Contents lists available at Science-Gate

International Journal of Advanced and Applied Sciences

Journal homepage: http://www.science-gate.com/IJAAS.html

The effects of forest type and land use on soil carbon stock in Malaysian dipterocarps forests

Ahmed Chinade Abdullahi [1,2,*], Chamhuri Siwar [1], Mohamad Isma'il Shaharudin [1], Isahak Anizan [3]

[1]*Institute of Environment and Development, National University of Malaysia, 43600 Bangi, Selangor, Malaysia*
[2]*Department of Environmental Management Technology, Abubakar Tafawa Balewa University, Bauchi, Nigeria*
[3]*Faculty of Science and Technology, National University of Malaysia (UKM), 43600 Bangi, Selangor, Malaysia*

ARTICLE INFO

Article history:
Received 9 February 2018
Received in revised form
8 May 2018
Accepted 16 May 2018

Keywords:
Soil carbon stock
Carbon sequestration
Forest soils
Tropical rainforest
Dipterocarps

ABSTRACT

This study examines the carbon stock in the soils of natural, disturbed and managed dipterocarps forest types located in and around Berembun (BFR) and Kenaboi Forest Reserves (KFR), Negeri Sembilan, Malaysia. The objective was to empirically establish the effects of forest types and land use on the soil carbon stock with a view to evolving management and policy strategies of preserving the soil carbon stock. Consequently, soil samples were collected in the field down to 1m and analyzed in the laboratory for bulk density and soil organic carbon (SOC). The results of the total soil carbon to 1m depth across plots reveal that the highest value (96.1 ±4.1 t C ha^{-1}) was found in the unlogged forest (plot 5) and the lowest at the degraded forest (plot 10) (44.8 ±3.77 t C ha^{-1}. Although there was no statistically significant difference in the means of SOC and forest land use, however, the mean SOC in logged forest was lower than unlogged forest. The SOC in the rubber plot was higher than the value obtained in the logged twice plotting. Rehabilitating a degraded forest rejuvenates the soil carbon stock as the SOC in the rehabilitated forest was higher than that of the degraded plot. The key finding of the study suggests that the soil holds a substantial amount of organic carbon, which, although not statistically significant, but seems to be influenced by forest type and land use. It is recommended that intact natural forests may be preserved, unsustainable logging activities may be replaced with sustainable logging techniques such as RIL and degraded forests should also be rehabilitated through reforestation to restore the soil carbon stock. In addition, routine silvicultural practices should be sensitive to the vulnerability of the forest soil in order to protect the top soil where a greater percentage of carbon is found.

1. Introduction

Carbon storage in soil and biomass of the forest ecosystem is important for carbon dioxide mitigation in the atmosphere (Swift, 2001; Lal, 2008), and enhancement of forest land productivity (Batjes, 2013; Jurgensen et al., 1997; Grigal and Vance, 2000). Growing concern over increased accumulation of human-induced carbon dioxide and other greenhouse gases in the atmosphere has generated interest in identifying all opportunities of mitigating these gases from the land use sectors (Lal, 2004). The forest ecosystem covers 4.1 billion hectares of land globally (Dixon and Wisniewski, 1995) and has 56% of carbon in land use sectors (IPCC, 2000; Lorenz and Lal, 2009). Forest soils account for 36-40% of carbon in the forest ecosystem (FAO, 2001a;b; Dixon et al., 1994).

Although, the estimation of soil carbon stock in different forest types will help in generating the baseline data (Ross et al., 2013) necessary for carbon modelling (Ravindranath and Ostwald, 2008; Ngo et al., 2013) and will facilitate decision making in forest management and policies (Jeyanny et al., 2013), however, there is a dearth of in-depth field level estimates of soil carbon stock in Malaysian forests (Hamdan et al., 2011; Kato, 1978; Niiyama et al., 2010). Failure to include soil and belowground carbon in tree based systems is reported to significantly lead to the underestimation of the total carbon in such systems (Bruun et al., 2009). This paper analyses the soil carbon stock in two forest reserves, namely Berembun and Kenaboi Forest Reserves, located in Negeri Semibilan, Peninsular

* Corresponding Author.
Email Address: acabdullahi08@gmail.com (A. C. Abdullahi)
https://doi.org/10.21833/ijaas.2018.08.002
2313-626X/© 2018 The Authors. Published by IASE.

Malaysia with a view to understanding the effect of forest type and land use on the soil carbon stock.

2. Methodology

2.1. Study area

This study was conducted at the Berembun Forest Reserve (BFR) and Kenaboi Forest Reserve (KFR) located in Negeri Sembilan, Peninsular Malaysia. The sites were selected in order to estimate the carbon stock of soils under unlogged, logged, rubber plot, rehabilitated and degraded forest conditions.

2.1.1. Berembun forest reserve (BFR)

The Berembun Forest Reserve is a hill dipterocarp forest located at the latitude of N.02o 55’ and the longitude of E 101o 46’; 15. It covers a total area of 3,214 ha extending to an altitude of 600 meters above sea level (asl). The reserve has unlogged (compartment 32) and logged components (compartment 31). A portion of compartment 31 was logged twice in 1968 and 1988 and another portion was logged only once in 1968. Compartment 32 still remains unlogged (intact natural or primary forest) to date. The vegetation comprises species such as the Dipterocarpus spp. and Shorea spp., among others. The mean monthly rainfall in BFR is 302.4 mm and the mean daily temperature is 23.5 oC (estimated from data analysed in the present study).

2.1.2. Kenaboi forest reserve (KFR)

The Kenaboi Forest Reserve (KFR) is located between the latitude of N.02o 57’ and the longitude of E. 102o 04’ in Negeri Sembilan, Malaysia. The altitude extends to 300m asl. KFR is drier and cooler than BFR with an average monthly rainfall of 168.36 mm and mean daily temperature of 23.6 ^{o}C (estimated from data analysed in the present study). The vegetation is dominated by hill and lowland dipterocarps species such as the Shorea leprosula, Shorea ovalis and Shorea acuminata. Prior to 1968, the area was the site of one of the largest agricultural ‘taungya’ systems in Malaysia. Taungya system is an agroforestry system where short term crops are planted in the early years of a tree plantation in order to utilize the land, control weeds, reduce costs of establishing the plantation and generate early income to the farmers. The forest reserve was established from 1968 to 1975 to rehabilitate it to natural conditions from the degraded status through taungya method.

2.2. Sampling plan

The two forest reserves were proportionately stratified into different categories (or strata) based on forest type and land use. The strata in BFR include: Unlogged, Logged once, Logged twice and Rubber plot plantation (jungle rubber). In KFR, the selected forest strata include Rehabilitated and Degraded forest areas. The sampling plots were allocated proportionately based on the sizes of each stratum.

The unlogged (primary) forest area (UFA) in compartment 32 of BFR was selected to assess the SOC stock and sequestration under natural (or undisturbed) forest conditions. Five plots were established in the unlogged area because of its size (344 ha). These plots were established at different elevations ranging from 100 to 600m above sea level (asl). The logged once (LFA1) and logged twice (LFA2) strata, also in BFR, were selected to estimate the soil organic carbon loss as a result of logging activities. The type of logging done in both locations was conventional logging. One plot each was established for soil sampling in the logged once and logged twice portions of the compartment (31). One plot each was allocated for the rubber plot, rehabilitated and degraded strata. The rubber plot was located in a 10 hectare land adjoining BFR. The rehabilitated area was located in a 26.7 hectare area within compartment 107 of the Kenaboi Forest Reserve. The degraded forest plot was located in a 10 hectare area in a land adjoining KFR.

A total number of ten (10) sampling plots with the dimension of 20 m × 40 m (0.08 ha) were laid in the selected strata. At the unlogged strata, five plots were laid-out 100 m a.s.l. apart from each other while one plot each was laid randomly in the remaining strata. For the horizontal sampling, three plots only were laid out randomly in the unlogged strata while one plot each was randomly laid-out in the remaining strata. The soil samples were taken from these plots for characterization and estimation of the carbon stock.

2.3. Soil sampling

Soil samples were collected at both locations from June 2015 to February 2016. Three samples each were collected for determination of total carbon from 0-30 cm, 30-60 cm and 60-100 cm depth, in three randomly selected positions, with a 7.5 cm diameter auger. Samples collected at the same depths from the three positions in the same plot were pooled together to make one composite sample. A total number of 90 samples were collected (270 soil samples before compositing) for assessment of soil organic carbon. Two sub-samples, 10 g each, were put in a labelled polythene bag and taken for total carbon analyses in the laboratory. The forest categories, number and sizes of plots as well as number of samples are shown in Table 1.

In addition, three 1 m soil profile pits were dug randomly in each of the forest categories (plots) for collection of bulk density samples and profile description making a total number of 30 pits. Ninety (90) undisturbed soil samples were collected for bulk density assessment at 0-30cm, 30-60cm and 60-100cm with the aid of a metal cylinder (5cm in diameter, 5.1cm in length and 3mm thick). The undisturbed samples obtained were put into a polythene bag, sealed, labelled, and taken to the laboratory. The samples were then analysed for total carbon and bulk density in the laboratory.

Table 1: Forest strata and area; number of plots and samples

S/N	Forest strata	Location*	Area	Number of plots	Size of plots	No. of samples**
1	Unlogged Forest	BFR	344 ha	5 (UFA1, UFA2, UFA3, UFA4, UFA5)	20m×40m=800m²	Total carbon: 3×3×3 × 5=135 Bulk Density: 3 × 3 × 5 = 45
2	Logged Forest (once)	BFR	80 ha	1 (LFA1)	20m×40m=800m²	Total carbon: 3×3×3 × 1 =27 Bulk Density: 3×3×1 = 9
3	Logged Forest (twice)	BFR	75 ha	1 (LFA2)	20m×40m=800m²	Total carbon: 3×3×3 × 1 =27 Bulk Density: 3×3×1 = 9
4	Rubber Plantation	Adjoining BFR	10 ha	1 (RFA)	20m×40m=800m²	Total carbon: 3×3×3 × 1 =27 Bulk Density: 3×3×1 = 9
5	Rehabilitated Forest	KFR	26.7 ha	1 (RHA)	20m×40m=800m²	Total carbon: 3×3×3 × 1 =27 Bulk Density: 3×3×1 = 9
6	Degraded Forest	Adjoining KFR	10 ha	1 (DFA)	20m×40m=800m²	Total carbon: 3×3×3 × 1 =27 Bulk Density: 3×3×1 = 9

*BFR=Berembun Forest Reserve; KFR=Kenaboi Forest Reserve; **No.of samples for Total Carbon = 3 samples × 3 depths × 3 profiles × 10 plots = 270 samples. Composited to 90 samples; **No. of samples for Bulk Density = 3 samples × 3 profiles × 10 plots = 90 Samples

2.4. Analysis of total carbon

Soil Carbon was determined in the laboratory by using the dry combustion method with CHNS analyzer (Thermo Finnigan Flash EA 1112 (CE Elantech, Lakewood, NJ) because of the accuracy of the method.

The results were obtained as concentration of total carbon in the soil as a percentage by weight (comprising both inorganic and organic carbon). These were converted to tonnes per hectares by using the bulk density values, soil depth, and the percentage of carbon of each of the forest categories as shown in Eq. 1 (Pearson et al., 2005).

$$Total\ Carbon\ (C)\ (t/ha)\ = \frac{\text{(Soil bulk density (gcm−3) x Soil depth (cm) x C (%)]}}{100} \quad (1)$$

2.5. Bulk density

Bulk density was estimated with a metal cylinder (coring method) as described by Rowell (1994). Ninety (90) undisturbed soil samples were collected for bulk density assessment in 0-30cm, 30-60cm and 60-100cm with the aid of a metal cylinder (5cm in diameter, 5.1cm in length and 3mm thick). The undisturbed samples obtained were put into a polythene bag, sealed, labelled, and taken to the laboratory.

The soil bulk density is therefore calculated with the following formula, Eq. 2.

$$Bulk\ Density\ (Db)\ = \frac{Mass\ of\ oven\ dry\ soil\ (g)}{Volume\ of\ cylinder\ (cm^3)} \quad (2)$$

3. Results

3.1. Total soil organic carbon across forest types (Plots)

The results of the total soil carbon (means and standard deviations) to 1m depth, across plots reveal that, the highest value (96.1 ±4.1 t C ha^{-1}) was found in the unlogged forest (plot 5) and the lowest at the degraded forest (plot 10) (44.8 ±3.77 t C ha^{-1}). This is shown in Table 2.

Table 2: Total soil organic carbon to 1m depth

	SOC (t C ha^{-1})				
Plots*	0-30cm	30-60cm	60-100cm	Total	SD
Unlogged Forest Plot 1	41.1	23.8	17.5	82.4	12.2
Unlogged Forest Plot 2	26.7	36.5	21.2	84.4	7.8
Unlogged Forest Plot 3	44.7	17.7	26.8	89.2	13.7
Unlogged Forest Plot 4	30.7	28.7	27.8	87.2	1.5
Unlogged Forest Plot 5	27.4	33.8	34.9	96.1	4.1
Average for Unlogged Forest Plots	34.12	28.1	25.64	87.86	8.7
Logged Forest Plot 1	40.8	19.4	21.4	81.6	11.8
Logged Forest Plot 2	19.9	21.4	8.2	49.5	7.2
Average for Logged Forest Plots	30.35	20.4	14.8	65.55	15.8
Rubber smallholder Plot	31.5	20.6	15.4	67.5	8.2
Rehabilitated Forest Plot	28.9	26.3	20.8	76	4.1
Degraded Forest Plot	18.9	11.4	14.5	44.8	3.8

*Unlogged, logged, and rubber smallholder plots are located in BFR while degraded and rehabilitated plots are located in KFR

The total soil carbon stock in the logged once area was 81.6±11.8 tC ha^{-1}, a figure that almost doubled that of the logged twice area which had 49.5±7.2 tC ha^{-1} at 1m depth. Both logged once and logged twice areas are located in compartment 31 of BFR. The Rubber plot (adjoining BFR) had a lower carbon content of 67.5 ±8.2 tC ha^{-1} compared to the unlogged forest (in BFR) which had 87.86 ±8.7 tC ha^{-1} at 1 meter depth. The rehabilitated forest (in KFR) was found to contain more soil carbon (76 ±4.1 tC ha^{-1}) compared to the degraded area (located in an adjoining land to KFR) which had 44.8 ±3.8 tC ha^{-1}. The total soil carbon stock in the degraded forest area (adjoining KFR) was 49.5 ±3.7 tC ha^{-1}; 50% lower than that of the unlogged forest (which remains an intact natural forest) at 1m depth. These results are presented in Table 2.

3.2. Comparison of mean soil carbon across forest types (land use)

A one-way ANOVA was conducted to determine if the means of SOC were statistically different with forest land use (plots) in BFR and KFR. The analysis of variance results shows that there was no statistically significant difference in the means of SOC and forest land use F (9.20) =1. 358, p=0. 270 (p>0.05). A multiple comparison test was not conducted as the differences in the group means are not statistically significant. The result is presented in Table 3.

4. Discussion

4.1. Soil organic carbon stock

The stock of carbon in the soil of forest ecosystems depends on the type of forest, forest land use, and depth of sampling. Other factors include climate, the type of dominant species, topography, and soil characteristics such as clay (Wiesmeier et al., 2013; Poeplau and Don, 2013; Ngo et al., 2013). Findings from the present study revealed that the average SOC stock, to 1m depth, in Berembun Forest Reserve is 79.74 (±14.7) and 60.4 (±22.1) in Kenaboi Forest Reserve. The average SOC, to 1m depth, in all the plots in the study area (i.e. Both BFR and KFR) is 75.87 (±17.0).

4.2. Effect of logging on SOC

Studies examining the effect of logging activities on soil carbon stock in Malaysia are very few to date with most of the studies concentrating on biomass and aboveground carbon (Pinard and Putz, 1996; Pinard and Cropper, 2000). However, Satrio et al. (2009) investigated effects of logging on soil carbon in peat swamp.

Pinard and Putz (1996) reported that reducing the damage caused by logging through reduced impact logging (RIL) increased carbon storage in biomass. However, they did not state the effect on soil carbon. In another study, Pinard and Cropper (2000) compared the effect of logging on conventional and reduced impact logging (RIL) and found that RIL had not affected soil carbon. Satrio et al. (2009) reported that although logging activities on peat soil increased the bulk density due to compaction, the disturbance does not alter the carbon stored in the stable fraction. This is because they observed that the carbon in humic acid (the stable fraction) remained unchanged one year after logging. However, they agreed that logging affects the unstable carbon fraction.

Table 3: Results of ANOVA between SOC and forest strata (Plot)

Plots	N	Mean SOC (0-100cm)	Std. Deviation
Unlogged Forest 1	3	29.07 (N.S)	1.48
Unlogged Forest 2	3	27.47 (N.S)	12.22
Unlogged Forest 3	3	28.13 (N.S)	7.75
Unlogged Forest 4	3	14.93 (N.S)	3.77
Unlogged Forest 5	3	32.03 (N.S)	4.05
Logged Forest 1	3	25.33 (N.S)	4.14
Logged Forest 2	3	27.20 (N.S)	11.82
Rubber Smallholder	3	22.50 (N.S)	8.22
Rehabilitated Forest	3	29.73 (N.S)	13.74
Degraded Forest	3	16.50 (N.S)	7.23
Total	30	25.29 (N.S)	8.87

N.S: Not significant at P<0.05

The findings from the present study suggest that, although not statistically significant, logging leads to a decline in soil carbon stock based on the paired comparison with the SOC results obtained from the unlogged forest areas. However, it is prudent to stress that the logging activity in the present study was conventional logging not reduced impact logging (RIL).

Studies abound that compared SOC stock between primary and secondary forests, but not necessarily investigated the effect of logging. The results of some of these studies are compared with that from the present study. The high soil carbon content found in the unlogged forest plots (87.86 ±8.7 $tCha^{-1}$) compared with the logged forest plots (65.55 ±15.8 $tCha^{-1}$) in the present study is consistent with findings made by some of these studies (Sierra et al., 2007; De Camargo et al., 1999). Neto et al. (2012) reported a higher carbon stock in a secondary forest with 178.5 $tCha^{-1}$ at 1.2m depth while this study found 65.5 $tCha^{-1}$ (at 1m depth) in a similar forest type (secondary/logged forest). Saner et al. (2012) reported a decrease in dipterocarp C stock by 55-66% due to selective logging activities in the Malua Forest Reserve of Sabah Malaysia. The figure reported by Lasco et al. (2006) in the Philippines for selectively logged forest at 30cm ranges from 30-106 $tCha^{-1}$. The lower range falls below the value obtained in the present study while the higher range exceeded it, although still lower than the figure obtained by Neto et al. (2012). The figures reported by Saner et al. (2012) and Di Rocco (2012) were lower than the results of the present study although they measured at different depths (Table 4). However, Ngo et al. (2013) found more total carbon in a logged (secondary forest) compared to the unlogged (primary) forests in Singapore, contrary to the findings in the present study.

Table 4: Comparison of soil carbon stock by different authors

Forest Type/Land-use	Total Carbon (tC/ha)	Author	Country
Rehabilitated Forest (0-20cm)	70.616 ±3.117 (0-20cm); 73.568 ±3.573 (20-40cm)	Akbar et al. (2010)	Malaysia
Secondary Forest	63.048 ±2.809 (0-20cm); 63.558 ±3.315 (20-40cm)	Akbar et al. (2010)	Malaysia
Hill Dipterocarp	27 (3m)	Di Rocco (2012)	Malaysia
Lowland Dipterocarp	39.6(±0.9 SEM).	Saner et al. (2012)	Malaysia
Secondary Forest	178.5 (1.2m)	Neto et al. (2012)	Malaysia
Unlogged (Primary Forest)	87.86 ±8.7 (1m)	This study	Malaysia
Logged (Secondary Forest)	65.55 ±15.8 (1m)	This study	Malaysia
Rubber Smallholder	67.5 ± 8.2 (1m)	This study	Malaysia
Rehabilitated Forest	76.0 ± 4.14(1m)	This study	Malaysia
Degraded Forest	44.8 ±3.77 (1m)	This study	Malaysia
Primary Forest	77.5 (1m); 110.8 (3m)	Ngo et al. (2013)	Singapore
Secondary Forest	103.9 (1m); 143.2 (3m)	Ngo et al. (2013)	Singapore
Selectively Logged Dipterocarp	30-106 (0-30cm)	Lasco et al. (2006)	Philippines

The SOC recorded at logged once plot (LFA1=81.6±11.8 t C ha^{-1}) exceeds that of twice logged plot (LFA2=49.5 ±7.2 t C ha^{-1}) to 1m depth, suggesting that logging has a negative effect on SOC stock. The disturbance caused by the logging activities at two different times (1961 and 1988) is likely to have affected the SOC stock in the logged twice plots.

4.3. Effect of rubber plot on soil carbon stock

The SOC measured in the rubber plot (67.5±8.2 t C ha^{-1}) adjoining the BFR, was lower than the values obtained in all the five unlogged plots in BFR as well as logged once plot (81.6 ±11.8 t C ha^{-1}). The mean SOC in the rubber plot was; however, higher than the value obtained in the logged twice plot (49.5 ±7.2 t C ha^{-1}).

Studies on the effects of rubber plot on SOC stock in the literature are replete with varied and mixed results. Most of the results indicate that SOC stock and sequestration depends on the age of rubber plot and the land use prior to the plantation establishment. In a study conducted to evaluate the temporal effects of rubber plot on soil carbon sequestration in the north-eastern Indian state of Tripura by Mandal and Islam (2010), soil C concentration, stock and sequestration were found to vary significantly by age of the rubber plots. SOC stock increased by 14–57%, which accounted for an accumulation of 34 Mg C ha^{-1} over a 20 year period (Mandal and Islam, 2010). The authors concluded that, if managed properly, rubber plot on degraded tropical forest lands can be a C sink over time (Mandal and Islam, 2010). These results show that degraded land-to-rubber leads to increase in SOC stock.

Zhang et al. (2007) evaluated changes in SOC in different ages of rubber plot in Xishuangbanna, Southwestern China and found no change in SOC in 12, 20 years stand ages, on the contrary SOC decreases at the 26 year old stand. However, SOC was found to increase substantially in tea-rubber intercropping. They attributed the decline on SOC to removal of rubber latex in the 12 and 26 year stands; increase in the TOC (total organic carbon) at age 40 was attributed to cease or reduced rubber latex harvesting. This study, therefore, linked SOC stock to the age of the rubber plot. Yang et al. (2005) also found that rubber plot established on a former arable land, enhanced carbon sequestration at 21 year old plantation. They found that SOC increased before latex removal, decline during removal stages and increased again when harvesting ceased. They concluded that latex harvesting affects soil carbon stock and sequestration in rubber plot.

However, De Blecourt et al. (2013) found that rubber plot lead to a decrease in SOC in a former secondary forest. They investigated the changes in SOC stocks following secondary forest conversion to rubber plots using space-for-time substitution approach in Yunnan Province, China. The results revealed that forest-to-rubber plot conversion decreased SOC stocks by an average of 37.4 ± 4.7 (S.E) Mg C/ha in 1.2m depth over a 46 year time period. This was 19.3% ±2.7% of the initial SOC stocks in the secondary forest. The SOC stock decline is much larger than the changes observed in the above ground carbon stock. They opined that the decline can have implications in the estimates of land use changes in the national inventories based on the IPCC guidelines due to large expanse and continually growing size of rubber plantation in the region. They therefore suggested the inclusion of soil carbon changes in estimating ecosystem carbon fluxes in general.

4.4. Effect of rehabilitating a formerly degraded forest on SOC

Rehabilitating a degraded forest seems to rejuvenate the soil carbon stock as attested by the higher SOC stock in the rehabilitated forest (76 ±4.1) compared with the degraded forest (44.8 ±3.8) (both plots located in KFR). Considering the fact that both RHA and DFA were in degraded conditions in the past suggests that the practice of rehabilitating degraded forests is useful in regaining lost organic carbon in forest soils.

The present study found a higher soil carbon in the rehabilitated and secondary forests at 76.0 ± 4.14 $tCha^{-1}$, compared to Akbar et al. (2010) and Lee et al. (2009) who reported 73.6 ±3.6 $tCha^{-1}$ and 63.6 ±3.3 $tCha^{-1}$, respectively. However, the difference may be due to depth of sampling as the SOC stock was measured to 1m depth in the present study while Akbar et al. (2010) measured the soil carbon up to 40cm Table 4.

It is important to stress that, the comparison of SOC stock across forest types described above was done among forest types in the same location (adjacent land) and bearing the same edaphic, topographical and climatic characteristics. The unlogged forest, logged forest and rubber plots were compared with each other because they are located in BFR while the rehabilitated and the degraded forests were compared because the plots were located in KFR.

However, the differences in the mean SOC across forest types notwithstanding, the results of analysis of variance conducted in the present study indicate that these differences are not statistically significant.

5. Conclusion

The soil in the study areas is ultisol that developed from granite and kaolinitic minerals. It is inherently not fertile. The bulk density is low and increases with depth and seems to be more influenced by land use than vegetation or forest type.

The SOC stock in the different plots and forest types indicate that the soil stores significant, but variable amounts of organic carbon, which is capable of reducing the total forest carbon stock if omitted from measurement and inventories. Persistent logging has a negative effect on soil carbon stock. The lower carbon content found in the rubber plot compared to the unlogged forest suggests that conversion of intact forest to plantation agriculture reduces the soil carbon stock. The stark contrast in soil carbon stock in the rehabilitated forest and the adjoining degraded forest indicate that rehabilitation of a hitherto degraded area is a useful way of restoring lost soil carbon status and forest productivity. A key conclusion is that the soil holds a substantial amount of organic carbon (to 1m depth), which varies across different forest types and is also influenced by land use.

It is recommended that intact natural forests be preserved from conversion to other forms of land use and unsustainable logging activities be replaced with sustainable logging techniques such as reduced impact logging (RIL). Degraded forests should also be rehabilitated through reforestation to restore the soil carbon stock. In addition, routine silvicultural practices should be sensitive to the vulnerability of the forest soil in order to protect the top soil where a greater percentage of carbon is found.

Acknowledgement

The authors wish to acknowledge the support received from National University of Malaysia (UKM) through grant number UKM-AP-2014-017 and also ERGS/1/2013/SS07/UKM/01/1.

References

Akbar MH, Ahmed OH, Jamaluddin AS, Majid NNA, Abdul-Hamid H, Jusop S, and Abdu A (2010). Differences in soil physical and chemical properties of rehabilitated and secondary forests. American Journal of Applied Sciences, 7(9): 1200-1209.

Batjes NH (2013). Reader for the soil carbon benefits module. In the ISRIC Spring School Conference, Wageningen University Campus, Wageningen Netherlands: 1-16.

Bruun TB, De Neergaard A, Lawrence D, and Ziegler AD (2009). Environmental consequences of the demise in swidden cultivation in Southeast Asia: carbon storage and soil quality. Human Ecology, 37(3): 375-388.

De Blecourt M, Brumme R, Xu J, Corre MD, and Veldkamp E (2013). Soil carbon stocks decrease following conversion of secondary forests to rubber (Hevea brasiliensis) plantations. PloS one, 8(7): e69357.

De Camargo PB, Trumbore SE, Martinelli L, Davidson E, Nepstad DC, and Victoria RL (1999). Soil carbon dynamics in regrowing forest of eastern Amazonia. Global Change Biology, 5(6): 693-702.

Di Rocco TL (2012). A thorough quantification of Tropical Forest Carbon Stocks in Malaysia. Unpublished PhD Dissertation, University of California, Berkeley Environmental Sciences. Available online at: http://nature.berkeley.edu/classes /es196/projects/2012final/DiRoccoT_2012.pdf

Dixon RK and Wisniewski J (1995). Global forest systems: An uncertain response to atmospheric pollutants and global climate change?. Water, Air, and Soil Pollution, 85(1): 101-110.

Dixon RK, Solomon AM, Brown S, Houghton RA, Trexier MC, and Wisniewski J (1994). Carbon pools and flux of global forest ecosystems. Science, 263(5144): 185-190.

FAO (2001a). Production yearbook. Food and Agriculture Organization, Rome, Italy.

FAO (2001b). Plantations as greenhouse gas mitigation: A short. Food and Agriculture Organization, Rome, Italy.

Grigal DF and Vance ED (2000). Influence of soil organic matter on forest productivity. New Zealand Journal of Forestry Science, 30(1/2): 169-205.

Hamdan O, Aziz HK, and Rahman KA (2011). Remotely sensed L-Band SAR data for tropical forest biomass estimation. Journal of Tropical Forest Science, 23(3): 318-327.

IPCC (2000). Special reports on emission scenarios: Summary for policy makers. Intergovernmental Panel on Climate Change, Geneva, Switzerland.

Jeyanny V, Balasundram SK, Husni MHA, Rasidah KW, and Arifin A (2013). Spatial variability of selected forest soil properties related to carbon management in tropical lowland and montane forests. Journal of Tropical Forest Science, 25(4): 577-591.

Jurgensen MF, Harvey AE, Graham RT, Page-Dumroese DS, Tonn JR, Larsen MJ, and Jain TB (1997). Impacts of timber harvesting on soil organic matter, nitrogen, productivity, and health of Inland Northwest forests. Forest Science, 43(2): 234-251.

Kato R (1978). Plant biomass and growth increment studies in Pasoh Forest Reserve. Malayan Nature Journal, 30: 211-224.

Lal R (2004). Soil carbon sequestration to mitigate climate change. Geoderma, 123(1-2): 1-22.

Lal R (2008). Carbon sequestration. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1492): 815-830.

Lasco RD, MacDicken K, Pulhin FB, Guillermo IQ, Sales RF, Cruz RVO (2006). Carbon stocks assessment of a selectively logged dipterocarp forest and wood processing mill in the Philippines. Journal of Tropical Forest Science, 18: 166-172.

Lee Y, Osumanu HA, Nik M, and Mohamadu BJ (2009). Organic matter, carbon and humic acids in rehabilitated and secondary forest soils. American Journal of Applied Sciences, 6(5): 824-828.

Lorenz K and Lal R (2009). Carbon sequestration in forest ecosystems. Springer Science and Business Media, Berlin, Germany.

Mandal D and Islam KR (2010). Soil Carbon sequestration under rubber plantations in North-East India. In: Lal R, Sivakumar MV, Faiz SMA, Rahman AM, and Islam KR (Eds.), Climate change and food security in South Asia: 433-444. Springer, Dordrecht, Netherlands.

Neto V, Ainuddin NA, Wong MY, and Ting HL (2012). Contributions of forest biomass and organic matter to above- and belowground carbon contents at Ayer Hitam Forest Reserve, Malaysia. Journal of Tropical Forest Science, 24(2): 217-230.

Ngo KM, Turner BL, Muller-Landau HC, Davies SJ, Larjavaara M, bin Nik Hassan NF, and Lum S (2013). Carbon stocks in primary and secondary tropical forests in Singapore. Forest Ecology and Management, 296: 81-89.

Niiyama K, Kajimoto T, Matsuura Y, Yamashita T, Matsuo N, Yashiro Y, and Noor NS (2010). Estimation of root biomass based on excavation of individual root systems in a primary dipterocarp forest in Pasoh Forest Reserve, Peninsular Malaysia. Journal of Tropical Ecology, 26(3): 271-284.

Pinard MA and Cropper WP (2000). Simulated effects of logging on carbon storage in dipterocarp forest. Journal of Applied Ecology, 37(2): 267-283.

Pinard MA and Putz FE (1996). Retaining forest biomass by reducing logging damage. Biotropica, 28(3): 278-295.

Poeplau C and Don A (2013). Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. Geoderma, 192: 189-201.

Ravindranath NH and Ostwald M (2008). Generic methods for inventory of carbon pools. In: Ravindranath NH and Ostwald M (Eds.), Carbon inventory methods handbook for greenhouse gas inventory, carbon mitigation and roundwood production projects: 99-111. Springer Science and Business Media, Berlin, Germany.

Ross CW, Grunwald S, and Myers DB (2013). Spatiotemporal modeling of soil organic carbon stocks across a subtropical region. Science of the Total Environment, 461: 149-157.

Rowell DL (1994). Soil science: Methods and applications. Department of Soil Science, University of Reading, Reading, UK.

Saner P, Loh YY, Ong RC, and Hector A (2012). Carbon stocks and fluxes in tropical lowland dipterocarp rainforests in Sabah, Malaysian Borneo. PloS one, 7(1): e29642.

Satrio AE, Gandaseca S, Ahmed OH, and Majid NM (2009). Effect of logging operation on soil carbon storage of a tropical peat swamp forest. American Journal of Environmental Sciences, 5(6): 748-752.

Sierra CA, del Valle JI, Orrego SA, Moreno FH, Harmon ME, Zapata M, and Berrouet LM (2007). Total carbon stocks in a tropical forest landscape of the Porce region, Colombia. Forest Ecology and Management, 243(2-3): 299-309.

Swift RS (2001). Sequestration of carbon by soil. Soil Science, 166(11): 858-871.

Wiesmeier M, Prietzel J, Barthold F, Spörlein P, Geuß U, Hangen E, and Kögel-Knabner I (2013). Storage and drivers of organic carbon in forest soils of southeast Germany (Bavaria)– Implications for carbon sequestration. Forest Ecology and Management, 295: 162-172.

Yang JC, Jian HH, Jian WT, Qing MP, and Xing GH (2005). Carbon sequestration in rubber tree plantations established on former arable lands in Xishuangbanna, SW China. Acta Phytoecologica Sinica, 29(2): 296–303.

Zhang M, Fu XH, Fang WT, and Zou X (2007). Soil organic carbon in pure rubber and tea-rubber plantations in southwestern China. Tropical Ecology, 48(2): 201-207.