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Effect of Skidding Operations on Soil Carbon Storage of a Tropical Peat Swamp Forest

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Abstract: Problem statement: There is still lack of a study that compares the soil carbon storage of kuda-kuda skidding system and excavator skidding system in tropical peat swamp forests. The objective of this study was to determine whether skidding operations affects soil carbon storage of a tropical peat swamp forest. **Approach:** Soil sampling was conducted on two different plots (0.3 ha each plot) to a depth of 15 cm under different skidding systems at Sibu, Sarawak, Malaysia. Plots were in the same forest concession area but considerably independent from each other. 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. The calculation of carbon storage was by the bulk density method. Unpaired t-test was used to compare variables under the two systems and correlation analysis was used to correlate variables (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:** Soil organic matter, total carbon and unstable carbon were found to be negatively correlated with nitrogen but positively correlated with C/N ratio under kuda-kuda skidding system indicating that the lower nitrogen and higher C/N ratio markedly slowed decomposition process and enabled soil organic matter to accumulate as well as total carbon. Unstable carbon stocks under excavator skidding system was found to be higher (130.200 Mg ha^{-1}) compared with kuda-kuda skidding system (117.124 Mg ha^{-1}), under kuda-kuda skidding system, unstable carbon stock seemed to be preserved better and this was because of the better carbon storage. Although stable carbon contents of the two systems were similar, the excavator skidding system had faster decomposition processes, thus unstable carbon stocks decomposed more and this probably affects its function as carbon storage for further periods. Total phosphorus positively correlated with nitrogen but negatively correlated with C/N ratio under kuda-kuda skidding system, indicating that low nitrogen (0.914%) results in high C/N ratio (55.236) and this may have affected phosphorus (0.024%), thus enabled organic material to accumulate instead of losses through decomposition process. The low phosphorus (0.024%) or high C/P ratio (2346.345) under kuda-kuda skidding system resulted in decreased soil pH (3.552), thus enabled soil organic matter (97.603%) and total carbon (48.802%) to accumulate as well as unstable carbon stocks (117.124 Mg ha^{-1}). **Conclusion:** The application of skidding systems in this peat swamp forest possibly alters their carbon storage particularly unstable carbon by altering their decomposition rates. Kuda-kuda skidding system is able to maintain decomposition process in this peat swamp forest. Hence, unstable carbon stocks can be preserved for further persistent breakdown processes, hence maintaining their function for carbon storage.

Key words: Peat swamp forest, kuda-kuda skidding system, excavator skidding system, humic acid, soil carbon storage

INTRODUCTION

Most carbon is released to the atmosphere from vegetation and soils[1] and this occurrence is concentrated in the tropics, particularly from land cover change[2] including deforestation. Peatlands are scattered about 3.3% of the earth's surface[3], however they contain about 15-25% of global terrestrial nitrogen and carbon[4].

Logging operation is a set of activities which forest products is delivered from forest to a mill at the least

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possible cost[5]. Environment destruction should be the other concern during its processes especially on sensitive forest site with peat soil[6]. Skidding system is one of the components of logging operation which involves a process of transporting logs along the ground from the felling site to the landing site. Indeed, this activity is the most activity that interacts with the ground while extracting the trees and possibly interfere intangible function of peat swamp forest soil as a carbon sink.

Kuda-kuda skidding system is considered environmentally friendly since it does not involve heavy machinery while extracting the logs. Unfortunately, this method has declined and has been replaced with excavator skidding system since 2004. There is still lack of a study that compares the soil carbon storage of kuda-kuda skidding system and excavator skidding system in tropical peat swamp forests. Therefore, the objective of this study was to determine whether skidding operations affect soil carbon storage of a tropical peat swamp forest.

MATERIALS AND METHODS

Soil sampling was conducted in August 2008 on two different plots (0.3 ha each plot) to a depth of 15 cm under different skidding systems at Sibu, Sarawak, Malaysia. The plots were in the same forest concession area but considerably independent from each other. Kuda-kuda plot was in abandoned peat swamp forest which was former kuda-kuda skidding system in 2004. Excavator skidding system plot was in peat swamp forest which was former of excavator skidding system in June 2008.

The potentiometric method was used to determine soil pH[7]. The loss on ignition method was used to determine total C[7]. Total nitrogen was determined by Kjeldahl method[8]. Total phosphorus was determined by Aqua Regia and Molybdate blue Methods. Humic acid extraction was carried out by the methods of Stevenson[9] and Susilawati *et al*.[10]. The calculation of carbon storage was done by the bulk density method. Unpaired t-test was used to compare variables under the two systems and correlation analysis was used to correlate variables such as 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 kuda-kuda skidding system was significantly lower compared with excavator skidding system in soil pH, total nitrogen and total phosphorus, but significantly higher in soil organic matter, total carbon and C/N ratio. However, kuda-kuda and excavator skidding systems were not statistically different in bulk density, C/P ratio and humic acid yield.

The results in Table 2 indicate that excavator skidding system showed statistically higher unstable carbon compared with kuda-kuda skidding system. However, the stable carbon of the two systems were similar.

The correlations between variables are summarized in Table 3. Under kuda-kuda skidding system, soil pH was found to be positively correlated with total phosphorus, but negatively correlated with C/P ratio (Table 3). Soil organic matter, total carbon and unstable carbon was found to be negatively correlated with total phosphorus, but positively correlated with C/P ratio (Table 3). Unstable carbon positively correlated with soil organic matter and total carbon for the two areas with different skidding system (Table 3). However, unstable carbon also negatively correlated with soil pH under excavator skidding system (Table 3).

Table 1: Selected soil physical and chemical properties of a tropical peat swamp forest under different skidding systems

	Mean	
Variable	Kuda	Excavator
Bulk density (g cm^{-3})	0.160[a]	0.180[a]
Soil acidity (pH)	3.552[a]	3.845[b]
SOM (%)	97.603[a]	96.444[b]
C (%)	48.802[a]	48.222[b]
N (%)	0.914[a]	1.357[b]
P (%)	0.024[a]	0.036[b]
C/N ratio	55.236[a]	39.700[b]
C/P ratio	2346.345[a]	1774.046[a]
Humic acid yield (g)	1.300[a]	1.293[a]

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

Table 2: Carbon storage of a tropical peat swamp forest under different skidding systems

	Mean (Mg ha^{-1})	
Variable	Kuda	Excavator
Unstable C	117.124[a]	130.200[b]
Stable C	62.402[a]	69.827[a]

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

Table 3: Correlation between unstable C, stable C and some selected chemical properties of peat swamp forest under different skidding systems

Variable	pH	SOM	C	P	C/N ratio	Unstable C	Stable C
Kuda							
pH							
SOM			1.0000		0.6200	1.0000	
			<0.0001		0.0049	<0.0001	
C					0.6200	1.0000	
					0.0049	<0.0001	
N		-0.6500	-0.6500	0.4800	-0.9800	-0.6500	
		0.0024	0.0024	0.0385	<.0001	0.0024	
P	0.5800	-0.7200	-0.7200		-0.4800	-0.7200	
	0.0086	0.0005	0.0005		0.0367	0.0005	
C/P ratio	-0.4900	0.5700	0.5700	-0.9200		0.5700	
	0.0319	0.0110	0.0110	<0.0001		0.0110	
C/N ratio						0.6200	
						0.0049	
Humic acid							1.0000
							<0.0001
Stable C							
Excavator							
pH		-0.6300	-0.6300			-0.63000	
		0.0035	0.0035			0.00350	
SOM			1.0000			1.00000	
			<.0001			<0.00010	
C						10.00000	
						<0.00010	
N					-0.8800		
					<0.0001		
P							
C/P ratio				-0.7600			
				0.0002			
C/N ratio							
Humic acid		0.5100	0.5100			0.5100	1.0000
		0.0268	0.0268			0.0268	<0.0001
Stable C		0.5100	0.5100			0.5100	
		0.0268	0.0268			0.0268	

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

DISCUSSION

The high bulk density found under excavator skidding system was because of the use of heavy machinery. However, the bulk density of the two systems were statistically similar (Table 1).

The low soil pH for the kuda-kuda skidding system (Table 1) could be due to production of CO_2 in soil air by root and microbial decomposition of soil organic matter[7]. As its soil organic matter availability was higher compared with excavator skidding system, thus indicating proper peat decomposition. Obviously, it was found that under excavator skidding system, soil pH negatively correlated with soil organic matter (Table 3). It suggests that the decline of soil organic matter increases soil pH and vice versa. This was because organic matter is a source of H^+ ions and contributes to soil acidification[7]. Under excavator skidding system, there was more organic matter decomposition and low carbon content (Table 1). This process leads to more CO_2 evolution[11]. The soil pH also negatively correlated with total carbon under excavator skidding system (Table 3). This is because; in peat soils large amounts of carbon accumulate as soil organic matter[7]. Hence, soil pH has association with total carbon as well as with soil organic matter. In both sites, total carbon positively correlated with soil organic matter (Table 3) also indicating that carbon accumulates as soil organic matter. The association between total carbon and soil organic matter seems not to be influenced by skidding systems. Excavator skidding system causing low total carbon as well as low soil organic matter, while under kuda-kuda skidding system, the high total carbon resulting in high soil organic matter (Table 1).

Under excavator skidding system, the C/N ratio decreased as nitrogen increased (Table 1) and this was because of increased decomposition[12]. This low C/N ratio markedly accelerates the decomposition process and causing organic matter loss. Inversely, a higher C/N ratio of kuda-kuda skidding system (Table 1) suggests a lower decomposition rate. Under kuda-kuda skidding system; soil organic matter, total carbon and unstable carbon were found to be negatively correlated with nitrogen but positively correlated with

C/N ratio (Table 3). A further indication that the lower nitrogen and higher C/N ratio under kuda-kuda skidding system (Table 1) seems to slow decomposition process and enabled soil organic matter to accumulate as well as total carbon (Table 1). Furthermore, it was found that the skidding systems did not alter stable carbon (Table 2). Stable carbon refers to long term carbon which is sequestered in the soil[7]. However, it seems to alter unstable carbon availability (Table 2). Though unstable carbon stock under excavator skidding system was found to be higher compared with kuda-kuda skidding system (Table 2), under kuda-kuda skidding system, unstable carbon stock seemed to be preserved better and this was because of the better carbon storage. Although stable carbon contents of the two systems were similar, the excavator skidding system had faster decomposition processes, thus unstable carbon stocks decomposed more and this probably affects its function as carbon storage for further periods. Total phosphorus positively correlated with nitrogen but negatively correlated with C/N ratio under kuda-kuda skidding system (Table 3). A further indication that under kuda-kuda skidding system, low nitrogen results in high C/N ratio and this may have affected phosphorus (Table 1), thus enabled organic material to accumulate instead of losses through decomposition process. It can be explained that the low phosphorus or high C/P ratio under kuda-kuda skidding system resulted in decreased soil pH, thus enabled soil organic matter and total carbon to accumulate as well as unstable carbon stocks (Table 1 and Table 3). Nitrogen was found to be fluctuating instead of carbon, thus affected the C/N ratio level in both sites (Table 3).

Total phosphorus was found to be higher under excavator skidding system compared with under kuda-kuda skidding system (Table 1). The association between total phosphorus and C/P ratio under kuda-kuda skidding system was prominent compared the same association under excavator skidding system (Table 3). Thus, the difference in C/P ratio under the excavator skidding system was found to be ambiguous compared with the C/P ratio of kuda-kuda skidding system (Table 1) because this high phosphorus fluctuation under excavator skidding system was imbalance with the low total carbon fluctuation when compared with the kuda-kuda skidding system. This difference of C/P ratio between excavator and kuda-kuda sites were not significant because of the high variability at each site. However, it suggests a tendency that low C/P ratio of the excavator skidding system to increase the decomposition process.

Unstable carbon is derived from accumulation of soil organic matter as well as total carbon in both sites (Table 3). Soil acidity has a role in controlling the availability of unstable carbon under excavator skidding system (Table 3). The accumulation of unstable carbon occurs if soil pH declines and vice versa. However, higher soil pH of the excavator skidding system compared with kuda-kuda skidding system (Table 1) seems to accelerate unstable carbon losses instead of accumulated.

It was found that stable carbon associated with humic acid in both sites (Table 3). It suggests that humic acids are extremely stable form of soil organic matter[13]. Moreover, large amounts of of stable carbon on earth is found as humic acids[2]. However, humic acid and stable carbon also positively associated with soil organic matter, total carbon and unstable carbon under excavator skidding system (Table 3). It means that under excavator skidding system, unstable carbon stocks in the soil organic matter tends to decompose and the remaining becomes stable carbon through humification processes.

CONCLUSION

Any disturbances with the application of skidding systems in this peat swamp forest possibly alter their carbon storage through altering their natural processes, particularly their decomposition rates. The skidding systems alter the unstable carbon availability.

The kuda-kuda skidding system is environmentally friendly. This skidding system is able to maintain decomposition process in this peat swamp forest properly and allow soil organic matter accumulation as well as total carbon. Hence, unstable carbon stocks can be preserved for further persistent breakdown processes, hence maintaining their function for carbon storage.

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