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Huck Ywih Ch'ng
Faculty of Agro-Based Industry, University Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli Kelantan, Malaysia

Mas Amiera Bt Ibrahim
Faculty of Agro-Based Industry, University Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli Kelantan, Malaysia

Suhaimi Bin Othman
Faculty of Agro-Based Industry, University Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli Kelantan, Malaysia

Jen Young Liew
Faculty of Agro-Based Industry, University Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli Kelantan, Malaysia

Correspondence
Huck Ywih Ch'ng
Faculty of Agro-Based Industry, University Malaysia Kelantan Jeli Campus, Locked Bag No. 100, 17600 Jeli Kelantan, Malaysia

Assessment of soil carbon storage between secondary forest and banana plantation

Huck Ywih Ch'ng, Mas Amiera Bt Ibrahim, Suhaimi Bin Othman and Jen Young Liew

Abstract
Decrease of tropical rainforests affects global warming and has attracted much attention. The increase of world population results in more forestland being converted into agricultural land and other land uses in order to fulfil the demands. Theoretically, the conversion of forest to other land uses will release more carbon. Many studies have reported the carbon storage of temperate forests and other land uses but little is known about the trend of soil carbon storage in Malaysia, especially Kelantan. Thus, the objectives of this study were to: (i) quantify soil organic matter, soil total carbon, soil total nitrogen, humic acids, and stable carbon between a secondary forest and a banana plantation in University Malaysia Kelantan Jeli Campus, and (ii) compare the soil carbon storage between secondary forest and banana plantation land in University Malaysia Kelantan Jeli Campus. Ten soil samples were collected from the secondary forest and banana plantation, respectively at the soil depth of 0-25 cm and 25-50 cm using a soil auger. The size of each experimental plot was 30 m x 40 m. The bulk densities of these depths were determined using the metal corings. The bulk density data was used to quantify the soil total organic matter, total carbon, total nitrogen, humic acids, and stable carbon on per hectare basis. There was no significant difference in the amount of soil stable carbon between the secondary forest and banana plantation at 0-25 cm soil depth. This indicates the conversion of secondary forest to banana plantation did not exert any significant changes on C storage in the soil. This could be due to less disturbance on the soil during the cultivation and management process of the banana plantation. Since the stable carbon derived from humic acid is more stable, it is more realistic to quantify the amount of carbon storage in the soil.

Keywords: Soil carbon storage, soil total carbon, soil stable carbon, secondary forest, banana plantation, humic acids

1. Introduction

Naturally or unnaturally disturbed rainforest is known as secondary forest. It consists of less developed canopy structure, smaller trees, and less diversity. These characteristic allows more light to reach the floor and support vigorous ground vegetation [1]. According to Paramananthan and Zauyah [2], the soils in Malaysia are categorized into two groups, namely non-active soil formed in upland from various rock types and the coastal alluvial plain soil. The first group of soil is mostly available in the east coast of peninsular Malaysia, which is mainly coarse in texture and mostly kaolinitic clays. The second group of soil is mostly available in east coast, which is covered by sandy soil with approximately 155,400 hectare of total area. The two types of soil share a similar characteristic. They are coarse textured soil, the soil with low water holding capacity, low erodibility, and fast breakdown process of soil organic matter (SOM) due to high availability of oxygen for decomposition [3].

Soil organic matter is a part of terrestrial ecosystems where the function and structure are involved in basic ecosystem process. The changes in climate, parent stock, vegetation, and biological, chemical and physical soil properties affect the SOM and its turnover [4]. Shifting cultivation on secondary forest influences the SOM content in soil as well as soil fertility. Soil organic matter tends to increase temporary due to clearing and burning of forest as the dead root is degraded [5]. Deforestation followed by cultivation land use decreases the carbon (C) content in tropical forest soil by 40% [6].

The rising intensification of land use and resource demand causes a serious threat to soil C storage. Based on United Nation [7], the world population is expected to reach 9.6 billion by

2050. Over the coming four decades, this demographic pressure creates '4 x 40' challenges for soil to meet the humanity anticipated demands [8]. The conversion of forest to agriculture land showed depletion on soil organic carbon (SOC) [9]. Moreover, Ch'ng *et al*. [10] concluded that SOC sequestration can be affected by three processes, namely conversion of biomass into humus (including humic acids), aggregation to prevent carbon oxidation, and translocation of carbon into sub-soil.

Deforestation in Kelantan nowadays is caused by excessive logging and shifting cultivation. It results in significant changes of land uses in Kelantan. According to Lal [11], agriculture activities can influence the losses of C storage in soil. These activities include forestation by biomass burning activities, conversion of agricultural ecosystems from natural, tillage and other soil disturbances, drainage of wetlands, cultivation of organic soils, biomass removal for fuel, fodder and other uses, and increment of soil erosion. However, according to Minansy *et al*. [12], agricultural activities such as crop sequence, tillage, and the input and output of fertilization influence the C dynamic in agricultural soils. The SOC content in Java Indonesia had decreased from 0.75 to 2% in 1960 due to rapid conversion of natural vegetation to agricultural land in 1930s [12]. This finding indicates human or management can influence SOC stock more than environmental factors.

Carbon is a basic building block in soil and plant tissue. Deforestation in order to serve arable land use may release more C. The losses of C may be worsening when plantation is established on mineral land as it releases C in the form of CO_2. In Malaysia, banana is the second most widely cultivated fruit, covering about 26,000 ha with a total production of 530,000 metric tonnes [13]. There are many researches had been done by comparing C stock between oil palm plantation and secondary forest. However, there is a dearth of information on the soil C stock upon conversion of secondary forest to banana plantation especially in Kelantan. Hence, the objectives of this study were to: (i) quantify SOM, soil total C, soil total nitrogen (N), humic acid (HA) and C in HA upon the conversion of a secondary forest to banana plantation, and (ii) compare the soil C storage between a secondary forest and a banana plantation.

2. Materials and Methods

(a) Sampling of soil samples

Soil samples from secondary forest and banana plantation in Universiti Malaysia Kelantan Jeli Campus, Kelantan Malaysia (latitude 5° 4315" N and longitude 101° 51'15" E) were collected. The mean annual rainfall, relative humidity and temperature of 2933 mm, 80%, and 27°C, respectively. The secondary forest consists of indigenous timber species from the family Dipterocarpaceae and Non-Dipterocarpaceae. The soil texture of the rehabilitated forest is sandy loam. The soil samples were taken at two different depths, which are 0 – 25 cm and 25-50 cm. The size of each experimental plot was 30 m x 40 m. Ten soil samples were taken randomly from each location and each soil depth by using soil auger. Each sample was a bulk of three samples. Each soil sample represents a replication in the soil chemical analyses.

(b) Soil samples preparation and analysis

Soil samples were air-dried. Then, the soil samples were grounded manually using a pestle and mortar and later sieved to pass a 10-mesh (2 mm) screen. The soil samples were then kept in zipper plastic bags. The subsequent soil chemical analyses below were done at the same time, that is, they were not analysed on soil depth-by-soil depth basis (not separately) to avoid bias. The bulk densities at these depths were determined by the coring method [14]. The bulk density method was used to quantify soil total N stock, soil total C, SOM, HA, and C in HA at the stated sampling depths on per hectare basis. Soil total N stocks were determined using the micro-Kjeldahl method [15]. The soil total C and CHA were analysed using loss on ignition method [15]. SOM was calculated by dividing soil total C with 0.58 [15]. 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 [16]. The extraction of HA was done using the method described by Stevenson [17]. 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 [17]. Humin was excluded in this study because it is chemically non-reactive due to its insolubility characteristic and difficulties in its isolation [18]. Purification process was conducted to purify the HA. It was done by using the method described by Ahmed *et al*. [19]. The HA was purified using distilled water [19]. 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.

Data obtained from the laboratory analysis were analyzed using the Statistical Analysis System (SAS) Version 9.2. Independent t-test was used to detect significant difference and separate the means between bulk densities, soil pH, soil total C, C in HA, soil total N stock, C/N ratio and HA at different soil depths and between secondary forest and banana plantation within the same soil depth.

3. Results and Discussion

a) Soil total carbon and carbon in humic acids

Soil C is corresponding to the SOM content in the soil. In this study, soil total C in percentage and quantities between 0 – 25 cm and 25 – 50 cm of the secondary forest was found to be not statistically different (Table 1). This was related to the steady-state condition where heterotrophic respiration produced by litter and SOM decomposer equalized the carbon gained with C losses from the soil [20, 21]. As for banana plantation, there was significant difference in percentage of soil total C between 0 – 25 cm and 25 – 50 cm but no significant difference between both soil depths in soil total C quantity. The soil total C in percentage and quantity content in the banana plantation was found to be higher at the soil depth of 0 – 25 cm compared to soil depth 25 – 50 cm. The soil total C in the banana plantation at the soil depth of 0 – 25 cm was also significantly higher than the secondary forest. This finding contradicts with studies by Davidson & Ackerman [22] and Murty *et al*. [21] where forest soil usually contains most organic material and soil total C in the upper soil compared to cultivated soil. Moreover, the soil total C in the banana plantation at the soil depth of 25 – 50 cm was also significant higher than the secondary forest. This was probably due to the application of organic fertilizers and organic materials during the cultivation of banana.

Carbon in HA in percentage and quantity were able to be determined only at the soil depth of 0 – 25 cm in secondary forest (Table 1). In a meanwhile, C in HA in percentage and quantity were able to be determined at both soil depths (0 – 25 cm and 25-50 cm) in banana plantation. Carbon in HA at banana plantation showed no significant difference in percentage but there was significant difference in terms of quantity. At the soil depth of 0 – 25 cm, there was no significant difference in the C in HA and its quantity between secondary forest and banana plantation. This shows that conversion of secondary forest to a banana plantation does not exert any difference in the amount of C sequestered in the soil. This finding was similar to that of Ch'ng *et al.* [10] where a conversion of secondary forest to initial stages of oil palm plantation did not shows any changes in the C quantity in peat soil at early stages of conversion. Upon the conversion of secondary forest to banana plantation, it is more practical to estimate the C quantity as C in HA because C derived from HA is more stable and humic substances are less susceptible to further decomposition in the soil [23, 10].

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

Locations	Total carbon (%)	Quantity of carbon (Mg ha^{-1})	Carbon in humic acid (%)	Quantity of carbon in humic acid (Mg ha^{-1})
Secondary Forest				
0 – 25 cm	3.34a	95.19a	36.67	0.53
25 – 50 cm	3.45a	105.23a	n.d.	n.d.
Banana Plantation				
0 – 25 cm	4.82a	119.54a	35.09a	0.59a
25 – 50 cm	3.98b	100.69a	33.34a	0.08b
Locations (0 – 25 cm)				
Secondary Forest	3.34a	95.19a	36.67a	0.53a
Banana Plantation	4.82b	119.54b	35.09a	0.59a
Locations (25 – 50 cm)				
Secondary Forest	3.45a	105.23a	n.d.	n.d.
Banana Plantation	3.98b	100.69a	33.4	0.80

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test. The abbreviation "n.d." indicates not determined.

b) Selected soil physical and chemical analyses

There was no significant difference in the soil bulk densities between 0 – 25 and 25-50 cm soil depths in the secondary forest and banana plantation (Table 2). The soil bulk densities in this study were relatively higher than that of Akbar *et al.* [24]. The soil bulk densities (Table 2) indicate that the soils in this study contains relative amount of clay [2]. Bulk density is affected by the soil texture and SOM content in the soil. Based on the soil texture analysis, the soil texture in this study was sandy loam texture in both locations (secondary forest and banana plantation), where the clay content is around 5 – 10%. The bulk density values in this study (ranged from 1.0 g cm^{-3} to 1.2 g cm^{-3}) also suggest that the soil has high degree of aggregation with small total porosity [25]. Besides, it indicates that the soil is a fine-textured soil [26]. The soil bulk density for both secondary forest and banana plantation regardless soil depth, respectively were not significantly different. This could be partly associated with the absence of significant difference in the SOM of secondary forest at both soil depths (Table 4). The absence of significant difference in the soil bulk densities between 0 – 25 cm and 25-50 cm at banana plantation was due to the compaction of soil by machinery during land clearing prior to banana cultivation. The machinery compaction will increase the soil bulk density [26]. At 0 – 25 cm, there was no significant difference in the soil bulk densities between secondary forest and banana plantation. However, there was significant different between both locations at the soil depth of 25 – 50 cm. This was due to the age-hardening of secondary forest where soil strength is increased especially for subsoil level [27].

Table 2: Soil bulk densities (g cm^{-3}) of different soil depths and comparison between secondary forest and banana plantation.

Location	Soil bulk density (g cm^{-3})
Secondary Forest	
0 – 25 cm	1.142a
25 – 50 cm	1.222a
Banana Plantation	
0 – 25 cm	1.068a
25 – 50 cm	1.012a
Locations (0 – 25 cm)	
Secondary Forest	1.142a
Banana Plantation	1.068a
Locations (25 – 50 cm)	
Secondary Forest	1.222a
Banana Plantation	1.012b

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test.

The pH readings for both locations were ranged between 4.76 and 5.07 (Table 3). According to USDA [28], the pH of the soils are considered strongly acidic. There was significant difference in the soil pH between the depth of 0 – 25 cm and 25 – 50 cm of secondary forest. The significant higher pH value at 0 – 25 cm than 25 – 50 cm was due to the decomposition of dead litters on the secondary forest floor. On the other hand, there was no significant difference in the soil pH between 0 – 25 cm and 25 – 50 cm of banana plantation. This could be due to the uniform absorption of nutrients in both soil depths as a result of the application of chemical and organic fertilizers during banana cultivation. The conversion of secondary forest land to agriculture cultivation land only shows significant pH changes after a period of time [28]. The recent cultivation of banana (approximately one year) might also explain the absence of significant difference in the soil pH between two different depths. There was significant difference in the soil pH at 25 – 50 cm between secondary forest and banana plantation. The soil pH was more acidic in secondary forest compared to banana plantation. This was due to the higher leaching rate of basic cations from 0 – 25 cm to 25 – 50 cm soil depth in secondary forest.

Table 3: Soil pH of different soil depths and comparison between secondary forest and banana plantation.

Location	Soil pH
Secondary Forest	
0 – 25 cm	5.07a
25 – 50 cm	4.76b
Banana Plantation	
0 – 25 cm	4.92a
25 – 50 cm	4.95a
Locations (0 – 25 cm)	
Secondary Forest	5.07a
Banana Plantation	4.92a
Locations (25 – 50 cm)	
Secondary Forest	4.76a
Banana Plantation	4.95b

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test.

Soil total N is one of the major indicator for soil fertility and quality, and also soil productivity. Table 4 shows that there was significant difference in the soil total N between secondary forest and banana plantation. The deeper soil depth (25 – 50 cm) contains less soil total N in both locations. This finding is consistent with that of Ch'ng *et al.* [10] where soil total N declines as the soil depth increases. This was due to the decrease of organic N content in the soil. There was no significant difference between secondary forest and banana at 0 – 25 cm and 25-50 cm, respectively. According to Murty *et al.* [21], losses and gained of C and N is correlated. Soil C/N ratio increases when soil total N decreases and vice-versa. At 0 – 25 cm, there was significant difference in the soil C/N ratio between secondary forest and banana plantation (Table 4). The C/N ratio of secondary forest was significantly higher than banana plantation. This finding is consistent to that of Murty *et al.* [21] where the conversion of forest to cultivation land decreased the mean soil C/N ratio. At 25-50 cm, there was also significant difference in the soil C/N ratio between secondary forest and banana plantation. However, the soil C/N ratio in the banana plantation was significantly higher than that of secondary forest. This was due to the significantly higher soil total carbon content in the banana plantation than the secondary forest (Table 1). Besides, Zheng *et al.* [29] mentioned that cultivated area commonly have lower soil C/N ratio due to the lower C/N ratio of crop litter and its microbial decomposers.

The percentage and quantities of SOM for secondary forest and banana plantation is shown in Table 5. There was no significant difference in percentage and quantities of SOM between 0 – 25 cm and 25 – 50 cm of secondary forest. This indicates the SOM had reached equilibrium state between both soil depths. This finding was consistent with the study by Ch'ng *et al.* [10]. On the other hand, there was significant difference in the percentage and quantities of SOM between 0 – 25 cm and 25 – 50 cm of banana plantation. This could be due to the application of organic fertilizers during the banana cultivation which resulted in the built up of SOM. The trend of this study was similar to that of Akbar *et al.* [24], where SOM decreased with increase soil depth. Besides, development of root mats on the upper surface of soil results in higher SOM [30]. The SOM percentage and quantity of banana plantation was significantly higher at both soil depths compared to secondary forest. This was due to the soil surface of the banana plantation was fully covered by weeds, indicating that the soil was fertile. This explanation was supported by the significant higher SOM content in banana plantation at both soil depths compared to secondary forest.

Table 4: Soil total N and C/N ratio of different soil depths and comparison between secondary forest and banana plantation.

Location	Soil total N (%)	Soil C/N ratio
Secondary Forest		
0 – 25 cm	0.120a	8.848a
25 – 50 cm	0.080b	7.238b
Banana Plantation		
0 – 25 cm	0.124a	7.436a
25 – 50 cm	0.084b	8.870b
Locations (0 – 25 cm)		
Secondary Forest	0.120a	8.848a
Banana Plantation	0.124a	7.436b
Locations (25 – 50 cm)		
Secondary Forest	0.080a	7.238a
Banana Plantation	0.084a	8.870b

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test.

Table 5: Soil organic matter and corresponding quantities (Mg ha^{-1}) of different soil depths and comparison between secondary forest and banana plantation.

Location	Soil organic matter (%)	Quantity of organic matter (Mg ha^{-1})
Secondary Forest		
0 – 25 cm	6.68a	190.38a
25 – 50 cm	6.90a	210.45a
Banana Plantation		
0 – 25 cm	9.64a	258.23a
25 – 50 cm	7.96b	201.39b
Locations (0 – 25 cm)		
Secondary Forest	6.68a	190.38a
Banana Plantation	9.64b	258.23b
Locations (25 – 50 cm)		
Secondary Forest	6.90a	210.45a
Banana Plantation	7.96b	201.39a

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test.

The yield of HA (%) and quantity of HA (Mg ha^{-1}) of secondary forest was only able to be extracted and determined at the soil depth of 0 – 25 cm (Table 6). The HA at 25 – 50 cm of the secondary forest was in a minute quantity. However, HA was able to be extracted at two different soil depths of banana plantation. The HA content and its quantity in Mg ha-1 at 0 – 25 cm was significantly higher than the soil depth of 25 – 50 cm in banana plantation. This was due to the higher percentage of SOM (Table 5) and soil total C (Table 1) at the soil depth of 0 – 25 cm in banana plantation. However, there was no significant difference in the HA and its quantity between secondary forest and banana plantation at the soil depth 0 – 25 cm. This was probably due to the low N for efficient biomass humification where it involves the conversion of biomass C into humus C in both secondary forest and banana [10, 31].

Table 6: Humic acid and corresponding quantities (Mg ha^{-1}) of different soil depths and comparison between secondary forest and banana plantation.

Location	Humic acid (%)	Quantity of humic acid (Mg ha^{-1})
Secondary Forest		
0 – 25 cm	2.50	1.43
25 – 50 cm	n.d.	n.d.
Banana Plantation		
0 – 25 cm	3.17a	1.69a
25 – 50 cm	0.50b	0.25b
Locations (0 – 25 cm)		
Secondary Forest	2.50a	1.43a
Banana Plantation	3.17a	1.69a
Locations (25 – 50 cm)		
Secondary Forest	n.d.	n.d.
Banana Plantation	0.50	0.25

Note: Means within column with different alphabets indicate significant difference between soil depths and locations by independent t-test. The abbreviation “n.d.” indicates not determined.

4. Conclusions

The SOM, soil total C, soil total N, HA and C in HA upon the alteration of soil management from secondary forest to banana plantation had been quantified in this study. There was no significant difference in the amount of C in HA between secondary forest and banana plantation at 0 – 25 cm soil. This indicates that conversion of secondary forest to banana plantation at initial stage did not give any significant changes on C storage in the soil. It is realistic to quantify the total C in HA accumulated in the secondary forest and banana plantation because the C in HA is more stable and resist to further decomposition.

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