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FORESTS CARBON INPUT AND CHANGES IN SOIL PROPERTIES OF THE TROPICAL RAIN FOREST, MALAYSIA

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ABSTRACT
The tropical forest ecosystem plays a critical role in the forest carbon input and it is important to understand the rate of occurrences by quantifying the forest biomass and its effect on soil properties in relation to microclimate condition and environmental factors. The study was conducted in the tropical forest ecosystem of Malaysia with the aim to estimate the forest carbon input and its effects on changes in soil properties The Malaysia lowland tropical forest was found to be a carbon sink with an accumulation rate of total above ground biomass (TAGB), below ground biomass (BGB) and total forest carbon (SOCs) of 2788.64 to 3009.97, 100.88 to 134.94 and 2996.13 to 3088.98 mg ha^{-1} respectively and varied between February and September and October and January. The soil properties; total organic carbon (TOC), soil organic carbon (SOC) and soil carbon stock (SOCstock) varied in relation to forest biomass at a ranges of 1.1 to 3.0, 1.1 to 5.89 and 58.01 to 70.46 mg ha^{-1}, respectively. The forest biomass gradually increases over time and also influences the concentration and increase in soil properties influences environmental factors responsible for physiological activity. The multiple linear regression and Pearson correlation indicated a strong positive correlation (R^2=0.98, p<0.01) between forest biomass, soil properties and environmental factors. The tropical lowland forest of Malaysia indicated increase in the forest biomass over time and significantly influenced the concentration of soil properties.

Keywords: Forest biomass, Soil organic carbon stock, Soil temperature, Total above ground biomass, Total forest carbon

INTRODUCTION

Forest carbon cycling has been of key research focus as it plays a major role in global climate change, (Watson *et al.* 2000; Davis *et al*. 2003; Laporte *et al.* 2003). However, the forest serve as a source or sinks for carbon as they vary widely according to forest species, trees age and region (Lee &Jose 2003; Pypker & Fredeen 2003). Forests is considered as a potential carbon sinkin terms of contributing carbon input, effective change in soil properties and carbon dioxide storage that is being emitted into the atmosphere (Janssens *et al.* 2002; Adachi *et al.* 2006). Carbon input into the soil increases soil nutrients such soil organic carbon (SOC), total organic carbon (TOC) and soil organic carbon stock (SOCstock) thereby influence soil properties. These soil organic matter serve as source of electrons and source of carbon of metabolism (Creed *et al*. 2012).

The global soils, hosts about 1,500 Gt carbon (C) and 300 Gt nitrogen (N) in the top 1m (Jobbágy & Jackson 2000) while 37% of the carbon is stored in the tropical forest as the largest amount (Dixon *et al*. 1994) with the tropical forests carbon sink estimated at 1-3 Pg C y^{-1}(1 Pg =10^{15}) (Malhi & Grace, 2000). It is acceptable that the forest carbon input and soil properties acts as a vital source, pool, sink for carbon and cycling of carbon in the terrestrial ecosystems, (Xu *et al.* 2010). Carbon input play a critical role in transformation of forest soils. However, it is unclear whether the tropical forest of Malaysia are currently sequestering carbon as a large source as uncertainties remains in estimating the tropical forest carbon input and changes soil properties as the underlying rate and amount of carbon input are affected by environmental factors (Melillo *et al.*1993; Malhi & Grace, 2000; Lewis, 2000). The undisturbed tropical forests have historically been presumed to contribute little to changes in atmospheric carbon dioxide(Waring & Schlesinger 1985) that decrease the net primary production (NPP) (Kira & Shidei 1967;Dexiang *et al.* 2010). Recent studies inventory plots across tropical Amazonian forests show that old-growth forests have carbon storage by 0.5-3.0 Pg C (Grace & Malhi 2002)pr year over recent decades, at a rate of 0.62±0.23 Mg C ha^{-1}yr^{-1}(Baker *et al*. 2004).Consequently, the environmental determinants that affect the changes in forest biomass remain unclear and are not well quantified (Malhi *et al*. 2006), although old-growth tropical forests have recently demonstrated an increase in stem turnover (Malhi & Grace 2000; Baker *et al*. 2004). Forest carbon input and net carbon balance for the tropical land ecosystems remains one of the largest uncertainties in the global carbon budget(Houghton 2005). Therefore, determination and estimation of forest carbon input and changes soil properties of the tropical forest terrestrial ecosystems is an important aspect of understanding the forest carbon cycling as the combined aforementioned factors play major role in the various forest carbon flow, (Raich 1998; Kim 2004).

Little progress has been made in improving understanding of the role of increasing forest biomass on soil properties in relation to environmental factors in the tropical forest ecosystems. Consequently, the tropical forest constitute great amount of forest biomass as particular vegetation type may have specific input to soil carbon and soil nutrients, which could impacts on soil biological activity through soil temperature and soil moisture, (Emmett *et al*. 2004; Kovscek 2002). The magnitude of soil nutrients occurrences in the tropical forests could be more pronounced than in other ecosystems as they are largely availableas nutrient for microorganism activity in presence of other environmental factors. Is the increasing forest biomass of the tropical forests of Malaysia having any effect in the carbon storage? If so, how is the forest biomass input affect the changes in soil properties Answers to these questions will help improve the understanding of the forest carbon budget. The objective of this study was to estimate the forest carbon input and its effects on changes in soil properties in the tropical forests.

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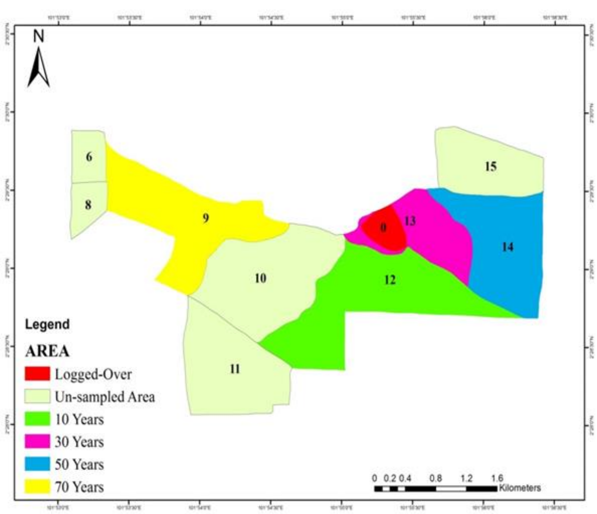
MATERIALS AND METHODS

Experimental site

The study was conducted in a tropical lowland forest of Sungai Menyal, $27^{0}47'99''$N, $43^{0}76'90''$E, located in Port Dickson, Negeri Sembilan approximately 93.1km from Kuala Lumpur Malaysia (Fig1). The soil is classified as belonging to the Serdang-Kedah series with a combination of local alluvium colluvium resulting from metamorphic rock. The study area is located in Peninsula Malaysia and has a wet and humid tropical climate throughout the year that is characterized by high annual rainfall, humidity and temperature. The average temperature ranged between 23.7-32^{o}C, (Suhaila & Jemain, 2008), while the average solar radiation is at an average of 17.00MJm^{-2} and daily evaporation rate stood at 3.1 mm day^{-1}, (MMD 2013). The soil was classified as the Serdang-Kedah series developed over mixed sedimentary rocks with a combination of local alluvium colluvium resulting from metamorphic rock (Paramananthan 1998; Paramananthan 2012). In the FAO/UNESCO Soil Map of the World – Revised Legend (FAO 1990) the Serdang series is classified as Haplic Nitisols. An experimental plot of 1 ha x 1 ha plot size with two replicates were designed for the field experiment.



Source: Negeri Sembilan Forest Dept. 2013.
Figure1: Map of Sungai Menyala Forest Reserved showing various forest compartments

Total Aboveground Biomass, Total Belowground Biomass, and Total Forest Carbon

Stock

The Estimation of forest biomass was carried out using allometric relationships obtained in the forest according to the International Biological Programme (Kira 1978) and a diameter at breast height (DBH) of about 368 trees were measured for total above ground biomass (TAGB), using the DBH tape, 1.3 m above the forest floor of each tree within the confirmed plot (Manokaran *et al*. 1990). All the trees > 5 cm in DBH were identified, mapped and tagged, and their DBH were measured. If a tree had a large buttresses, it DBH was measured just above the buttresses (Niiyama et al. 1999). The DBH was estimated to ascertain the total above ground biomass (TAGB) based on Kato *et al.* (1978) model, while below ground biomass (BGB) and total forest carbon (SOCs) was based on Ogawa *et al.* (1963) model. The models estimate the tree stem, branch and leave biomass. These components form the total above ground biomass (TAGB) based on simple regression lines fitted for DBH and tree height as indicated in equation 1-7.

$$Tree\ height\ (H)\frac{1}{H} = \frac{1}{(a.D)} + \frac{1}{MaxHt} \qquad (1)$$

Where:
H is the tree height (m)
D is *DBH* (cm)
MaxHt is the maximum tree height (m), and '*a*' is the coefficient with 2.0 for trees with *DBH*>4.5cm.
Weight (kg) of main stem (Ws):

$$Ws\ = 0.313(D^2\ \ H)^{0.9733} \qquad (2)$$

Weight (kg) of branches(Wb):

$$Wb\ = 0.313(D^2 H)^{1.041} \qquad (3)$$

Weight (kg) of leaves(Wl):

$$\frac{1}{Wl} = \frac{1}{(0.124.Ws^{0.794})} + \frac{1}{125} \qquad (4)$$

The total above ground biomass (*TAGB*) was calculated as:

$$TAGB\ = Ws + Wb + Wl \qquad (5)$$

The below ground carbon biomass was calculated using the model of Ogawa et al. (1963);

$$Root\ (W_R) = 0.0264\ (D^2H)^{0.775} \qquad (6)$$

The total forest carbon stock was estimated based on the carbon content in the biomass data. The default value for the carbon content on biomass is 0.47 (Feldpausch et al. 2004), which varies among different countries; it was calculated as:

$$C_b = B \text{ x } \%\ C\ organic \qquad (7)$$

where;
$C_b$is the carbon content from the biomass
B is the total biomass
%C organic is the percentage value for carbon content, amounting to 0.47 default value or laboratory obtained value.

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Soil Sampling and Analysis
Soil samples from 0 - 100 cm depth were collected from three sampling points using a soil auger based on soil samples collection protocol, samples were placed in sterile plastic bags, sealed and returned to the laboratory and later oven-dried at 105°C for 48 hours to determine the soil water content (mass basis) (Gong *et a*l. 2012). The standard method was used to analyse for soil organic carbon (SOC), soil moisture contents (SMC) and bulk density, while soil pH was measured in water (1:2.5 w/v) according to the Kjeldahl method (Bremner 1960), and the Walkley Black wet oxidation technique was used to determine the total organic carbon (TOC) (Sollins *et al.* 1999). The soil carbon stock (SOCstock) was estimated using the model of (Eleanor 2008) within a given depth of top soil range from 0 to 100 cm. The soil moisture content was estimated using the standard method based on the following equation:

$$Moist\ (wt\%) = \left[\frac{(A-B)}{B - tare\ tin}\right] \text{x}\ 100 \qquad (8)$$

where:
A is the mass of moist soil (g),*B* is the mass of oven dry soil (g).

The bulk density was estimated in accordance with the standard method(Nhantumbo & Bennie 2001):

$$Bulk\ density\ (mg\ m^{-3}) = {}^{g}/_{v} \qquad (9)$$

where:
g = oven dry mass of the sieve soil (g), v = sample volume (cm^{-3}).
Soil organic carbon (*SOC*) was determined using the following equation:

$$M = {}^{10}/_{Vblank} \qquad (10)$$

$$\%oxidizable\ organic\ carbon\ ({}^{W}/_{W}) = {}^{[V\ blank - V\ sample]}/_{Wt}\ x\ 0.3\ x\ mass \qquad (11)$$

$$\%total\ organic\ carbon\ ({}^{W}/_{W}) = 1.334\ x\ \%\ oxidazable\ organic\ carbon \qquad (12)$$

$$\%organic\ matter\ ({}^{W}/_{W}) = 1.724\ x\ \%total\ organic\ carbon \qquad (13)$$

where:
M = molarities of ferrous ammonium sulphate solution (app 0.5 cm^{-3})
V blank = volume of ferrous ammonium sulphate solution required to titrate the blank (cm^{-3})
Wt = weight of air dry soil (g)
0.3 = 3 x 10^{-3} x 100 where 3 is the equivalent weight of C.

The total organic carbon (TOC) was determined by the Walkley-Black method using a correction factor of 1.33 (Sollins et al. 1999) as it is appropriate for moisture analyses because of its simplicity.

$$Toc\ (\%c) = M\ x\ \left[{}^{(V1 - V2)}/_{S}\right] x\ 0.39\ x\ mcf \qquad (14)$$

where:
M = molarities of ferrous sulphate solution (from blank titration)
V1 = cm^{-3}ferrous sulphate solution required for blank
V2 = cm^{-3}ferrous sulphate solution required for S = weight of air dry sample in grams
mcf = 3 (equivalent weight of carbon) corrected factor.

The moisture corrected factor (mcf) is:

$$Moist\ corection\ factor = {}^{(100 +\ \%\ moist)}/_{100} \qquad (15)$$

Soil carbon stock (SOCstock) using the model of Eleanor (2008), where the given depth of soil was from 0 to 100 cm. The soil organic carbon based on the compacted soil was estimated by determining the bulk density (BD). The equation is expressed as:

$$SOC_{stock} = \frac{SOC\ content\ of\ the\ soil\ x\ BD\ x\ area\ x\ depth}{10} \qquad (16)$$

To measure the carbon to nitrogen (C/N) input due to litter fall, ten rectangular litter traps with surface area of 1 x 1 m were installed 1 m above the forest floor. Litter was collected at two weeks interval for a period of one year. The litter from each trap was transported to a laboratory and oven-dried at 65°C for 48 h. All dried samples were separated into needle, bark, cones branches and miscellaneous components, and each component was weighed. The C/N ratio concentration was determined using a TruMac CNS Macro Analyser (LecoCorp), while the mass loss rates in the needle litter were estimate using the litterbag technique(Kim, 2007).

Microclimate Condition
To quantify the environmental factors effect on soil properties and carbon nutrients, soil temperature, soil moisture and water potential were measured using probes (Watchdog data logger model 125 spectrum technology, TDR Trime FM and Delmorst model KS-D1), respectively as described by Mande *et al.* (2013). All measurement were conducted concurrently on a daily basis from 0800hours to1700hours over a period of one year cutting across the entire tropical climate season. The forest canopy stand densities and light intensity distribution were determined based on leaf area Index (LAI) using the sunfleck ceptometer (AccuPAR model sf-80, Decagon, Pullman, WA) to measure over 368 trees.
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Statistical analysis
Forest biomass (TAGB, BGB andSOCs), changes soil properties (TOC, SOC and SOCstock) and environmental factors data were analysed using a one-way ANOVA, followed by a post hoc Dunn's test and Turkey multiple comparison test(Mande *et al.* 2013, Müller *et al.* 2011).The analysis of variance (ANOVA) was used to test the difference of standard deviation and mean soil temperature, soil moisture and water potential in different months. The descriptive statistics was established to calculate and explain the normality of data distribution and also to quantify the correlations between forest biomass, changes in soil properties and as well as environmental factors. Exponential regression and the multiple linear regression models were employed to ascertain the significant effect of environmental factors on soil properties in the study area, likewise the Pearson correlation was calculated to show the correlation of forest biomass, soil properties with the environmental factors. Before analysis, all data were tested for the assumptions of ANOVA. In a situation when data are heterogeneous, they were In-transformed before analysis. The statistical tests were considered significant at the $p< 0.05$ level. The entire statistical tests were performed using SPSS version 21

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software (SPSS Inc., Chicago, Illinois, USA). The techniques were used for both predictive and explanatory purposes with the experimental design.

RESULTS

Forest Biomass Distribution

To understand the biomass distribution within months, we analysed the data between twelve months from the study plot. The results showed that the number of trees with DBH > 5 cm averaged 368 per half a hectare and average number of species is about 10 within the study plot. Measurements of forests biomass and the changes in biomass that occurs over time provide an important method for evaluating carbon sequestration by an ecosystem. The forest biomass varied between February and September and between October and January at 2788.64 to 3009.97, 100.88 to 134.94 and 2996.13 to 3088.98 mg ha^{-1} for TAGB, BGB and SOCs respectively. The temporal dynamics of the forest biomass are associated strongly with the tropical microclimate as they increased linearly over time, as quadratic relationships were found in the temporal dynamics of forest biomass and microclimate. The forest biomass was found to gradually increased during the early year, beginning in February 2013 and reaching their highest value in January 2014, showing a significant increase in forest biomass over time. The variation in the temporal dynamics of forest biomass may be related to the tropical climate.

Soil Properties and Environmental Factors

The strength of forest carbon input and storage can be used to assess the changes soil properties. Soil analysis revealed a considerable amount of soil properties, as TOC and SOC decreased with soil depth between 0 and 100 cm (Fig.2) with the highest concentration occurring between the top 0 and 30 cm of soil depth indicating they are being influenced by forest biomass The results showed an increase of soil properties over time between February and September and October and January. Soil properties and forest biomass showed a positively and strong relationship (R^2=0.98 at p<0.01). Soil moisture content was observed to bebetween 16.79 and 18.1% in February to September and October to January, respectively and a corrective factor of 1.12 and 1.84 between February to September and October to January, respectively.

The estimated soil organic carbon stock (SOCstock) in the top 100 cm was 65.85 and 70.46 Mg ha^{-1} between February and September and October and January respectively, and decreased with soil depth. The high percentage of occurrence of SOCstock is as result of the increasing forest biomass as the correlation coefficients between the two variables do reflect a strong relationship (R^2=0.96, p<0.01). The bulk density (BD) was found to increase with l depth between 0 and 100 cm (Fig.2) given a good porosity for soil water movement and cation exchange capacity to hold onto nutrients. Furthermore, carbon and nitrogen input from litter fall contributed about 49.99-51.86 and 1.55 – 1.86% C/N between February and September, 51.98-52.14 and 1.91 – 1.98% C/N for October to January (Fig.3). The C/N is responsible for the decomposition of organic matter by micro-organisms.

The trends of increase in forest biomass, concentration in soil properties and considerable amount of C/N were significant to the variation in environmental factors; soil temperature, soil moisture and water potential which were found to occurred at a range of 24.92-25.88^{0}C, 24.63-25.67% and 85.22-96%, respectively between February and September and October and January, respectively.

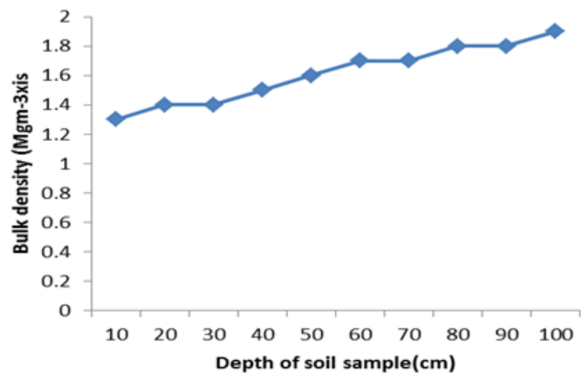

Figure 2: Distribution of Bulk Density with Soil Depth

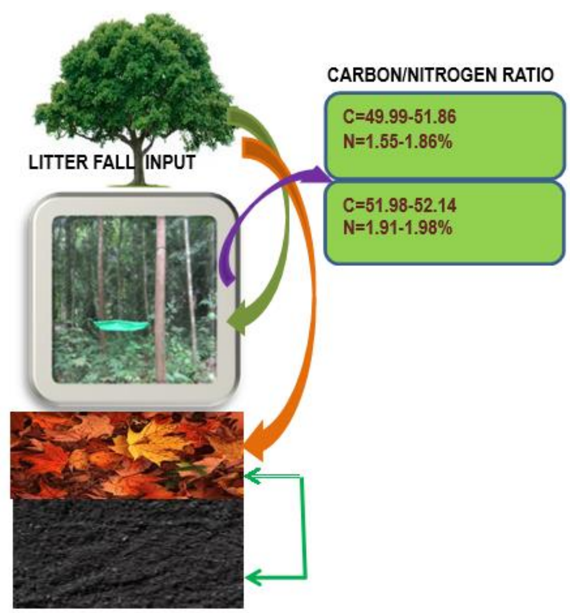

Figure 3: Carbon to Nitrogen Occurrences

Discussion

Forest Carbon Input

Studies across the tropical forests of China, African and Amazonian show that forests have increased carbon storage over decades (Malhi & Grace 2000; Schuur 2001; Baker *et al.* 2004; Lewis *et al.* 2009; Dexiang *et al.* 2010), but it is unclear what environmental determinants and the rate of increase of forest biomass and it influence on changes soil properties over time in the tropical lowland forests Malaysia. The net carbon balance for tropical forest ecosystems remain uncertainin the global carbon budget (Brown *et al.* 1993; Melillo *et al.* 1995) due to an absence of accurate estimations of forest biomass input in the tropical forests ecosystems (Tian *et al.* 2000). An understanding of the contribution of the tropical forest biomass to changes in soil properties and influence of environmental factors could improve the understanding of the forest carbon budget.

The recorded values of the forest biomass input (Fig.2) varied, and such variation may be due to the tropical microclimate condition and changes in environmental factors. The correlation analysis indicate that the primary microclimate drivers are precipitation, which affects increasing forest biomass and is positively correlated with precipitation (Tian *et al*. 2000). The forest biomass values of the tropical lowland forests of Malaysia were observed to be low between February and September in absence of rain fall but attend it peak between October and January the monsoon regime. The results indicated that the increase in forest carbon input was strongly associated with the changes in season, this proved that the growth of trees was enhanced by increased in rain fall, this is due to sufficient water transpiration from being affected by pressure, during the dry season (Dexiang *et al*. 2010).

Changes soil Properties and Environmental Factors

The significant input from the forest biomass was positively correlated with increasing soil properties. The results obtained indicated that soil properties (TOC, SOC and SOCstock) spontaneously increased and it was attributed to forest biomass input. The average TOC, SOC and SOCstock recorded ranges from 1.1 to 3.0, 1.1 to 5.89 and 58.01 to 70.46 mg ha^{-1}, respectively similar to what Mande *et al.* (2014), observed in the tropical forest, which show that soil properties are being influenced by the rate of changes in forest biomass. The overall increase in soil properties are the combined function of the high percentage of TAGB, BGB and SOCs recorded from the forest biomass (Saiz *et al*. 2006). Subsequently, recovering forest and old growth forest increases with an increase in forest biomass in the presence of precipitation (Li *et al.* 2000). The bulk density was found to increase with depth indicating the role that pore space plays in water movement, electric conductivity and microbial activity. Likewise soil temperature, soil moisture, and water potential were found to occur between 24.92-25.88^{0}C, 24.63-25.67% and 85.22-96%, respectively, similar to the study by Mande *et al*.(2014) in the recovering forest Malaysia., Subsequently, litter deposition and carbon-nitrogen ratio increases decomposition rate for microorganism to supply more soil nutrients. Partial correlation and multiple regression analysis indicated a high and significant (R^2=0.98, p<0.01) positive correlation between forest biomass, changes soil properties and environmental factors. Soil properties is controlled by increasing forest biomass and litter fall (Neergaard *et al.* 2002; Adachi *et al.* 2006; Subke *et al.* 2006) while soil temperature, soil moisture and water potential are key factors as they can increase the physiological activity of soil microorganism, leading to higher decomposition rate and higher soil properties (Han *et al*. 2007).

The Pearson correlation analysis indicated that the strength of association between forest biomass and soil properties was very high significantly (p<0.01) confirmed that the contribution of forest biomass to increasing soil properties is stronger and played the dominant role. When other factors were added to the analysis, it was found that soil properties were strongly influenced by the combined factors.

Conclusion

The study of forest biomass indicated that the tropical lowland forest increases it biomass over time and as a source for soil properties and soil carbon stock. The forest's biomass, soil properties and soil carbon stock varied between 100.88 to 3088.98 mg ha^{-1}, 1.1 to 5.89% and 58.01 to 70.46 mg ha^{-1}, respectively. The study demonstrated that increasing forest biomass is a function of microclimate condition and environmental factors having a strong relationship at R^2=0.96, p<0.01. The contribution of forest biomass to the increasing in soil properties was remarkable and varied over the months. Our ground measurement indicated that forest biomass increases with changes seasons and influence soil properties showing that the tropical lowland forest of Malaysia was a net source of carbon. The strength of carbon sequestration had a quadratic relationship with precipitation, which are a major factor controlling trees growth, canopy formation and carbon sequestration in the tropical forest Malaysia. Additionally, also we found a strong relationship between the dynamic of forest biomass and changes soil properties. The forest biomass increase with gradual increased in soil properties over time. Furthermore, we found a significant relationship between forest biomass, soil properties and environment factors as they influence the physiological activities to enhanced decomposition. In conclusion, the tropical lowland forest of Malaysia increase in forest biomass over time and contributing significantly to increase in soil properties in present of other environmental factors indicated that the forest is a source of carbon sink.

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