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Assessment of soil carbon storage in a tropical rehabilitated forest

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Decrease of tropical rainforests affects global warming and has attracted much attention. Afforestation programs have been suggested to mitigate this problem. But there is little research on the assessment of soil carbon (C) storage in a rehabilitated forest in tropical areas such as Malaysia. The objective of this study was to determine the C accumulation of a rehabilitated forest of different ages. Soil samples were collected from the 1 year old till 7 year old rehabilitated forest. Ten samples were taken randomly with a soil auger at depths 0-20, 20-40 and 40-60 cm. Materials and methods section were used to analyse the soil samples for pH, total C, soil organic matter (SOM), total N, C/N ratio, yield of humic acids (HA), and C in HA (CHA). Results showed that pH decreased significantly with increasing age of rehabilitated forest regardless of depth. SOM and total C contents increased with age. No significant difference in the quantity of CHA content for the different ages of rehabilitated forest at 0-20, 20-40 and 40-60 cm soil were observed. Forest rehabilitation by planting indigenous tree species at initial ages (till 7 years old) has shown signs of C sink but does not exert any difference in the amount of C accumulated across the initial ages.

Key words: Soil carbon, carbon in humic acids, tropical rehabilitated forest, initial age, humic acids, carbon storage.

INTRODUCTION

The C cycle in terrestrial ecosystems plays an important role in regulating gas exchange between soils and the atmosphere because it is one of the contributing factors leading to greenhouse gases emissions (Houghton et al., 2000). Currently, land-use changes are becoming the largest contribution of the anthropogenic emissions besides fossil fuels emissions (Canadel, 2002). This is because land use changes affect the C storage and also the amount of biomass and C stored in vegetation, thus causing a decrease in soil fertility (Power et al., 2004). Land use in Malaysia especially Sarawak has changed significantly. Excessive logging and shifting cultivation contribute to deforestation in Sarawak (Dimin, 1988). In particular, conversion of forests to different land use affects several soil properties and especially on the soil Cstock and concentration (Lal, 2005). According to Lasco (2002), deforested area covered with grasses and annual crops have C densities less than 40 Mg ha-1, which is much less than natural forests. As a result of concerns about climate change, Land use, land-use change, and forestry (LULUCF) has been recognized in playing the role of C source and sink in relation to change in land cover and carbon stocks (IPCC, 2000).

One of the important researches is investigating soil and living biomass for C sequestration and storage. Since soils are the largest C reservoirs in terrestrial eco-systems, they are good choice for C sequestration and storage (Wang and Hsieh, 2002). Processes which lead to soil organic carbon (SOC) sequestration are conversion

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Abbreviations: SOM, Soil organic matter; **C,** carbon; **HA,** humic acids; **CHA,** carbon humic acids; **LULUCF,** land use, land-use change, and forestry; **SOC,** soil organic carbon; **FA,** fulvic acid; **SAS,** statistical analysis system; **ANOVA,** analysis of variance.

of biomass into humus, including HA, aggregation to prevent C oxidation and translocation of C into sub-soil (Canadel, 2002). Forests soils contain approximately half of Earth's terrestrial C (Johnson and Curtis, 2001). Forest plays an important role in storing C because approximately 60 to 70% of C in forests is stored as organic material in the soil (Janssen et al., 1999). Understanding the mechanism and factors contributing to C storage in soil is important to enhance natural sinks of C sequestration to mitigate the climate change (Lal, 2005). Afforestation is believed to have a good potential to enhance C storage (Ritcher et al., 1999; Silver et al., 2000). Montagnini and Porras (1998) stated that facilitating afforestation can be an effective C management approach. To date, many studies have been done to estimate regional carbon storage and national carbon budgets of temperate forests in many countries. Unfortunately, there is little information on the soil C storage at the initial ages of a rehabilitated forest in tropical areas such as Malaysia. Information on C accumulation of rehabilitated forests suggests whether these forests can serve as C sink to mitigate climate change. Thus, the objective of this study was to determine the C accumulation in soil of a newly established rehabilitated forest.

MATERIALS AND METHODS

Site description and soil sampling

A study was conducted in a UPM-Mitsubishi rehabilitated forest at University Putra Malaysia, Bintulu Sarawak Campus (latitude 03°12 N and longitude 113°02 E at 50 m above sea level) with mean annual rainfall, relative humidity and temperature of 2933 mm, 80%, and 27°C, respectively. The area was previously abandoned after shifting cultivation and it has been rehabilitated since 1991 by planting indigenous timber species from the family Dipterocarpaceae and Non-Dipterocarpaceae. The soil texture of the rehabilitated forest is sandy loam and was typical of Nyalau Series (*Typic Paleudults*) and is a typical of Ultisols, which is characterized by the coarse loamy yellow podzolic group that developed from weathering of sandstone. An auger was used to collect soil samples from 1-, 2-, 3-, 4-, 5-, 6 and 7-year-old rehabilitated forest during dry weather. Soil sampling for all of the ages of the rehabilitated forest was done at the same time to avoid bias. The size of each experimental plot was 30 x 40 m. A total of 10 soil samples were taken at random depths of 0-20, 20-40 and 40-60 cm in each plot for each age. Each sample was a bulk of three samples. Each soil sample represents a replication in the soil chemical analyses.

Soil samples preparation and analysis

The soil samples were air-dried, crushed manually and sieved to pass a 2 mm size sieve. The subsequent soil chemical analyses below were done at the same time, that is, they were not analysed on an age-by-age basis (not separately) to avoid bias. The bulk densities at these depths were determined by the coring method (Dixon and Wisniewski, 1995). The bulk density method was used to quantify soil total N stock, soil total C, SOM, HA, and CHA at the stated sampling depths on per hectare basis. Soil total N stocks were determined using the micro-Kjeldahl method (Tan, 2003). The soil total C and CHA were analysed using CHNS analyser. SOM was calculated by dividing soil total C with 0.58 (Tan, 2003). The soil pH was determined in a ratio 1: 2.5 of soil: distilled water suspension and/or 1 M KCl using a glass electrode (Peech, 1965). The extraction of HA was done using the method described by Stevenson (1994). Only HA was extracted in this study because of the difficulties in recovering fulvic acid (FA) from the acidified soil extract following separation of HA and the removal of substantial amounts of inorganic contaminants such as NaCl. These processes cause significantly low yield of FA (Stevenson, 1994). Humin was excluded in this study because it is chemically non-reactive due to its insolubility characteristic and difficulties in its isolation (Tan, 2003). Purification process was conducted to purify the HA. It was done by using the method described by Ahmed et al. (2004).

The HA was purified using distilled water (Ahmed et al., 2004). The washed HA was oven dried at 40°C to a constant weight. The yield of the HA was expressed as percentage of the weight of soil used. Characterization of HA was carried out in order to determine the purity of HA extracted. Level of humification of HA was determined by E_4/E_6 method using Lambda 25 UV/VIS. Functional group analyses (phenolic –OH, carboxylic –COOH, and total acidity) were determined by the method described by Inbar et al. (1990). Data obtained from the laboratory analysis were analyzed using the Statistical Analysis System (SAS) Version 9.2. One-way Analysis of Variance (ANOVA) was used to detect significant difference between bulk densities, soil pH, soil total C, CHA, soil total N stock, C/N ratio and HA at different soil depths and different ages of rehabilitated forest. Tukey's HSD test ($p \leq 0.05$) was used to separate the means of bulk densities, soil pH, soil total C, CHA, soil total N stock, C/N ratio and HA between soil depths and different ages of rehabilitated forest.

RESULTS AND DISCUSSION

Soil total carbon and carbon in humic acids

There was significant difference in the percentages of total C in different soil depths of the rehabilitated forests with depth (Table 1). The top soil (0-20 cm) total C of the different ages of the rehabilitated forest was significantly different from those of the subsoil (20-40 cm and 40-60 cm). This was due to the positive correlation of C and the SOM (Schuur et al., 2001). This suggests that the SOM is a source of C as C is stored in the soil profiles in the form of SOM (Brady and Weil, 2002). The high total C at 0–20 cm indicates that higher decomposition of biomass may have occurred through the decomposition of plant and animal residues, root exudates, living and dead micro-organisms, and soil biota. The lower content of C in the subsoil was due to the lack of N for efficient conversion of biomass C to humus C which is required for humification of biomass returned to soil.

It also indicates that higher decomposition of biomass may have occurred through the decomposition of plant and animal residues, root exudates, and living and dead microorganisms. Besides, pH has an association with the total C as well as SOM. This is because the acidic nature of the soil may have limited the abundance of microbes

Table 1. Soil total carbon, carbon in humic acids, and corresponding quantities (Mg ha^{-1}) of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	Soil total carbon (%)	Quantity of total carbon (Mg ha^{-1})	Carbon in humic acids (%)	Quantity of carbon in humic acids (Mg ha^{-1})
(a) 1-year-old rehabilitated forest				
0-20 cm	0.764^{aBC}	18.736^{aB}	37.267^{aA}	2.594^{aA}
20-40 cm	0.529^{abBC}	18.559^{aAB}	37.177^{aA}	0.543^{bA}
40-60 cm	0.473^{bBC}	14.720^{bAB}	35.940^{aA}	3.340^{aA}
(b) 2-year-old rehabilitated forest				
0-20 cm	1.297^{aA}	30.804^{aA}	43.169^{aA}	5.625^{aA}
20-40 cm	0.837^{abAB}	24.850^{abA}	34.678^{aA}	2.019^{abA}
40-60 cm	0.611^{bABC}	19.373^{bA}	41.924^{aA}	0.827^{bA}
(c) 3-year-old rehabilitated forest				
0-20 cm	1.134^{aAB}	21.848^{aAB}	34.272^{aA}	2.160^{aA}
20-40 cm	0.687^{bAB}	17.701^{bAB}	34.256^{aA}	0.511^{bA}
40-60 cm	0.668^{bAB}	18.760^{bAB}	29.337^{aA}	0.133^{bA}
(d) 4-year-old rehabilitated forest				
0-20 cm	1.065^{aAB}	17.384^{aB}	39.556^{aA}	2.494^{aA}
20-40 cm	0.947^{abA}	18.441^{aAB}	36.777^{aA}	2.294^{aA}
40-60 cm	0.815^{bA}	17.868^{aAB}	39.134^{aA}	1.827^{aA}
(e) 5-year-old rehabilitated forest				
0-20 cm	0.578^{aC}	14.729^{aB}	34.973^{aA}	2.030^{aA}
20-40 cm	0.326^{bC}	10.580^{bB}	35.916^{aA}	2.098^{aA}
40-60 cm	0.296^{bC}	11.054^{bB}	35.889^{aA}	1.084^{bA}
(f) 6-year-old rehabilitated forest				
0-20 cm	0.702^{aBC}	17.632^{aB}	43.644^{aA}	1.446^{aA}
20-40 cm	0.611^{abABC}	16.656^{abAB}	33.432^{bA}	0.452^{bA}
40-60 cm	0.488^{bABC}	13.632^{bB}	38.641^{abA}	0.093^{bA}
(g) 7-year-old rehabilitated forest				
0-20 cm	1.288^{aA}	24.639^{aAB}	31.919^{bA}	1.966^{aA}
20-40 cm	0.587^{bBC}	13.901^{bB}	43.290^{aA}	0.533^{bA}
40-60 cm	0.537^{bABC}	17.086^{bAB}	31.891^{bA}	0.582^{bA}

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths while different letter(s) (uppercase) indicate significant difference between ages of rehabilitated forests by Turkey test at $p \leq 0.05$.

and their ability to decompose biomass to release more C. Thus, soil with high acidity regardless of depth usually tends to have low organic matter (Ahmed et al., 2010). However, there was no significant difference in the quantity of CHA for the different ages of rehabilitated forest at 0-20, 20-40 and 40-60 cm soil depth (Table 1). The percentage and quantities of CHA from the one year old to five year old rehabilitated forest at the depth of 0-20 cm were generally higher than those in the 20-40 and 40-60 cm although there was no significant difference between the depths except 6 and 7 year old. This shows that planting the indigenous tree species in the rehabilitated forest at initial ages (till 7 years old) does not exert any difference in the amount of C sequestered in the Ultisols. Since the CHA is more stable, it is more realistic to quantify the amount of C sequestered in setting up the rehabilitated forest at initial stages (Milori et al., 2002; Ywih et al., 2009).

Soil chemical analyses

The soil bulk densities (Table 2) of the three depths of the rehabilitated forest were found to be within the range

Table 2. Soil bulk density of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	Bulk density ($g\ cm^{-3}$)
(a) 1-year-old rehabilitated forest	
0-20 cm	1.227[a]
20-40 cm	1.543[b]
40-60 cm	1.556[b]
(b) 2-year-old rehabilitated forest	
0-20 cm	1.207[a]
20-40 cm	1.483[b]
40-60 cm	1.583[b]
(c) 3-year-old rehabilitated forest	
0-20 cm	0.963[a]
20-40 cm	1.250[b]
40-60 cm	1.423[c]
(d) 4-year-old rehabilitated forest	
0-20 cm	0.816[a]
20-40 cm	0.973[ab]
40-60 cm	1.096[b]
(e) 5-year-old rehabilitated forest	
0-20 cm	1.273[a]
20-40 cm	1.620[b]
40-60 cm	1.686[b]
(f) 6-year-old rehabilitated forest	
0-20 cm	1.257[a]
20-40 cm	1.360[b]
40-60 cm	1.385[b]
(g) 7-year-old rehabilitated forest	
0-20 cm	0.957[a]
20-40 cm	1.233[b]
40-60 cm	1.593[c]

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths of rehabilitated forests by Turkey test at $p \leq 0.05$.

reported by Leng et al. (2009) and Akbar et al. (2010), which was between 0.9 to 1.6 g cm^{-3}. Generally, there was significant difference between the bulk density of 1-, 2-, 3-, 4-, 5-, 6-, and 7-year-old rehabilitated forests at 0-20, 20-40, and 40-60 cm depths. This suggests that the soil got compacted down their profiles. Perhaps it could be also attributed to eluviation of clay in the top soil to subsoil (Brady and Weil, 2002). Soil pH in water was not affected by the depth of the rehabilitated forest, but the contrary was true for soil pH in KCl (Table 3). In terms of age, the results of the statistical means comparison were (1) soil pH (1 M KCl and water) between different ages at 0–20 cm significant difference; (2) soil pH between different ages at 20–40 cm significant difference; (3) soil pH between different ages at 40–60 cm significant difference. These pH values in water and 1 M KCl were consistent with those reported by Leng et al. (2009). The authors reported a range of 4.3–4.9 for pH in water and 3.1–4.0 for pH in KCl. The higher pH (1 M KCl) values at 20-40 and 40-60 cm than those of 0-20 cm of the 2-, 3-, 4-, and 7-year-old of rehabilitated forests could be due to the leaching of basic cations from 0-20 cm to 20-40 and 40-60 cm. The difference between soil pH of the different ages of the rehabilitated forest regardless of soil depth suggests that different age of rehabilitated at different locations had significant effect on the soil pH. This was because the rate of litter production of different ages and distribution of SOM across the ages of the rehabilitated forest and soil depths could be different (Ahmed et al., 2010). Decaying of more SOM at the soil depth of 0-20 cm produces organic acids that might cause the soil pH to be lower on the 0-20 cm compared to 20-60 cm.

The soil total N (Table 4) obtained for the different ages of the rehabilitated forest were in the range reported by Leng et al. (2009). Soil depth affected the total N and C/N ratios significantly except for the 2 year old rehabilitated forest, where the C/N ratio was greater at 20–40 and 40-60 cm than at 0–20 cm. The following means comparison revealed that: (1) total N stock in 1- to 7-year-old rehabilitated forest irrespective of soil depths no significant difference; (2) C/N ratio irrespective of age of the rehabilitated forest at depth of 0 to 20, 20 to 40 and 40 to 60 cm significant difference. The percentage of soil total N of the rehabilitated forests significantly decreased down the soil profile due to the general observation that soil N decreases with increasing soil depth because of decrease in organic N. This absence of significant difference in total N of 2-year-old rehabilitated forest could be attributed to the soil texture which was sandy loam, whereby there was a possibility of the N being leached out from 0 to 20 cm and accumulated in the 20 to 40 and 40 to 60 cm (Lu et al., 2002) The significant difference observed in the C/N ratios in terms of age at 0 to 20, 20 to 40 and 40 to 60 cm may not necessarily suggest differences in the humification levels. The lower C/N ratios of 1-, 2-, and 5-year-old rehabilitated forests compared to those of 3-, 6-, and 7-year-old could be due to the significant accumulation of N at 0-20 cm depth as discussed previously. In terms of depth, the SOM (Table 5) at 0–20 cm of the 1- till 7-year-old rehabilitated forest were higher than those at 20–40 and 40-60 cm. In terms of age, the statistical comparison of means revealed the following: (1) SOM of the 1-year-old rehabilitated forest at 0 to 20 cm compared to the 2-, 3-, 4-, 5-, 6-, and 7-year-old rehabilitated forest significant difference; (2) SOM of the 1- till 7-year-old rehabilitated forest at 20 to 40 cm significant difference; (3) SOM of the 1- till 7-year-old

Table 3. pH of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	pH (Water)	pH (1 M KCl)
(a) 1-year-old rehabilitated forest		
0-20 cm	4.70^{aAB}	3.99^{aA}
20-40 cm	4.72^{aAB}	4.02^{aA}
40-60 cm	4.73^{aAB}	4.03^{aA}
(b) 2-year-old rehabilitated forest		
0-20 cm	4.61^{aBC}	3.73^{aC}
20-40 cm	4.62^{aAB}	3.79^{bB}
40-60 cm	4.67^{aBC}	3.81^{bB}
(c) 3-year-old rehabilitated forest		
0-20 cm	4.66^{aAB}	3.68^{aCD}
20-40 cm	4.69^{aAB}	3.71^{bC}
40-60 cm	4.70^{aAB}	3.72^{bC}
(d) 4-year-old rehabilitated forest		
0-20 cm	4.84^{aA}	3.76^{aC}
20-40 cm	4.88^{aA}	3.80^{bB}
40-60 cm	4.90^{aA}	3.84^{bB}
(e) 5-year-old rehabilitated forest		
0-20 cm	4.34^{aC}	3.84^{aB}
20-40 cm	4.42^{aC}	3.85^{aB}
40-60 cm	4.44^{aC}	3.87^{aB}
(f) 6-year-old rehabilitated forest		
0-20 cm	4.61^{aBC}	3.09^{aE}
20-40 cm	4.63^{aB}	3.09^{aD}
40-60 cm	4.63^{aBC}	3.10^{aD}
(g) 7-year-old rehabilitated forest		
0-20 cm	4.44^{aC}	3.61^{aD}
20-40 cm	4.56^{bBC}	3.69^{bC}
40-60 cm	4.60^{bBC}	3.73^{bC}

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths while different letter(s) (uppercase) indicate significant difference between ages of rehabilitated forests by Turkey test at $p \leq 0.05$.

rehabilitated forest at 40 to 60 cm – significant difference.

The values of SOM and total C recorded in this study was lower compared to the data reported by Lee et al. (2009), whereby SOM ranged between 5 and 6%, while the total C ranged between 3 and 5%. This is because the SOM and total C stock recorded by Leng et al. (2009) were from a 16-year-old rehabilitated forest and a secondary forest. General increase in SOM and total C with age regardless of depth could be due to production and decomposition of litter, which leads to formation of humus. The age of a tree always correlates with litter production. Older trees (depending on species) tend to produce more litter that contributes to high litter accumulation and high build-up of SOM. The percentage of SOM of SOM of the rehabilitated forest significantly decreased down the soil profile was due to decrease of SOM with increasing soil depth which in line with an increase in C/N ratio and soil pH (Table 3). This was because SOM is a source of H^+ ions and contributes to soil acidification (Brady and Weil, 2002). The lower content of SOM in the

Table 4. Soil total N and C/N ratio of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	Total N (%)	C/N ratio
(a) 1-year-old rehabilitated forest		
0-20 cm	0.102aA	7.574aBC
20-40 cm	0.056bA	10.321bB
40-60 cm	0.056bA	12.918cAB
(b) 2-year-old rehabilitated forest		
0-20 cm	0.093aA	8.741aB
20-40 cm	0.084aA	11.630bAB
40-60 cm	0.074aA	14.138cA
(c) 3-year-old rehabilitated forest		
0-20 cm	0.102aA	10.912aA
20-40 cm	0.065bA	11.243abAB
40-60 cm	0.056bA	14.384bA
(d) 4-year-old rehabilitated forest		
0-20 cm	0.112aA	9.924aA
20-40 cm	0.074abA	12.936bA
40-60 cm	0.065bA	13.154bAB
(e) 5-year-old rehabilitated forest		
0-20 cm	0.084aA	7.113aC
20-40 cm	0.056abA	7.456aC
40-60 cm	0.028bB	10.600abC
(f) 6-year-old rehabilitated forest		
0-20 cm	0.084aA	8.347aAB
20-40 cm	0.065abA	9.708abBC
40-60 cm	0.046bA	11.628bBC
(g) 7-year-old rehabilitated forest		
0-20 cm	0.112aA	9.320aAB
20-40 cm	0.065abA	11.720abAB
40-60 cm	0.056bA	12.006bB

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths while different letter(s) (uppercase) indicate significant difference between ages of rehabilitated forests by Turkey test at $p \leq 0.05$.

subsoil was also due to the low N content in the 20-40 and 40-60 cm which leads to lack of N for efficient conversion of biomass C to humus C which is required for humification of biomass returned to soil. The percentages of HA yields and corresponding quantities in Mg ha^{-1} of the rehabilitated forests at three different depths were statistically different (Table 6).

The yield of HA reported by Leng et al. (2009) in a 16 year old rehabilitated forest was slightly higher, ranged between 0.6 and 1.2%, while the yield of HA reported in this study ranged between 0.04 and 0.5%. The percentages and corresponding quantities of HA significantly decreased down the soil profile except 1-year-old rehabilitated forest whereby the percentage and corresponding yield at 20-40 cm was lower than in 40-60 cm. This suggests that there was more humification at 0-20 cm than in 20-40 and 40-60 cm depths. Besides, the lack of sufficient N for efficient conversion of biomass C to humus C which is required for humification of biomass returned to soil through litter and roots was also one of

Table 5. Soil organic matter and corresponding quantities (Mg ha^{-1}) of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	Soil organic matter (%)	Quantity of organic matter (Mg ha^{-1})
(a) 1-year-old rehabilitated forest		
0-20 cm	1.317^{aBC}	32.305^{aB}
20-40 cm	1.020^{abBC}	32.000^{aAB}
40-60 cm	0.815^{bBC}	25.380^{bAB}
(b) 2-year-old rehabilitated forest		
0-20 cm	2.236^{aA}	53.112^{aA}
20-40 cm	1.444^{abAB}	42.846^{abA}
40-60 cm	1.055^{bABC}	33.402^{bA}
(c) 3-year-old rehabilitated forest		
0-20 cm	1.956^{aAB}	37.669^{aAB}
20-40 cm	1.214^{bAB}	30.538^{bAB}
40-60 cm	1.136^{bAB}	32.345^{bAB}
(d) 4-year-old rehabilitated forest		
0-20 cm	1.836^{aAB}	29.973^{aB}
20-40 cm	1.633^{abA}	31.795^{aAB}
40-60 cm	1.405^{bA}	30.808^{aAB}
(e) 5-year-old rehabilitated forest		
0-20 cm	0.997^{aC}	25.386^{aB}
20-40 cm	0.562^{bC}	18.207^{bB}
40-60 cm	0.511^{bC}	19.060^{bB}
(f) 6-year-old rehabilitated forest		
0-20 cm	1.210^{aBC}	30.401^{aB}
20-40 cm	1.054^{aABC}	28.718^{aAB}
40-60 cm	0.842^{bABC}	23.324^{bB}
(g) 7-year-old rehabilitated forest		
0-20 cm	2.221^{aA}	42.481^{aAB}
20-40 cm	1.012^{bBC}	24.967^{bB}
40-60 cm	0.926^{bABC}	29.460^{bAB}

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths while different letter(s) (uppercase) indicate significant difference between ages of rehabilitated forests by Turkey test at $p \leq 0.05$.

the reasons behind this observation (Rowell, 1994). The E_4/E_6 values, total acidity, carboxylic – COOH and phenolic – OH of HA (Table 7) extracted from the soil samples of the rehabilitated forest were found to be consistent with the ranges reported by other researchers (Schnitzer and Preston, 1986; Tan, 2003). The relatively high E4/E6 values in the rehabilitated forest indicate prominence of aliphatic components or the HA in this study were of low molecular weights. The effectiveness of washing the HA with distilled water is to indicate its purity by removing the organic fraction adsorbed on the HAs surface without altering its chemical characteristics and structures. Higher carboxylic group in HA of the 5- and 6-year-old rehabilitated forest contributed to higher acidity, probably due to inclusion of amides and esters in the analysis by spectroscopy (Stevenson, 1994).

Conclusion

There was no significant difference in the quantity of stable C for the different ages of rehabilitated forest at

Table 6. Humic acids yields and corresponding quantities (Mg ha^{-1}) of different soil depths and comparison between different ages of a rehabilitated forest.

Rehabilitated forest	Humic acids yield (%)	Quantity of humic acids (Mg ha^{-1})
(a) 1-year-old rehabilitated forest		
0-20 cm	0.284^{aAB}	6.963^{aAB}
20-40 cm	0.047^{bB}	1.461^{bB}
40-60 cm	0.298^{aA}	9.294^{aA}
(b) 2-year-old rehabilitated forest		
0-20 cm	0.540^{aA}	13.032^{aA}
20-40 cm	0.196^{bAB}	5.822^{bAB}
40-60 cm	0.062^{cB}	1.973^{bC}
(c) 3-year-old rehabilitated forest		
0-20 cm	0.327^{aAB}	6.304^{aAB}
20-40 cm	0.059^{bB}	1.492^{bB}
40-60 cm	0.016^{bBC}	0.455^{bC}
(d) 4-year-old rehabilitated forest		
0-20 cm	0.386^{aAB}	6.305^{aAB}
20-40 cm	0.320^{abA}	6.240^{abA}
40-60 cm	0.213^{bA}	4.669^{bB}
(e) 5-year-old rehabilitated forest		
0-20 cm	0.228^{aAB}	5.807^{aAB}
20-40 cm	0.180^{abAB}	5.842^{aAB}
40-60 cm	0.089^{bB}	3.023^{bB}
(f) 6-year-old rehabilitated forest		
0-20 cm	0.132^{aB}	3.315^{aB}
20-40 cm	0.049^{bB}	1.351^{bB}
40-60 cm	0.008^{bC}	0.240^{bC}
(g) 7-year-old rehabilitated forest		
0-20 cm	0.322^{aAB}	6.162^{aAB}
20-40 cm	0.050^{bB}	1.233^{bB}
40-60 cm	0.057^{bBC}	1.826^{bC}

Means within column with different letter(s) (lowercase) indicate significant difference between soil depths while different letter(s) (uppercase) indicate significant difference between ages of rehabilitated forests by Turkey test at $p \leq 0.05$.

Table 7. Comparison of ranges of phenolic –OH, carboxylic –COOH, total acidity, and E_4/E_6 ratio of HA of different ages of a rehabilitated forest.

Location	E_4/E_6	Range	Carboxylic	Range	Phenolic	Range	Toatl acidity	Range
a) 1-year-old rehabilitated forest								
0-20 cm	7.850	6 – 8$^{(a)}$	500	240 – 540$^{(a)}$	400	150 – 440$^{(b)}$	900	390 – 980$^{(a)}$
20-40 cm	8.144		550		400		950	
40-60 cm	7.715		500		400		900	
b) 2-year-old rehabilitated forest								
0-20 cm	6.628		510		360		870	
20-40 cm	7.150		450		360		810	
40-60 cm	6.995		500		360		860	

Table 7. Contd.

c) 3-year-old rehabilitated forest				
0-20 cm	7.052	530	420	950
20-40 cm	6.995	550	380	930
40-60 cm	7.150	500	400	900
d) 4-year-old rehabilitated forest				
0-20 cm	7.509	530	400	930
20-40 cm	7.588	560	400	960
40-60 cm	7.052	560	400	960
e) 5-year-old rehabilitated forest				
0-20 cm	7.621	600	400	1000
20-40 cm	7.154	490	400	890
40-60 cm	7.150	530	400	930
f) 6-year-old rehabilitated forest				
0-20 cm	7.621	600	400	1000
20-40 cm	7.154	490	400	890
40-60 cm	7.509	530	400	930
g) 7-year-old rehabilitated forest				
0-20 cm	7.150	550	400	870
20-40 cm	7.052	510	400	910
40-60 cm	7.154	530	400	930

[(a)] Tan (2003). [(b)] Schnitzer and Preston (1986).

0-20, 20-40 and 40-60 cm soil. This shows that forest rehabilitation by planting indigenous tree species at initial ages (till 7 years old) has shown signs of C sink but does not exert any difference in the amount of C accumulated across the initial ages. Since the CHA is more stable, it is more realistic to quantify the amount of C accumulated in setting up the rehabilitated forest at initial stages.

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