

Effect of Logging Operation on Soil Carbon Storage of a Tropical Peat Swamp Forest

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Abstract: Problem statement: Since heavy machinery are used in the logging operation activity for extracting the logs on sensitive forest site with peat soil, environment destruction should be the other concern during its processes especially on its important function as soil carbon storage. The objective of this study was to determine whether logging operation affect soil carbon storage of a tropical peat swamp forest. **Approach:** Soil sampling was conducted before and after logging operation in a 0.3 ha plot to a depth of 15 cm. The soil samples were analyzed for acidity, organic matter content, total carbon, total nitrogen and total phosphorus. The humic acid extraction was also done and soil carbon storage values were obtained by calculation. Paired t-test was used to compare variables under the two treatments (before and after logging) and correlation analysis was used to correlate variables such as soil pH, soil organic matter, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, humic acid yield, unstable carbon and stable carbon. **Results:** The availability of unstable carbon and stable carbon controlled by soil acidity on undisturbed peat swamp forest as a result, the accumulation of unstable carbon as well as stable carbon occurred even if the soil pH declines and vice versa. However, stable carbon associated well with soil acidity. It was found that the C/P ratio positively correlated with humic acid and stable carbon of both before and after logging conditions. Nevertheless, that association was prominent on logged peat swamp forest. An indication that even though this peat swamp forest had been logged, humification was strongly maintained. However, the similarity of stable carbon of the logged peat swamp forest with stable carbon of undisturbed peat swamp forest indicate an ineffectiveness humification of logged peat swamp forest. **Conclusion:** Logging operation on sensitive forest with peat soil using heavy machinery increased the bulk density because of compaction. Soil acidity has important role in preserving soil carbon storage of this natural peat swamp forest, especially stable carbon. After the peat swamp forest is logged, humification processes are strongly maintained but slows and becomes ineffective, hence unstable carbon decomposes more instead of it being preserved as stable carbon. Disturbance by logging operation does not alter their amount of soil carbon storage (stable carbon) due to the carbon in humic acid is quite stable within one year.

Key words: Peat swamp forest, logging operation, humification, soil carbon storage

INTRODUCTION

In recent years, most tropical peatlands especially in Southeast Asia, are now undergoing rapid land cover change because of timber harvesting or deforestation. Logging operation is a set of activities which forest products is delivered from forest to a mill at the least possible cost^[1]. Since heavy machinery are used in this operation for extracting the logs on sensitive forest site with peat soil, environment destruction should be the other concern during its

processes especially on its important function as soil carbon storage. Timber harvesting and skidding have the potential to cause detrimental levels of soil and site disturbances, particularly soil compaction, rutting and organic matter removal through trafficking with heavy equipment^[2]. The increased of soil surface temperature possibly occur once the peat swamp forest logged and cleared thereby aerobic degradation may become prominent and consequently accelerating organic matter decomposition. These processes probably lead to more CO₂ evolution.

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Therefore, the objective of this study was to determine whether logging operation affect soil carbon storage of a tropical peat swamp forest.

MATERIALS AND METHODS

Soil sampling was conducted in March 2008 (before logging) and in February 2009 (after logging) in a 0.3 ha plot to a depth of 15 cm at Sibul, Sarawak, Malaysia. The peat swamp forest was logged in June 2008.

The potentiometric method was used to determine soil pH^[3]. The loss on ignition method was used to determine total C^[3]. Total nitrogen was determined by Kjeldahl method^[4]. Total phosphorus was determined by Aqua Regia method and Murphy and Riley methods^[5]. Humic acid extraction was carried out by the methods of Stevenson^[6] and Susilawati *et al.*^[7]. The calculation of carbon storage was done by the bulk density method^[8]. The humic acid characterization such as ash content and organic carbon, functional groups and total acidity and E₄/E₆ was done to confirm its purity. Organic carbon and ash content in humic acid were determined by the dry combustion method^[9]. Functional groups and total acidity of humic acid were determined by the method of Inbar *et al.*^[9]. Humification level of humic acid was ascertained by analyzing the E₄/E₆ ratio by the method outlined by Stevenson^[6].

Paired t-test was used to compare variables under the two treatments (before and after logging) and correlation analysis was used to correlate variables such as soil pH, soil organic matter, total carbon, total nitrogen, total phosphorus, C/N ratio, C/P ratio, humic acid yield, unstable carbon and stable carbon. The Statistical Analysis System (SAS) version 9.1, was used for the aforementioned analysis.

RESULTS

The results in Table 1 indicate that undisturbed peat swamp forest was significantly higher in soil organic matter, total carbon and total phosphorus than logged peat swamp forest, but significantly lower in bulk density and C/P ratio. However, undisturbed and logged peat swamp forest were not statistically different in soil pH, total nitrogen, C/N ratio and humic acid yield.

The results in Table 2 indicate that logged peat swamp forest showed statistically higher unstable carbon compared with undisturbed peat swamp forest. However, the stable carbon before and after logging operation were similar.

Table 1: Selected soil physical and chemical properties of a tropical peat swamp forest before and after logging operation

Variable	Mean	
	Undisturbed	Logged
Bulk density (g cm ⁻³)	0.150 ^a	0.170 ^b
Soil acidity (pH)	3.719 ^a	3.672 ^a
SOM (%)	97.745 ^a	93.185 ^b
C (%)	48.872 ^a	46.593 ^b
N (%)	0.862 ^a	0.709 ^a
P (%)	0.020 ^a	0.013 ^b
C/N ratio	60.967 ^a	70.407 ^a
C/P ratio	2789.835 ^a	3826.634 ^b
Humic acid yield (g)	1.516 ^a	1.486 ^a

Note: Means with the same letter are not significantly different at p = 0.05 using paired t-test

Table 2: Carbon storage of a tropical peat swamp forest before and after logging operation

Variable	Mean (Mg ha ⁻¹)	
	Undisturbed	Logged
Unstable C	109.963 ^a	118.811 ^b
Stable C	68.190 ^a	75.801 ^a

Note: Means with the same letter are not significantly different at p = 0.05 using paired t-test

The correlations between variables are summarized in Table 3. Soil pH was found to be negatively correlated with soil organic matter, total carbon, humic acid, unstable carbon and stable carbon. However, those associations were not found after logging operation. Contrarily, the positive association between C/P ratio and soil organic matter, total carbon and unstable carbon was found after logging operation which was not found before on undisturbed peat swamp forest.

DISCUSSION

The higher bulk density found in logged peat swamp forest (Table 1) was because of the use of heavy machinery.

In natural peat swamp forest (undisturbed), soil pH negatively correlated with soil organic matter (Table 3) suggesting that the decline of soil organic matter increased soil pH and vice versa. This was because organic matter is a source of H⁺ ions and contributes to soil acidification^[3]. Obviously, those observations did not occur after peat swamp forest was logged. However, this ecosystem still maintained its soil acidity (Table 1). It could be due to production of CO₂ in soil air by root and microbial decomposition of soil organic matter^[3]. Furthermore, there was more organic matter decomposition and low carbon content found in this logged peat swamp forest (Table 1). This process leads to more CO₂ evolution^[10]. The soil pH of the

undisturbed peat swamp forest also negatively correlated with total carbon (Table 3), indicating that in natural peat soils large amounts of carbon accumulate as soil organic matter^[3]. Hence, soil pH has association with total carbon as well as with soil organic matter (Table 3). The association between total carbon and soil organic matter seems not to be influenced by logging (Table 3). Total carbon positively correlated with soil organic matter (Table 3) also indicating that carbon accumulates as soil organic matter. Logging operation caused low total carbon as well as low soil organic matter, while in undisturbed peat swamp forest, the high total carbon resulted in high soil organic matter (Table 1).

The C/N ratio of this peat swamp forest before and after logging was statistically similar (Table 1). Nitrogen was found to be fluctuating instead of carbon, thus affecting the C/N ratio levels of both before and after logging conditions (Table 3). There was higher bulk density was due to soil compaction.

The higher C/P ratio of peat swamp forest after logging indicates low humification (Table 1). After peat swamp forest logged, because of remarkable decrease in total phosphorus compared to total carbon, the C/P ratio was high (Table 1) and hence, slowed the humification processes. However, the C/P ratio was found to be negatively correlated with phosphorus instead of carbon content for both before and after logging conditions (Table 3), suggesting that little changes of phosphorus have stronger effect on humification instead of carbon content fluctuations. Furthermore, phosphorus was also found to be negatively with humic acid as well as with stable carbon under the two conditions (Table 3), again indicating that little changes in phosphorus may have affected the humification processes. However, the effect of phosphorus on humification was found to be stronger on logged peat swamp forest (Table 3).

Table 3: Correlation between unstable C, stable C and some selected chemical properties of peat swamp forest before and after logging operation

Variable	pH	SOM	C	P	C/N ratio	C/P ratio	Unstable C	Stable C
Undisturbed								
pH		-0.450	-0.4500				-0.4500	-0.5200
		0.0472	0.0471				0.0472	0.0185
SOM			1.0000				1.0000	0.4600
			<0.0001				<0.0001	0.0434
C							1.0000	0.4600
							<0.0001	0.0434
N					-0.9500			
					<0.0001			
P								-0.4800
								0.0307
C/P ratio				-0.9300				0.5600
				<0.0001				0.0107
Humic acid	-0.520	0.4600	0.4600	-0.4800		0.5600	0.4600	1.0000
	0.0185	0.0434	0.0434	0.0308		0.0107	0.0435	<.0001
Stable C							0.4600	
							0.0435	
Logged								
pH		0.010	0.110				0.1500	0.0690
		0.700	0.081				0.0920	0.0870
SOM			1.0000				1.0000	0.4700
			<0.0001				<.0001	0.0377
C							1.0000	0.4700
							<0.0001	0.0377
N					-0.9800			
					<0.0001			
P								-0.6100
								0.0043
C/P ratio		0.5000	0.5000	-0.9600			0.5000	0.6500
		0.0239	0.0239	<0.0001			0.0239	0.0021
Humic acid	0.4700	0.4700	0.4700	-0.6100		0.6500	0.4700	1.0000
	0.0374	0.0374	0.0374	0.0043		0.0021	0.0374	<0.0001
Stable C							0.4700	
							0.0377	

Note: The top value represents Pearson's correlation coefficient (r) and the bottom values represent the probability level

It was found that the C/P ratio positively correlated with humic acid and stable carbon of both before and after logging conditions (Table 3). Nevertheless, that association was prominent on logged peat swamp forest (Table 3). An indication that eventhough this peat swamp forest had been logged, humification was strongly maintained. The C/P ratio was also found to be positively correlated with soil organic matter, carbon content and unstable carbon on logged peat swamp forest (Table 3), indicating that humification processes occurred to the new organic materials added and this may have affected carbon content (Table 1) as well as unstable carbon evolution. However, higher unstable carbon stock on logged peat swamp forest (Table 2) seemed to decompose more and this probably affects their function as carbon storage for further periods.

Both unstable and stable carbon positively correlated with soil organic matter, total carbon and humic acid on those two different conditions. However, unstable carbon associated well with soil organic matter and total carbon (Table 3) indicating that unstable carbon is derived from accumulation of soil organic matter as well as total carbon, whereas stable carbon associated well with humic acid. It also suggests that humic acids are extremely stable form of soil organic matter^[11]. Moreover, large amounts of stable carbon on earth is found as humic acids^[12]. The availability of unstable carbon and stable carbon also controlled by soil acidity on undisturbed peat swamp forest (Table 3) as a result, the accumulation of unstable carbon as well as stable carbon occurred even if the soil pH declines and vice versa. However, stable carbon associated well with soil acidity (Table 3). The acidic condition retards the rate of decomposition of organic materials. Thus, organic matter was preserved as stable carbon in peat profiles for millennia and allow this ecosystem to continue to represent a sink for carbon. It also suggests that stable carbon is more sensitive to the acidic condition on this natural peat swamp forest. The association between unstable carbon and humic acid as well as the association between stable carbon and soil organic matter and total carbon was prominent on logged peat swamp forest (Table 3), indicating that more organic matter decomposition and low carbon content after peat swamp forest was logged. This might have led to more unstable carbon accumulation. Afterwards, that high unstable carbon formed on logged peat swamp forest (Table 2) was converted into humic acid and stable carbon through humification processes.

It was found that stable carbon positively correlated with unstable carbon on both conditions

(Table 3). Unstable carbon in the soil organic matter decomposes and releases carbon dioxide by oxidation and the remaining becomes stable carbon through humification processes. However, that association was prominent on logged peat swamp forest (Table 3); again, indicating more unstable carbon evolution into stable carbon after logging operation. However, the similarity of stable carbon of the logged peat swamp forest with stable carbon of undisturbed peat swamp forest indicate an ineffectiveness humification of logged peat swamp forest (Table 2).

In this study, the ash content of the humic acid was found to be 2.02 and 1.80% for undisturbed and logged peat swamp forest respectively. These values were comparable with the generally accepted value of ash content of $\pm 1\%$ ^[6], suggesting that the relatively low ash content of the humic acid indicates that the purification process was effective in reducing mineral matter or the humic acid was relatively pure or well washed. This observation also demonstrates relatively low content of inorganic ions in the humic acid^[6]. The consistency of the range of carbon content of the humic acid with those reported by other researchers (Table 4) also confirms the purity of the humic acid. The phenolic OH, carboxylic COOH and total acidity (summation of phenolic OH and carboxylic COOH) values of the humic acid obtained were found to be consistent with the range of previous studies (Table 4) also indicating the purity of the washed humic acid.

The ratio between absorbances at 465 and 665 nm (E_4/E_6 ratio) has been often used as a humification index because it decrease with increasing molecular weight and condensation of aromatic constituents^[6]. The E_4/E_6 ratios in this study were found to be within the range reported by other workers (Table 4). However, the relatively high E_4/E_6 ratios in this study compared with previous study indicate the relatively low degree aromatic condensation and the presence of relatively large proportions of aliphatic structures^[13,14] or the humic acid obtained was relatively low in molecular weights^[15,16].

Table 4: Comparison of selected chemical characteristics of humic acid obtained with previous study

Variable	Undisturbed	Logged	Previous study
Carbon (%)	48.99	49.11	48.90-58.50 54-59
Phenolic (cmol kg ⁻¹)	184.00	232.00	150-440
Carboxylic (cmol kg ⁻¹)	393.00	431.00	240-540
Total acidity (cmol kg ⁻¹)	577.00	663.00	390-980 570-890
E_4/E_6	8.62	7.11	7-8 or higher

Source: Stevenson^[6], Schnitzer and Preston^[17], Tan^[16]

CONCLUSION

Logging operation on sensitive forest with peat soil using heavy machinery increased the bulk density because of compaction. Soil acidity has important role in preserving soil carbon storage of this natural peat swamp forest, especially stable carbon.

After the peat swamp forest is logged, humification processes are strongly maintained but slows and becomes ineffective, hence unstable carbon decomposes more instead of it being preserved as stable carbon.

Disturbance by logging operation does not alter their amount of soil carbon storage (stable carbon) due to the carbon in humic acid is quite stable within one year.

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