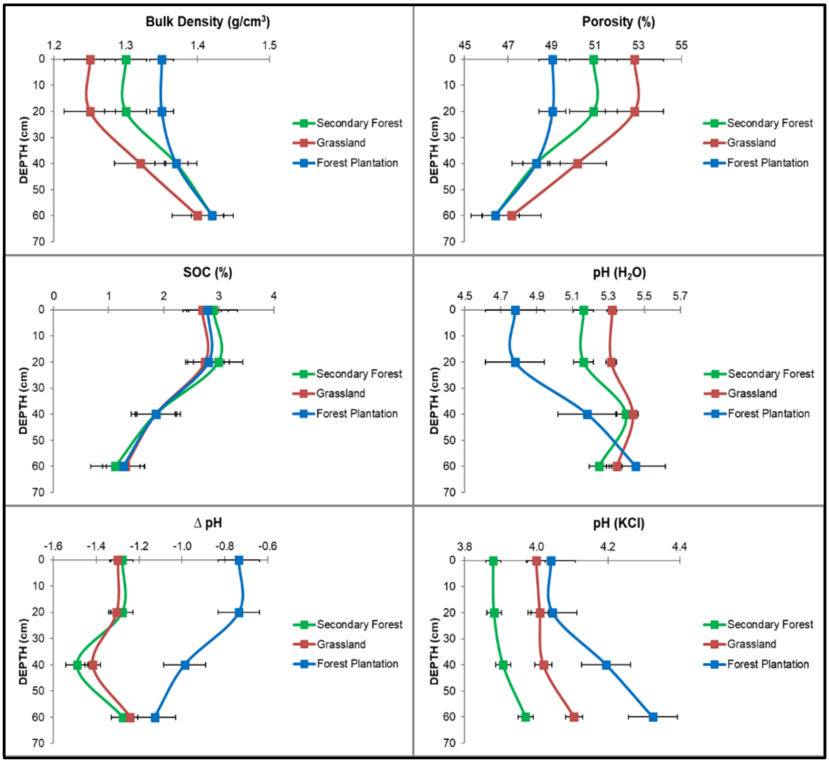
| Site Characteristics | Secondary Forest* | Silago Grassland* | Forest Plantation* |
|---|---|---|---|
| Location | Tubod, Silago, So. Leyte | Tubod, Silago, So. Leyte | Tubod, Silago, So. Leyte |
| Coordinates | N 10° 32' 59.16"<br>E 125° 07' 49.25" | N 10° 33' 02.98"<br>E 125° 07' 58.58" | N 10° 33' 08.85"<br>E 125° 07' 57.86" |
| Elevation | 219 m asl | 220 m asl | 222 m asl |
| Landform | Volcanic hill | Volcanic hill | Volcanic hill |
| Slope Position | Upper Backslope | Summit | Lower Backslope |
| Slope Gradient | Sloping | Sloping | Sloping |
| Parent Material | Basalt-andesitic Volcanics | Basalt-andesitic Volcanics | Basalt-andesitic Volcanics |
| Soil Moisture Regime | Udic | Udic | Udic |
| Soil Temperature | Isohyperthermic | Isohyperthermic | Isohyperthermic |
| Erosion | Slight | No evidence | No evidence |
| Rock outcrops/ stoniness | Few | Few | Few |
| Drainage | Well-Drained | Well-Drained | Well-Drained |
| Vegetation | Dipterocarp Species | *I. cylindrica* | *A. mangium* |

*Distance between land-uses is < 1 km away

## *3.2 Nutrient Stocks*

Bulk density (Db) is the bulk soil density in its natural state including both the particles and pore space (Soil Survey Staff, 2010). Across all land-uses, bulk density had lower values on the surface and tended to increase with depth. They ranged from 1.3 to 1.4 g $cm^{-3}$ across all profiles (Figure 2). Lower bulk density values in the surface horizon (Figure 2) may be attributed to the excellent soil aggregation due to the high organic matter from the decomposed tree leaf litter (SF and FP) and root systems (GL). Recent studies have similar results where bulk density increased with soil depth in agricultural soils

(Gebeyehu and Soromesa, 2018) and forest (Ouyang *et al.*, 2017; Gebeyehu *et al.*, 2019). High porosity in the surface soil confirmed the dominance of granular soil structure, which was easily observable during the morphological examination. High porosity also indicated low bulk density (Figure 2). Another reason could be the accumulation of high organic matter or humus in the surface giving higher porosity than the subsurface horizon. However, it could be observed that bulk density and porosity were not affected by land-use change.




Horizontal bars represent standard errors

Figure 2. Depth function of Db, porosity, OC and pH ($H_2O$, KCl, and Δ pH) of soils as influenced by SF transformations in Silago, Southern Leyte

The soils investigated were acidic ranging from 4.78 to 5.45 pH. Results revealed significant differences ($p$ = 0.0045) among different land-uses on pH in $H_2O$ values, especially in the upper surface horizon (0-20 cm). It was observed that FP (5.14) showed the highest range of pH in $H_2O$ values, which was strongly acidic, while SF (5.27) and GL (5.37) showed the lowest pH value – still indicating a very strongly acidic to strongly acidic soil. This study's pH values agree with the findings of Piamonte (2014) that soil pH in

Silago ranged from 4.52 to 6.75. The low pH in $H_2O$ values could be due to the parent material and soil type since Ultisols are naturally acidic and highly weathered soils. The highly weathered nature of the soils can also be caused by high rainfall in the area resulting in the leaching of some basic cations (Abua *et al.*, 2010). Figure 2 further shows that across depths, pH in $H_2O$ tended to increase at 20-40 cm depth except for FP in which pH in $H_2O$ significantly increased with depth ($p$ = 0.0003).

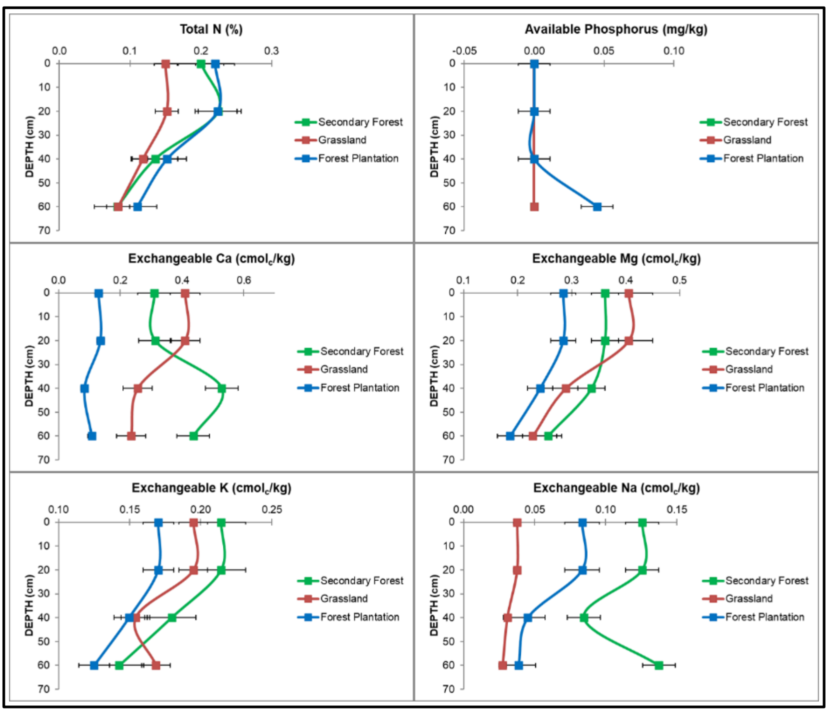
Similarly, a significant difference was noted on soil pH in KCl between land-uses ($p$ = 8.80E-06). FP (4.19) and GL (4.05) revealed higher value of pH in KCl while SF (3.92) soils exhibited the lowest pH, which means $H^+$ ions were held tightly in the soil particles of the SF soils. pH in $H_2O$ showed higher values than pH in KCl. It was expected since the addition of salt solution releases cations and it replaces some of the soil particles' protons. This process forces hydrogen ions to pass through the solution and make the concentration in the bulk solution closer to the value in the field. It could also be observed that pH in KCl slightly increased with depth ($p$ = 0.0062).

Furthermore, significant differences in Δ pH values were observed among land -uses (SF = -1.35, GL = -1.32 and FP = -0.95) ($p$ = 5.33E-09) as well as among soil depths ($p$ = 0.0021) (0-20 cm = -1.11, 20-40 cm = -1.3 and 40-0 cm = 1.22). All land-uses showed negative charge implying that the soil colloids possess cation exchange capacity and the occurrence of net negative charge could be ascribed to the negative charge of the clay minerals (Figure 2).

Soil organic carbon is C stored in soil organic matter (SOM). The surface horizons among different land-uses contained higher SOC than the lower horizons (Figure 2). Surface depths (0-20 cm) rendered 2.99% (SF), 2.75% (GL) and 2.82% (FP), which were higher compared with the lower depths (40-60 cm) which rendered 1.12% (SF), 1.31% (GL) and 1.27% (FP) in which these values between soil depths resulted in significant difference ($p$ = 2.01E-10). The significantly higher accumulation of organic matter on the surface than the sub-surface indicated that active microbial activity occurs on the aerobic surface horizons leaving decomposed materials. However, there was no significant difference on the SOC concentration between land-uses ($p$ = 0.9943) (SF = 1.99%, GL = 1.97% and FP = 1.98%). The results further implied that forest conversion into other land-uses did not change the SOC concentration in the Silago soils. It could be due to the soil's organic carbon preservation mechanisms, such as occlusion in aggregates, biochemical stabilization (recalcitrance), and the formation of organo-mineral complexes

(Keil and Mayer, 2014; Lehmann and Kleber, 2015; Hemingway *et al.*, 2019). The latter is highly possible because of abundance of iron oxides in the soil.

Total N contents were high on the soil surface (0-20 cm = 0.2%) and decreased with depth in all land-uses (20-40 cm = 0.14% and 40-60 cm = 0.09%) (Figure 3). Results showed significant differences between land-uses ($p$ = 0.0002) and soil depths ($p$ = 3.65E-11). Between land-uses, the mean total N value was found highest in FP (0.16%) but did not vary in SF (0.15%), while GL had the lowest total N (0.12%). A similar study in Ethiopia disclosed that five forests decreased in total N as soil depth increased (Gebeyehu *et al.*, 2019) since topsoil tends to have more organic matter closely associated with N. Such claims are the same with Ouyang *et al.* (2017) in forest and with Gebeyehu and Soromesa (2018) in agricultural soils. Nevertheless, results revealed a low to a meager amount of N across all land-uses. Such low contents of N could be due to low net mineralization as it could be influenced by organic matter, texture, water content, soil structure, temperature, pH, C:N ratio of added organic materials, and microorganism present in the soil.



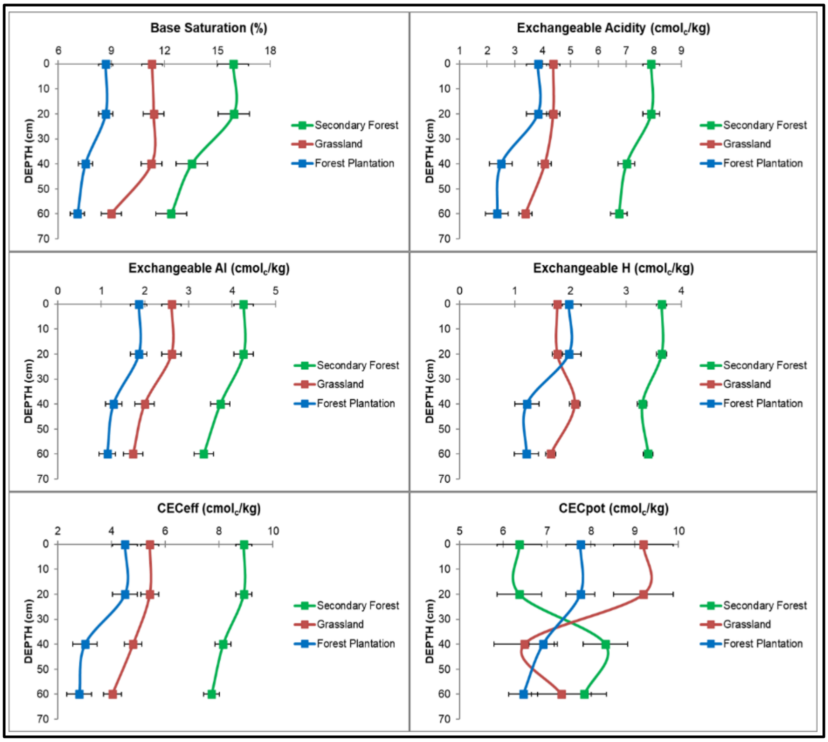

Horizontal bars represent standard errors

Figure 3. Depth function of total N, available P, exchangeable Ca, exchangeable Mg, exchangeable K, and exchangeable Na of soils as influenced by SF transformations in Silago, Southern Leyte

Available P content ranged from very low to trace amount (Figure 3). Ultisol is a highly weathered acidic soil and can fix phosphorus due to high amounts of iron and aluminum oxides. Inherent low amounts of P in the basaltic-andesite parent materials (Porder and Ramachandran, 2013) could also explain the soil's low P content. No significant differences both in mean available P among land-uses (SF = -0.02, GL = -0.03 and FP = 0.01) ($p$ = 0.7026) and in obtained mean soil depths (0-20 cm = 0.02, 20-40 cm = 0.04 and 40-60 m = 0.01) ($p$ = 0.484). The same results were obtained by Piamonte (2014) indicating that available P was low and slightly decreasing with soil depth. These results further specified that soil fertility status and the three adjacent land-use productivity were not good (Jiménez *et al.*, 2011).

Furthermore, Figure 3 shows the exchangeable bases values (Ca, Mg, K and Na). There were significant differences in the exchangeable Ca (SF = 0.43, GL = 0.30 and FP = 0.11 $cmol_c$ $kg^{-1}$) ($p$ = 0.0458), Mg (SF = 0.32, GL = 0.31 and FP = 0.24 $cmol_c$ $kg^{-1}$) ($p$ = 0.0416), and Na (SF = 0.12, GL = 0.03 and FP = 0.06 $cmol_c$ $kg^{-1}$) ($p$ = 0.0144) among land-uses but none with exchangeable K (SF = 0.18, GL = 0.17 and FP = 0.15 $cmol_c$ $kg^{-1}$) ($p$ = 0.1332). However, only Mg ($p$ = 0.0121) and K ($p$ = 0.0407) varied across depths. All levels of exchangeable bases (Ca, Mg, K and Na) were considered low to very low across all land-uses. This could stem from the inherent contribution of parent material with high rainfall of the area. A comparable area with five different types of land-use (3- and 5-year-old eucalyptus and 35-year-old rubber tree plantation, SF, and 50-year-old pasture) in the rainforest zone of Brazil under the same soil type (Ultisol) rendered the same results (Ca = 0.10-1.20 $cmol_c$ $dm^{-3}$; Mg = 0.1-0.50 $cmol_c$ $dm^{-3}$; and Na = 0.03-0.04 $cmol_c$ $dm^{-3}$) signifying low soil fertility (Vicente *et al.*, 2016).

Results depicted significant differences in base saturation among land-uses ($p$ = 0.0012). SF soils showed a significantly higher value of base saturation (13.97%) followed by GL (10.56%) and FP (7.77%). The values could be attributed to the parent material's inherent contribution and its very low pH values. Lower bases were observed in Brazil's Ultisol forest across five different land-uses with a range of 0.28-1.80 $cmol_c$ $dm^{-3}$ (Vicente *et al.*, 2016). A major factor that could have affected these soil nutrients' concentration is the periodic burning in GL and periodic harvest of FP, which made the soil unsustainable. The bases that plants extracted were not returned to the soil because burning had already ceased its mineralization, and the harvested woods were marketed. Nonetheless, as shown in Figure 4, the base saturation was relatively higher in the surface (0-20 cm = 12.01%) compared with the lower depths (20-40 cm = 10.79% and 40-60 cm = 9.49%) in which significant difference was also observed ($p$ = 0.0316). As discussed earlier in the SOC content, this could be due to higher organic matter content in the surface than in the lower depths.




Horizontal bars represent standard errors

Figure 4. Depth function of base saturation, exchangeable acidity, exchangeable Al, exchangeable H, $CEC_{eff}$ and $CEC_{pot}$ of soils as influenced by SF transformations in Silago, Southern Leyte

Relatively, results specified that exchangeable $Al^{3+}$ (SF = 3.78, GL = 2.11 and FP = 1.43 cmol$_c$ kg$^{-1}$) ($p$ = 1.58E-08 [land-use]; $p$ = 0.0174 [soil depth]), exchangeable $H^+$ (SF = 3.44, GL = 1.83 and FP = 1.46 cmol$_c$ kg$^{-1}$) ($p$ = 8.63E-07 [land-use]; $p$ = 0.4523 [soil depth]) and exchangeable acidity (SF = 7.22, GL = 3.94 and FP = 2.89 cmol$_c$ kg$^{-1}$) ($p$ = 3.08E-08 [land-use]; $p$ = 0.0886 [soil depth]) were significantly higher in the SF soils than in the other land-uses (Figure 4). Results also showed that exchangeable $Al^{3+}$ was the major component of exchangeable acidity in all soils across all land-uses. The increase in $Al^{3+}$ with depth resulted in a consistent significant decrease of pH in $H_2O$ and pH in KCl (Figure 2). Such results could be due to aluminum dependence of soil pH and exchangeable $Al^{3+}$ as the most toxic form to plants, increasing considerably below pH 5.0 in both $H_2O$ and in $CaCl_2$ (Awasthi *et al*., 2017).

Furthermore, SF showed higher acidity than the other land-uses, as shown in Figure 4, which could be attributed to higher organic matter content where exposed functional groups of organic matter also increase. In general, highly weathered soils like Ultisols naturally have high exchangeable acidity and high in $Al^{3+}$ from the active aluminum oxides resulting in increased soil acidity. Results indicated that under acidic conditions, $Al^{3+}$ is the major cation in the soil (Kobayashi *et al*., 2013; Chamier *et al*., 2015).

$CEC_{eff}$ values rendered 8.26, 4.76 and 3.44 $cmol_c$ $kg^{-1}$ in SF, GL and FP, respectively, indicating low to very low CEC (Figure 4). These data indicated low soil fertility and the soil was susceptible to acidification. Moreover, $CEC_{pot}$ (at pH 7.0) values gave significant interaction effects ($p$ = 0.0513) (SF = 7.51, GL = 7.67, and FP = 7.04 $cmol_c$ $kg^{-1}$) which explained that land-use and depth of sampling affect the $CEC_{pot}$ values. It can also be observed that $CEC_{eff}$ values were higher than $CEC_{pot}$ values (Figure 4). Results further showed that there was no significant amount of negative charge in the soil. There was significant differences in effective CEC between land-uses ($p$ = 4.06E-05); SF was the highest and between depths (0-20 cm = 6.28, 20-40 cm = 5.33 and 40-60 cm = 4.85 $cmol_c$ $kg^{-1}$) ($p$ = 0.0049); and topsoil was the highest. Such results are quite expected with Ultisols (Soil Survey Staff, 2010); frequent rainfall in the area, low pH and high presence of exchangeable $Al^{3+}$ could leach out cations (Awasthi *et al*., 2017).

### *3.3 Carbon Stocks Assessments*

#### 3.3.1 SOC Stocks

The determination of SOC stocks is a prerequisite for detecting C sequestration potential induced by land-use change. Carbon sequestration is the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids and in a form that is not immediately reemitted (Shimamoto *et al*., 2014). Therefore, soil carbon plays a crucial role in sequestering atmosphere carbon; hence, critical in mitigating global climate change.

FP obtained the highest soil C stocks followed by GL (276.78 tons C $ha^{-1}$) and lastly, by SF (274.99 tons C $ha^{-1}$) (Figure 5). Differences among land-uses were not significant ($p$ = 0.874) although results showed a relatively higher carbon accumulation in FP. It suggests that the conversion of forest into other land-uses did not affect the SOC stock (Figure 5). Such results are contrary to earlier studies (Liao *et al*., 2010; Gupta and Sharma, 2011; Ebasan *et al*., 2016; Gautam and Mandal, 2016; Vicente *et al*., 2016; Carnice and Lina, 2017), which underscored that conversion of forest to GL and other land-uses such as FP could lead to significant losses in soil organic carbon.

Contrarily, Geissen *et al.* (2009) did not observe any significant change in the organic carbon content upon deforestation. It was observed from the soil studied that it had a high amount of clay where clay surfaces absorbed the organic molecules and increased the organic carbon stabilization and resistance to microbial attack. Additionally, depending on soil type and precipitation, SOC stocks may decrease or increase after land-use conversion (Powers *et al*., 2011).

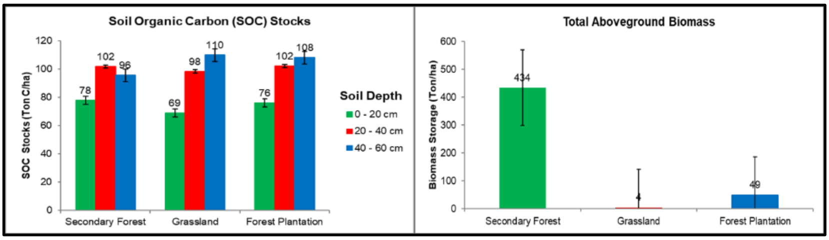
Mean SOC stocks of 280 tons C $ha^{-1}$ across the three adjacent land-uses were found to be lower compared with the mean SOC stocks of 323 tons C $ha^{-1}$ in Lake Danao National Park in Ormoc City, Leyte Island, Philippines, which has the same forest transformation but is under Andisol (Carnice and Lina, 2017). Nevertheless, in comparison, rubber tree plantation, pasture and SF in Brazil under Ultisol had lower SOC stocks of 219.34, 176 and 168 Mg C $ha^{-1}$, respectively (Vicente *et al*., 2016). In Western Himalaya, India, natural ecosystems such as forest and pas ture (112.5 to 247.5 Mg C $ha^{-1}$) and agriculture (63 to 120.4 Mg C $ha^{-1}$) tended to have the same SOC stocks range (Singh *et al*., 2011). Also, significant differences were observed in mean SOC stocks among soil depths (0-20 cm = 74.22, 20-40 cm = 100.62 and 40-60 cm = 104.42 Mg C $ha^{-1}$) ($p$ = 0.0008). It could be observed in all land-uses that SOC stocks increase with depths suggesting that organic carbon can be stored in subsoil.

#### 3.3.2 TAGB

Figure 5 shows that TAGB were significantly different among land-uses in Silago ($p$ = 0.0004). Forest vegetation revealed a TAGB of 434.37 tons $ha^{-1}$, which was substantially different from FP (49.36 tons $ha^{-1}$) and GL (4.38 tons $ha^{-1}$). The high TAGB in SF, compared with the other land-uses, was due to the few but more enormous trees (DBH > 50 cm) than FP (DBH < 50 cm). Expectedly, the TAGB of GL was low since grasses have lighter biomass.

Such results are comparable with Borneo's tropical forest of 457.1 Mg ha$^{-1}$ (Slik *et al*., 2010) but Vietnam's mean aboveground biomass in evergreen broadleaved forest was twice lesser that rendered only 230 Mg ha$^{-1}$ (Van Do *et al*., 2020) since 76% of trees had > 30 cm DBH (Slik *et al*., 2013). Unlike in Borneo, it contained dominant large-diameter dipterocarp trees (Slik *et al*., 2010). Additionally, Lake Danao National Park, a forest reserve, rendered higher TAGB in SF (690.43 Mg ha$^{-1}$) and FP (163.24 Mg ha$^{-1}$), which was caused by DBH tree values and FP was never harvested since 1971 (Carnice and Lina, 2017).

A 6.5-year-old *A. mangium* in Kerala, India, produced 81.82 Mg ha$^{-1}$ of TAGB (Kunhamu *et al*., 2011). In Sarawak, Malaysia, the second generation of *A. mangium* rendered 178.9 Mg ha$^{-1}$ and *Acacia* hybrid rendered 113.3 Mg ha$^{-1}$ (Adam and Jusoh, 2018), which are all relatively higher compared with TAGB values in Silago.



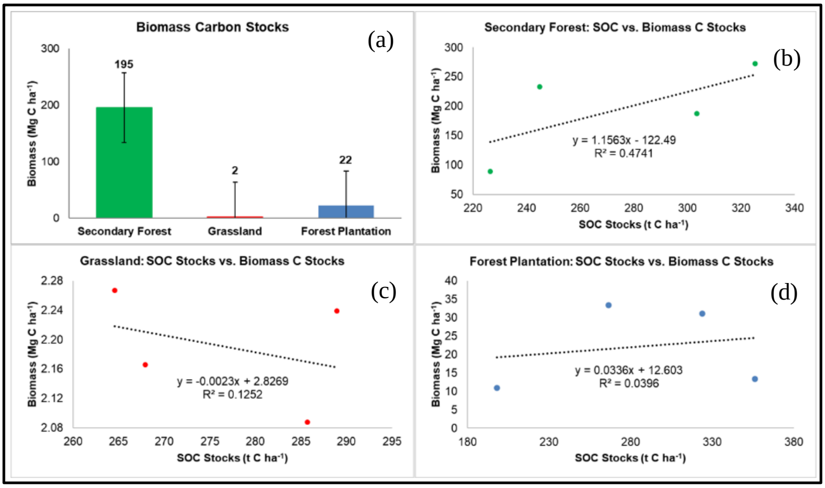

Horizontal bars represent standard errors

Figure 5. Depth function of SOC stocks and total aboveground biomass of soils as influenced by SF transformations in Silago, Southern Leyte

### 3.3.3 SOC Stocks versus Biomass Carbon Stocks

SF rendered the highest biomass carbon stocks of 195.47 Mg C ha$^{-1}$ but significantly decreased in GL with 2.19 Mg C ha$^{-1}$. However, it slightly recovered when converted into FP (22.21 Mg C ha$^{-1}$). Lake Danao National Park Forest rendered the same sequence of biomass C stocks recovery from SF (310.69 Mg C ha$^{-1}$) transformed into GL (0.89 Mg C ha$^{-1}$) and then slightly recovered when converted into FP (73.46 Mg C ha$^{-1}$) (Carnice and Lina, 2017). This coincides with the result of Lasco and Pulhin (2009) from forest plantations in Leyte Island that rendered 25.61 Mg C ha$^{-1}$ for *A. mangium*, *A. auriculiformis* (28.58 Mg C ha$^{-1}$) and the most common, *G. arborea* (31.59 Mg C ha$^{-1}$).

Furthermore, it has been recognized that aboveground C is an important part of forest C storage. However, there were few significant differences among sites. In Malaysia, lowland selectively-logged dipterocarp forest contained twice aboveground C than its soils (Saner *et al.*, 2012). In contrast, Peru's tropical forest soils had more C than its aboveground C (Gibbon *et al.*, 2010). Figure 6 shows the regression analyses results of SOC stocks and TAGB in SF ($R^2 = 0.4741$), GL ($R^2 = 0.1252$) and FP ($R^2 = 0.0396$). The results implied that SOC stocks did not have a positive relationship with TAGB, and they did not affect the TAGB across all land-uses.




Horizontal bars represent standard errors

Figure 6. Biomass carbon stocks (a), relationship between SOC stocks (t C $ha^{-1}$) and biomass carbon stocks (Mg C $ha^{-1}$) of SF (b), GL (c), and FP (d) in Silago, Southern Leyte

## 4. Conclusion

This study was conducted to quantify and evaluate the SOC stocks and nutrient status of soils under SF transformations and relate them with the aboveground biomass in Leyte Island forests. Results indicated that all soil chemical properties, except available P, seemed to be not affected by land-use change at all depths. The soil was very acidic (4.78 to 5.44 pH), low $CEC_{pot}$ values (6.36 to 9.20 $cmol_c$ $kg^{-1}$), very low to low base saturation (7.08 to 15.94%), and low to high organic C content (1.12 to 2.99%). Results also revealed that soils contained low to medium total N (0.08 to 0.22%) with deficient available P due to the soil's high P sorption. SOC stocks were not affected by land-use change. This result conveyed that the soil type (Hapludults) is one of the significant factors affecting carbon storage in the soil. On the other hand, TAGB was greatly influenced by land-use change implying that the type of vegetation affects C's storage in plant biomass. However, there was no clear relationship between SOC stocks and TAGB in both sites.

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## 6. References

Abua, M.A., Offiong, R.A., Iwara, A.I., & Ibor, U.W. (2010). Impact of newly constructed roads on adjoining soil properties in tinapa resort, South-Eastern Nigeria. Annals of Humanities and Development Studies, 1(1), 176-184.

Adam, N.S., & Jusoh, I. (2018). Allometric model for predicting aboveground biomass and carbon stock of Acacia plantations in Sarawak, Malaysia. BioResources, 13(4), 7381-7394.

Aureo, W.A., & Bande, M.M. (2017). Anurans species diversity and composition along the successional gradient of the evergreen rainforest in Silago, Southern Leyte, Philippines. International Journal of Scientific Research in Environmental Sciences, 5(3), 0082-0090. http://dx.doi.org/10.12983/ijsres-2017-p0082-0090

Awasthi, J.P., Saha, B., Regon, P., Sahoo, S., Chowra, U., Pradhan, A., Roy, A., & Panda, S.K. (2017). Morpho-physiological analysis of tolerance to aluminum toxicity in rice varieties of North East India. PLoS ONE, 12(4), e0176357. https://doi.org/10.1371/journal.pone.0176357

Brown, S., & Lugo, A.E. (1990). Effects of forest clearing and succession on the carbon and nitrogen content of soils in Puerto Rico and US Virgin Islands. Plant and Soil, 124(1), 53-64.

Carnice, P.A.B., & Lina, S.B. (2017). Carbon storage and nutrient stocks distribution of three adjacent land use patterns in Lake Danao National Park, Ormoc, Leyte, Philippines. Journal of Science, Engineering and Technology, 5, 1-14.

Cedamon, E., Harrison, S., Herbohn, J., & Mangaoang, E. (2011). Compiling market and other financial data on smallholder forestry in Leyte, the Philippines. Small-scale Forestry, 10(2), 149-162. https://doi.org/10.1007/s11842-010-9115-1

Ceniza, M.J., Bande, M.J., Fernando, E.S., Labastilla, P.K., Come, R.S., Omega, R.G., & Alesna, W.T. (2011). Community-based forest restoration and biodiversity protection and management of lowland dipterocarp forests in Silago, Southern, Leyte.

Chamier, J., Wicht, M., Cyster, L., & Ndindi, N.P. (2015). Aluminium (Al) fractionation and speciation; getting closer to describing the factors influencing $Al^{3+}$ in water impacted by acid mine drainage. Chemosphere, 130, 17-23. https://doi.org/10.1016/j.chemosphere.2015.01.026

Chen, J., John, R., Sun, G., McNulty, S., Noormets, A., Xiao, J., Turner, M.G., & Franklin, J.F. (2014). Carbon fluxes and storage in forests and landscapes. In Forest landscapes and global change (pp. 139-166). Springer, New York, NY.

Clemens, G., Fiedler, S., Cong, N.D., Van Dung, N., Schuler, U., & Stahr, K. (2010). Soil fertility affected by land use history, relief position, and parent material under a tropical climate in NW-Vietnam. Catena, 81(2), 87-96. https://doi.org/10.1016/j.catena.2010.01.006

Deborde, D.D.D., Hernandez, M.B.M., & Magbanua, F.S. (2016). Benthic macroinvertebrate community as an indicator of stream health: The effects of land use on stream benthic macroinvertebrates. Science Diliman, 28, 5-25.

Ebasan, M.S., Aranico, E.C., Tampus, A.D., Amparado, R.F. (2016). Carbon stock assessment of three different forest covers in Panaon, Misamis Occidental, Philippines. Journal of Biodiversity and Environmental Sciences, 8(4), 252-264.

Faber, J., Quadros, A.F., & Zimmer, M. (2018). A Space-For-Time approach to study the effects of increasing temperature on leaf litter decomposition under natural conditions. Soil Biology and Biochemistry, 123, 250-256. https://doi.org/10.1016/j.soilbio.2018.05.010

Gautam, T.P., & Mandal, T.N. (2016). Effect of disturbance on biomass, production and carbon dynamics in moist tropical forest of eastern Nepal. Forest Ecosystems, 3(1), 1-10. https://doi.org/10.1186/s40663-016-0070-y

Gebeyehu, G., & Soromessa, T. (2018). Status of soil organic carbon and nitrogen stocks in Koga Watershed Area, Northwest Ethiopia. Agriculture & Food Security, 7(1), 9.

Gebeyehu, G., Soromessa, T., Bekele, T., & Teketay, D. (2019). Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. Journal of Ecology and Environment, 43(1), 7. https://doi.org/10.1186/s40066-018-0162-8

Geissen, V., Sanchez-Hernandez, R., Kampichler, C., Ramos-Reyes, R., Sepulveda-Lozada, A., Ochoa-Goana, S., De Jong, B.H.J., Huerta-Lwanga, E., & Hernandez-Daumas, S. (2009). Effects of land-use change on some properties of tropical soils –

An example from Southeast Mexico. Geoderma, 151(3-4), 87-97. https://doi.org/10.1016/j.geoderma.2009.03.011

Gibbon, A., Silman, M.R., Malhi, Y., Fisher, J.B., Meir, P., Zimmermann, M., Dargie G.C., Farfan, W.R., & Garcia, K.C. (2010). Ecosystem carbon storage across the grassland-forest transition in the high Andes of Manu National Park, Peru. Ecosystems 13, 1097-1111. https://doi.org/10.1007/s10021-010-9376-8

Goetz, S.J., Hansen, M., Houghton, R.A., Walker, W., Laporte, N., & Busch, J. (2015). Measurement and monitoring needs, capabilities and potential for addressing reduced emissions from deforestation and forest degradation under REDD+. Environmental Research Letters, 10(12), 123001.

Gupta, M.K., & Sharma, S.D. (2011). Sequestrated carbon: Organic carbon pool in the soils under different forest covers and land uses in Garhwal Himalayan region of India. International Journal of Agriculture and Forestry, 1(1), 14-20. https://doi.org/10.5923/j.ijaf.20110101.03

Harris, N.L., Brown, S., Hagen, S.C., Saatchi, S.S., Petrova, S., Salas, W., Hansen, M.C., Potapov, P.V., & Lotsch, A. (2012). Baseline map of carbon emissions from deforestation in tropical regions. Science, 336(6088), 1573-1576. https://doi.org/10.1126/science.1217962

Hemingway, J.D., Rothman, D.H., Grant, K.E., Rosengard, S.Z., Eglinton, T.I., Derry, L.A., & Galy, V.V. (2019). Mineral protection regulates long-term global preservation of natural organic carbon. Nature 570, 228-31. https://doi.org/10.1038/s41586-019-1280-6

Houghton, R.A., House, J.I., Pongratz, J., van der Werf, G.R., DeFries, R.S., Hansen, M.C., Le Quéré, C., & Ramankutty, N., (2012). Carbon emissions from land use and land-cover change. Biogeosciences 9, 5125-5142. https://doi.org/10.5194/bg-9-5125-2012

Huang, J., Hartemink, A.E., & Zhang, Y. (2019). Climate and land-use change effects on soil carbon stocks over 150 years in Wisconsin, USA. Remote Sensing, 11(12), 1504. https://doi.org/10.3390/rs11121504

Hunter, M.O., Keller, M., Vitoria, D., & Morton, D.C. (2013). Tree height and tropical forest biomass estimation. Biogeosciences, 10, 8385-8399. https://doi.org/10.5194/bg-10-8385-2013

Jiménez, J.J., Lorenz, K., & Lal, R. (2011). Organic carbon and nitrogen in soil particle-size aggregates under dry tropical forests from Guanacaste, Costa Rica – Implications for within-site soil organic carbon stabilization. Catena, 86(3), 178-191. https://doi.org/10.1016/j.catena.2011.03.011

Keil, R.G., & Mayer, L.M. (2014).Mineral matrices and organic matter. In H. Holland & K .Turekian (Eds.), Treatise on geochemistry (pp. 337-359). Netherlands: Elsevier.

Kobayashi, Y., Kobayashi, Y., Watanabe, T., Shaff, J.E., Ohta, H., Kochian, L.V., Wagatsuma, T., Kinraide, T.B., & Koyama, H. (2013). Molecular and physiological analysis of Al3+ and H+ rhizotoxicities at moderately acidic conditions. Plant Physiology, 163(1), 180-192. https://doi.org/10.1104/pp.113.222893

Kunhamu, T.K., Kumar, B.M., & Samuel, S. (2011). Does tree management affect biomass and soil carbon stocks of *Acacia mangium* Willd. Stands in Kerala, India? In B.M. Kumar & P. K. R. Nair (Eds.), Carbon sequestration potential of agroforestry systems (pp. 217-228). Switzerland: Springer, Dordrecht.

Lai, L., Huang, X., Yang, H., Chuai, X., Zhang, M., Zhong, T., Chen, Z., Chen, Y., Wang, X., & Thompson, J.R., (2016). Carbon emissions from land-use change and management in China between 1990 and 2010. Science Advances, 2(11), e1601063.

Lasco, R.D., & Pulhin, F.B. (2009). Carbon budgets of forest ecosystems in the Philippines. Journal of Environmental Science and Management, 12(1), 1-13.

Lawler, J.J., Lewis, D.J., Nelson, E., Plantinga, A.J., Polasky, S., Withey, J.C., Helmers, D.P., Martinuzzi, S., Pennington, D., & Radeloff, V.C., (2014). Projected land-use change impacts on ecosystem services in the United States. Proceedings of the National Academy of Sciences, 111(20), 7492-7497. https://doi.org/10.1073/pnas.1405557111

Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. Nature, 528(7580), 60-68. https://doi.org/10.1038/nature16069

Liao, C., Luo, Y., Fang, C., & Li, B. (2010). Ecosystem carbon stock influenced by plantation practice: Implications for planting forests as a measure of climate change mitigation. PLoS ONE, 5(5), e10867. https://doi.org/10.1371/journal.pone.0010867

Luo, Z., Wang, E., Bryan, B.A., King, D., Zhao, G., Pan, X., & Bende-Michl, U. (2013). Meta-modeling soil organic carbon sequestration potential and its application at regional scale. Ecological Applications, 23(2), 408-420. https://doi.org/10.1890/12-0672.1

Narisma, G.T.T., Vicente, M.C.T.M., Capili-Tarroja, E.B., Cruz, F.A.T., Perez, R.T., Dayawon, R.S., Dado, J.M.B., Castillo, M.F., Villafuerte, I.M.Q., Loo, L.C.G., Olaguer, D.M.P., Loyzaga, M.A.Y., Banaticla, M.R.N., Ramos, L.T., Habito, C.M.D., & Lasco, R.D. (2011). Patterns of vulnerability in the forestry, agriculture, water, and coastal sectors of Silago, Southern Leyte, Philippines. Bonn, Germany: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and World Agroforestry.

Ouyang, S., Xiang, W., Gou, M., Lei, P., Chen, L., Deng, X., & Zhao, Z. (2017). Variations in soil carbon, nitrogen, phosphorus and stoichiometry along forest succession in southern China. Biogeosciences Discussions, 1-27. https://doi.org/10.5194/bg-2017-408

Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). (2014). Updating of the climate map of the Philippines based on the modified coronas' climate classification. Retrieved from http://bagong.pagasa.dost.gov.ph/information/climate-philippines

Pan, Y., Birdsey, R., Fang, J., Houghton, R., Kauppi, P.E, Kurz, W., Phillips, O.L., Shvidenko, A., Lewis, S.L., Canadell, J.G., Ciais, P., Jackson, R.B., Pacala, S.W., McGuire, D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. Science, 333, 988-993.

Piamonte, M.K.B., Asio, V.B., & Lina, S.B. (2014). Morpho-physical and chemical characteristics of strongly weathered soils in Silago, Southern Leyte, Philippines. Annals of Tropical Research, 36(2), 115-147.

Porder, S., & Ramachandran, S. (2013). The phosphorus concentration of common rocks – A potential driver of ecosystem P status. Plant and Soil, 367(1-2), 41-55. https://doi.org/10.1007/s11104-012-1490-2

Powers, J.S., Corre, M.D., Twine, T.E., & Veldkamp, E. (2011). Geographic bias of field observations of soil carbon stocks with tropical land-use changes precludes spatial extrapolation. Proceedings of the National Academy of Sciences, 108(15), 6318-6322. https://doi.org/10.1073/pnas.1016774108

Redondo-Brenes, A. (2007). Growth, carbon sequestration, and management of native tree plantations in humid regions of Costa Rica. New Forests, 34(3), 253-268. https://doi.org/10.1007/s11056-007-9052-9

Saner, P., Loh, Y.Y., Ong, R.C., & Hector, A. (2012). Carbon stocks and fluxes in tropical lowland dipterocarp rainforests in Sabah, Malaysian Borneo. PLoS ONE, 7, e29642. https://doi.org/10.1371/journal.pone.0029642

Sarmiento, G., Pinillos M., & Garay, I. (2005). Biomass variability in tropical American lowland rainforests. Ecotropicos, 18(1), 1-20.

Shimamoto, C.Y., Botosso, P.C., & Marques, M.C. (2014). How much carbon is sequestered during the restoration of tropical forests? Estimates from tree species in the Brazilian Atlantic forest. Forest Ecology and Management, 329, 1-9. https://doi.org/10.1016/j.foreco.2014.06.002

Singh, S.K., Pandey, C.B., Sidhu, G.S., Sarkar, D., & Sagar, R. (2011). Concentration and stock of carbon in the soils affected by land uses and climates in the western Himalaya, India. Catena, 87(1), 78-89. https://doi.org/10.1016/j.catena.2011.05.008

Slik, J.W.F., Aiba, S.I., Brearley, F.Q., Cannon, C.H., Forshed, O., Kitayama, K., Nagamasu, H., Nilus, R., Payne, J., Paoli, G., & Poulsen, A.D. (2010). Environmental correlates of tree biomass, basal area, wood specific gravity and stem density gradients in Borneo's tropical forests. Global Ecology and Biogeography, 19(1), 50-60. https://doi.org/10.1111/j.1466-8238.2009.00489.x

Slik, J.F., Paoli, G., McGuire, K., Amaral, I., Barroso, J., Bastian, M., Blanc, L., Bongers, F., Boundja, P., Clark, C., & Collins, M. (2013). Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. Global Ecology and Biogeography, 22(12), 1261-1271. https://doi.org/10.1111/geb.12092

Soil Survey Staff. (2010). Keys to soil taxonomy (11$^{th}$ ed.). Washington DC 338: USDA – Natural Resources Conservation Service.

Thompson, T.M. (2018). Modeling the climate and carbon systems to estimate the social cost of carbon. Wires Climate Change, 9(5), e532.

United Nations Framework Convention on Climate Change (UNFCCC). (2011). Outcome of the work of the ad hoc working group on long-term cooperative action under the convention. https://unfccc.int/sites/default/files/resource/docs/2012/awglca15/eng/l04.pdf

Van Do, T., Yamamoto, M., Kozan, O., Dai Hai, V., Trung, P.D., Thang, N.T., Hai, L.T., Nam, V.T., Hung, T.T., Van Thang, H., Manh, T.D., Khiem, C.C., Lam, V.T., Hung, N.Q., Quy, T.H., Tuyen, P.Q., Bon, T.N.,… Thu, N.T., (2020). Ecoregional variations of aboveground biomass and stand structure in evergreen broadleaved forests. Journal of Forestry Research, 31(5), 1713-1722.

Vicente, L.C., Gama-Rodrigues, E.F., & Gama-Rodrigues, A.C. (2016). Soil carbon stocks of Ultisols under different land use in the Atlantic rainforest zone of Brazil. Geoderma Regional, 7(3), 330-337. https://doi.org/10.1016/j.geodrs.2016.06.003

Xiao, K., He, T., Chen, H., Peng, W., Song, T., Wang, K., & Li, D. (2017). Impacts of vegetation restoration strategies on soil organic carbon and nitrogen dynamics in a karst area, southwest China. Ecological Engineering, 101, 247-254. https://doi.org/10.1016/j.ecoleng.2017.01.037