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Investigating the influence of rainfall on soil carbon quantity in a Tropical Peatland

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Abstract

Conversion of peat swamp forests to oil palm plantations has been a common practice in Southeast Asia in the face of oil palm boom. Soil carbon has been one of the numerous nutrients that are lost as a result of this practice. This work therefore attempts to study the influence of rainfall as one of the drivers of carbon loss in the peatlands. Four different sites were selected for the study which considered both dry and wet seasons. The results from the two seasons were analyzed and it was observed that soil carbon during the dry season was lower compared to the wet season's.

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Keywords: Peat swamp forest; Rainfall; Soil carbon; Tropical peatland; Southeast Asia

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1. Introduction

Immirzi et al.[1] and Strack [2] identified peatlands as terrestrial carbon pools and as links between soil carbon and atmospheric body. According to Immirzi et al.[1], peatlands possess the greatest extent in boreal and temperate zones by peatland area. Tropical peatlands, in the other hand, have been found to store large quantity of terrestrial carbon in both aboveground biomass and underlying thick deposit of peats (Rieley et al [3]; Page et al.[4]). These peatlands in the Southeastern part of the world are primarily coastally formed, developing behind mangroves where sulphides, water and anoxic conditions in peat water restrict bacterial activities, which leads to incomplete decomposition of plant debris and accumulation of organic matter as peat (Mutert et al.[5]; Jeffrey et al.[6]; Al-Ani et al.[7]).

In the past decades, many countries in Southeast Asia, like Indonesia and Malaysia, have converted most of their peatlands to either rubber or oil palm plantations as a result of boom recorded in the industries which made the available lands insufficient (Barbier [8]; Lee et al.[9]). This massive conversion of peat swamp forests (PSFs) did not come without its own negative effects as most of the peatlands that were known to be carbon sinks suddenly became carbon sources due to the indiscriminate felling of trees, fossil fuel burning and land tillage in the regions. Loss of biodiversity (Savilaakso et al.[10]), gully erosion (Evans et al.[11]), and loss of soil carbon, methane and other greenhouse gases (GHGs) to the atmosphere (Kurnianto et al.[12]) have been ranked among the major ecological consequences related to PSFs conversion to oil palm plantations. Thang and Chappell [13] also recorded that “greater mechanization within agriculture or urban development has magnified the detrimental impacts on the environment, as well as magnified the positive social effects”.

But the major area of concentration in recent time has been on the drivers of soil carbon loss within the peatland which has necessitated the need to assess the present soil carbon level for the appraisal of peatlands contribution to climate change. Various studies have identified soil characteristics like soil pH, soil texture, soil temperature (Chimner [14]), climate, (rainfall fluctuation and surface temperature, Satrio et al. [15]), groundwater level (Jauhianen et al.[16]) and management practices (Davis et al. [17]; Hooijer et al.[18]; Hooijer et al.[19]; Turetsky et al. [20]) as factors that can alter the amount of soil carbon.

This study therefore determines the influence of rainfall on the soil carbon sequestration within the peatland. The two major seasons with distinct rainfall patterns in the region were considered and we thus hypothesize that (i) rainfall distribution in the region influences the soil carbon storage and (ii), irrespective of rainfall patterns, soil carbon quantity changes with depth, and (iii) there is a significant relationship between soil moisture and soil carbon.

2. Materials and methods

Soil sampling was conducted in two different seasons (dry and wet) in May 2013 and October 2014 on four different times when the oil palm plantations were planted i.e. 2000, 2002, 2006 and 2010 (the years the peat swamp forests were converted to oil palm plantation). Soil sampling was done at three different depths of 0.5 m, 1.5 m and 2.5 m for dry season and 0.5 m and 1.5 m for wet season. Samples could not be collected at 2.5 m depth during the wet season as the soil was completely saturated at 2.5 m making it difficult to get soil samples out at that depth. The study sites are located at Kuala Langat South Forest Reserve area between latitude 02^{o} 43’N and longitude 101^{o} 39’E. The mean rainfall in May 2013 was 1.29 mm day^{-1} while in October, 2014, it was 9.06 mm day^{-1}.

A CNS-2000 automated elemental analyzer (LECO Corporation, St Joseph, Michigan, USA) was used to determine Carbon, Nitrogen, and Sulphur. The soil pH was determined by the potentiometric method (Brady and Weil [21]). Total phosphorus was determined by Aqua Regia method and laboratory method using Murphy and Riley [22]). Humic acid extraction was carried out by the methods of Stevenson [23] and Susilawati et al. [24]. Paired T-test was used in comparing between paired means of soil carbon storage of two different seasons. Correlation analysis was used to determine the correlation between the variables (Soil carbon, soil moisture, C/N ratio, and soil depth. These analyses were conducted using the IBM SPSS Statistics, version 21 (IBM SPSS Inc, Armonk, NY).

3. Results and discussion

Summary of the analysis conducted on soil samples is as shown in Tables 1 and 2. They presented the parameters' values recorded at different depth per each 'Age of oil palm within the plantation' during the dry and wet seasons respectively. For the two seasons considered, the correlation analysis was used in checking the relationships among the parameters (Tables 3 and 4).

Table 1. Results of Physical and Chemical properties of soil samples with mean and standard error of means for Dry season

YEAR	DEPTH (m)	pH	Mois. Content.%	Carbon %	Nitrogen %	Sulfur
2000	**0.5**	3.58 ±0.03	343.15±24.19	49.070 ± 2.16	1.20 ± 0.05	0.172 ± 0.01
	1.5	3.64 ± 0.02	506.34±80.80	45.97 ± 1.42	1.24 ± 0.04	0.136 ± 0.01
	2.5	3.79 ± 0.02	662.36±93.45	43.31 ± 1.32	1.93 ± 0.01	0.184 ± 0.001
2002	**0.5**	3.12 ± 0.01	371.65 ± 3.044	46.94 ± 0.66	1.30 ± 0.02	0.128 ± 0.003
	1.5	3.24 ±0.02	380.08± 28.61	26.124 ± 0.24	0.65 ± 0.02	0.070 ± 0.002
	2.5	3.27 ± 0.01	366.55 ± 8.65	12.11 ± 0.16	1.15 ± 0.41	0.126 ± 0.001
2006	**0.5**	3.16 ± 0.01	381.46 ± 9.13	40.292 ± 1.22	1.05 ± 0.04	0.167 ± 0.014
	1.5	3.23 ± 0.01	378.56 ± 7.53	21.60 ± 0.59	0.34 ± 0.01	0.039 ± 0.002
	2.5	3.31 ± 0.01	209.39 ± 3.04	24.687 ± 0.56	0.65 ± 0.05	0.102 ± 0.017
2010	**0.5**	3.64 ± 0.05	248.59 ± 10.94	32.87 ± 0.18	1.30±0.028	0.171 ± 0.001
	1.5	3.74 ± 0.04	159.13 ± 3.99	49.54 ± 0.58	0.60 ± 0.01	0.118 ± 0.047
	2.5	3.82 ± 0.04	129.83 ± 2.35	11.66 ± 0.33	0.235±0.008	0.391 ± 0.07

Table 2. Results of Physical and Chemical properties of soil samples with mean and standard error of means for Wet season

YEAR	DEPTH (m)	pH	Mois. Content.%	Carbon %	Nitrogen %	Sulfur (%)
2000	**0.5**	3.12 ±0.03	221.21 ± 11.88	51.05 ± 0.29	1.43 ± 0.06	0.12 ± 0.01
	1.5	3.15 ± 0.01	516.89 ± 23.90	51.76 ± 0.49	1.22 ± 0.01	0.22 ± 0.01
2002	**0.5**	2.82 ± 0.05	300.37 ± 7.51	48.97 ± 0.10	1.29 ± 0.01	0.09 ± 0.01
	1.5	3.24 ± 0.03	455.63 ± 2.01	37.04 ± 3.33	1.13 ± 0.04	0.05 ± 0.01
2006	**0.5**	3.17 ± 0.01	321.977 ± 2.44	51.04 ± 0.36	1.33 ± 0.05	0.09 ± 0.01
	1.5	3.19 ± 0.01	656.91 ± 97.22	46.85 ± 1.82	1.03 ± 0.11	0.13 ± 0.02
2010	**0.5**	3.39 ± 0.02	214.16 ± 3.49	39.46 ± 0.09	1.25 ± 0.06	0.12 ± 0.01
	1.5	3.43 ± 0.04	425.01 ± 6.78	47.65 ± 0.09	1.25 ± 0.01	0.15 ± 0.004

Figures 1 a&b show the soil carbon content as recorded during the dry and wet periods. The higher soil carbon content was recorded during the wet season at all depths in consideration compared to the values obtained during the dry season. Also, oil palm plantation cultivated in the Year 2000 for dry season has the highest soil carbon content of 49.07 % as against the highest value recorded during the wet season as 51.76 % at the same plantation at 1.5 m depth. The lowest soil carbon content recorded during the dry season analysis was 11.65 % which was observed in 2010 plantation at 2.5 m depth as against the lowest in wet season (37.04 %) which was obtained at 2002 plantation at 1.5 m depth. In other words, soil organic carbon declines with soil depth as shown in Table 1 (Fierer et al., [25]; Eilers et al., [26]). The difference in soil carbon content along the depth could be attributed to the fundamental difference in microbial activities between the soil surface and deep layers (Blume et al., [27]). Soil carbon and nitrogen are significantly correlated in dry season (Table 1) compared to no significance that existed between them during the wet season (Table 2).

(a). (b).

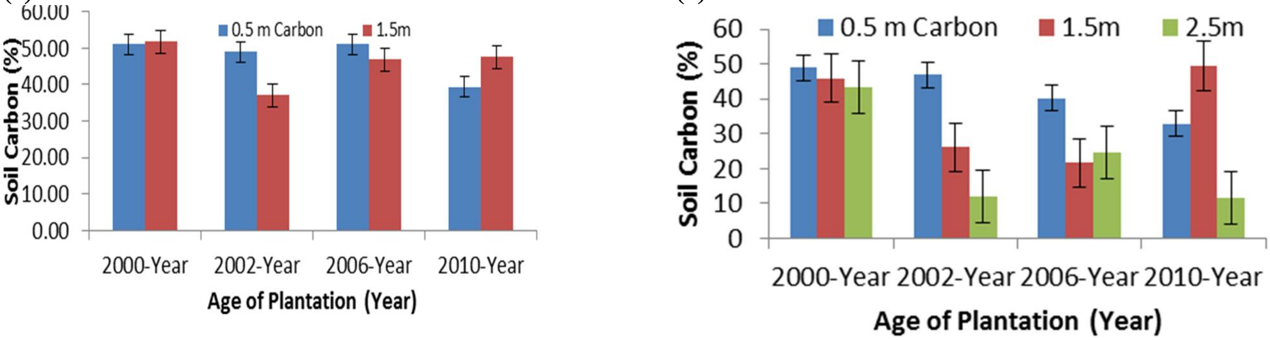

Fig. 1.**(a)** Soil carbon variation with age of plantation and soil depth (Wet season)- with error bars; **(b)** Soil carbon variation with age of plantation and soil depth (Dry season)

Table 3. Correlation between soil C, soil pH, soil moisture and some selected chemical properties of a peatland for dry season

		CARBON	NITROGEN	SULPHUR	CAR_NITRO	Ph	MOISTURE
CARBON	Pearson Correlation	1	.517**	-.140	.206*	.160	.235*
	Sig. (2-tailed)		.000	.174	.044	.120	.021
NITROGEN	Pearson Correlation	.517**	1	-.035	-.667**	.128	.597**
	Sig. (2-tailed)	.000		.738	.000	.215	.000
SULPHUR	Pearson Correlation	-.140	-.035	1	-.107	.420**	-.189
	Sig. (2-tailed)	.174	.738		.300	.000	.065
CAR_NITRO	Pearson Correlation	.206*	-.667**	-.107	1	.139	-.399**
	Sig. (2-tailed)	.044	.000	.300		.177	.000
pH	Pearson Correlation	.160	.128	.420**	.139	1	-.054
	Sig. (2-tailed)	.120	.215	.000	.177		.600
WATERCONT	Pearson Correlation	.235*	.597**	-.189	-.399**	-.054	1
	Sig. (2-tailed)	.021	.000	.065	.000	.600	

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

As shown in Table 3, soil carbon correlated positively with soil moisture during the dry season with no correlation during the wet season as against soil nitrogen which showed the exact opposite. During the dry season, soil pH showed no correlation with soil carbon, moisture and soil nitrogen except with sulphur. However, as shown in Table 4, soil pH was negatively and significantly correlated with both soil carbon and C/N during the wet season which could be attributed to the accumulation of the large amount of carbon as organic matter at the expense of soil nitrogen (Satrio et al., [15]). This also suggests that during the wet season the decline in soil organic matter with depth increases the soil pH or alkalinity and vice versa which was not obtainable during the dry season. Since organic matter is a source of H+ ions, the decrease in soil carbon will mean further reduction in the soil acidity with depth as evident in higher pH values recorded with depth. Highest soil carbon was recorded in the 2000-Year study plot followed by 2002-Year study plot as compared to other study plots in both seasons with the lowest soil carbon recorded in 2000-Year study plot and attributed to long period of oil palm cultivation. 2000-Year study plot was the first peat swamp forest to be converted to oil palm plantations in 1978 before further cultivation was made in the year 2000. This means oil palm cultivation contributed to the soil carbon loss in the study plots as a result of diverse anthropogenic activities associated with sustainable oil palm production.

Table 4. Correlation between soil C, soil pH, soil moisture and some selected chemical properties of a peatland for wet season

		CARBON	NITROGEN	SULPHUR	CAR_NITROGEN	pH	WATERCONT
CARBON	Pearson Correlation	1	.269	.415*	.468**	-.531**	-.097
	Sig. (2-tailed)		.137	.018	.007	.002	.596
NITROGEN	Pearson Correlation	.269	1	.051	-.704**	.115	-.596**
	Sig. (2-tailed)	.137		.781	.000	.532	.000
SULPHUR	Pearson Correlation	.415*	.051	1	.246	.070	-.028
	Sig. (2-tailed)	.018	.781		.175	.703	.881
CAR_NITROGEN	Pearson Correlation	.468**	-.704**	.246	1	-.463**	.500**
	Sig. (2-tailed)	.007	.000	.175		.008	.004
pH	Pearson Correlation	-.531**	.115	.070	-.463**	1	.043
	Sig. (2-tailed)	.002	.532	.703	.008		.815
WATERCONT	Pearson Correlation	-.097	-.596**	-.028	.500**	.043	1
	Sig. (2-tailed)	.596	.000	.881	.004	.815	

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

4. Conclusion

The resources and environmental gradients found within the soil profile coupled with higher storm events was responsible for high soil carbon storage which is as a result of change in microbial community composition with soil depth. As soil moisture and soil pH become less variable within the soil, the quantity and quality of soil carbon substrates keep declining with depth, particularly during the dry season. The higher contents of soil carbon at the root zones could be attributed to the inputs of root exudates, dead surface litter, and root left overs upon decay (root detritus). As a result of this, the amount of carbon stored at the surface (0-50 cm) is higher compared to the immediate layers below the root zones. Reduction in soil carbon content during the dry season could mean large quantity of it are being lost as CO_2 due to peat oxidation making the peatlands a carbon source rather than a sink of carbon.

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References

[1] Immirzi CP, Maltby E, Clymo RS The global status of peatlands and their role in carbon cycling. A report for Friends of the Earth by the Wetlands Ecosystems Research Group, Department of Geography, University of Exeter, UK. *Friends of the Earth*, London; 1992.

[2] Strack M, (Ed). Peatlands and Climate Change. *International Peat Society*, Jyva¨skyla¨ 2008, Finland.

[3] Rieley, JO, Wüst RA, J., Jauhiainen J. Tropical peatlands: carbon stores, carbon gas emissions and contribution to climate change processes. In: M. Strack (Ed.) Peatlands and Climate Change; 2008, pp. 148-181, *International Peat Society*, Jyväskylä, Finland.

[4] Page SE, Rieley JO, Banks, CJ. Global and regional importance of the tropical peatland carbon pool. *Global Change Biology*; 2011, *17*, 798-818

[5] Mutert E, TH, Fairhurst HR. von Uexküll. Agronomic Management of Oil Palms on Deep Peat. *Better Crops International Journals*; 1999, Vol. 13, No. 1. p. 36-38
[6] Jeffrey L, Norzaimawati A, Rosnah H. Prescreening of bioactivities from actinomycetes isolated from forest peat soil of Sarawak. *J. Trop. Agric. and Fd. Sc*.; 2011, 39, 245-253
[7] Al-Ani H, Oh E, Chai G. Characteristics of embedded peat in coastal environments. *International Journal of Geo-mate*; 2013, *5*, 609-618
[8] Barbier EB. Scarcity, frontiers and development. *The Geographical Journal*; 2012, *178*, 110-122
[9] Lee JSH, Abood S, Ghazoul J, Barus B, Obidzinski K., Koh LP. Environmental Impacts of Large-Scale Oil Palm Enterprises Exceed that of Smallholdings in Indonesia. *Conservation letters*; 2014, *7*, 25-33
[10] Savilaakso S, Laumonier Y, Guariguata MR, Nasi R. Does production of oil palm, soybean, or jatropha change biodiversity and ecosystem functions in tropical forests. *Environmental Evidence*; 2013, 2, 17
[11] Evans M., Stimson A, Allott T, Holland N. Impacts of peatland restoration on dissolved carbon loss from eroded upland peatlands in the UK. *In, EGU General Assembly Conference Abstracts*; 2012, (p. 2939)
[12] Kurnianto S, Warren M, Talbot J, Kauffman B, Murdiyarso D. Frolking, S. Carbon accumulation of tropical peatlands over millennia: a modeling approach. *Global Change Biology*; 2015, 21, 431-444
[13] Thang H, Chappell N. 36 Minimising the hydrological impact of forest harvesting in Malaysia's rain forests; 2005.
[14] Chimner RA. Soil respiration rates of tropical peatlands in Micronesia and Hawaii. *Wetlands*; 2004, 24: 51-56. DOI: 10.1672/0277-5212(2004)024[0051:SRROTP]2.0. CO;2
[15] Satrio AE, Gandaseca S, Ahmed OH, Majid NM. Effect of precipitation fluctuation on soil carbon storage of a tropical peat swamp forest. *American Journal of Applied Sciences*; 2009, 6, 1484
[16] Jauhiainen J, Takahashi H, Heikkinen JE, Martikainen PJ, Vasander H. (2005). Carbon fluxes from a tropical peat swamp forest floor. *Global Change Biology*; 2005, *11*(10), 1788-1797.
[17] Davis SC, Boddey RM, Alves BJ, Cowie AL, George BH, Ogle SM, Smith P, Noordwijk M, Wijk MT. Management swing potential for bioenergy crops. *GCB Bioenergy*; 2013, 5, 623-638
[18] Hooijer A, Page S, Canadell J, Silvius M, Kwadijk J, Wosten H, Jauhiainen J. Current and future CO; 2009.
[19] Hooijer A, Page S, Jauhiainen J, Lee W, Lu X. Recent findings on subsidence and carbon loss in tropical peatlands: reducing uncertainties. In, *Workshop on 'Tropical Ecosystems of Indonesia: Science Needs to Address Climate Change Adaptation and Mitigation'. 2011, Bali, 11-14 April 2011*
[20] Turetsky MR, Kane ES, Harden JW, Ottmar RD, Manies K.L, Hoy E, Kasischke ES. Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. Nature Geoscience; 2011, **4**, 27-31
[21] Brady NC, Weil RR. The Nature and Properties of Soils. 13th Edn., Pearson Education, Inc., New Jersey, ISBN: 0130167630, 2002, pp: 498-540.
[22] Murphy J, Riley PJ. A modified single solution method for the determination of phosphate in natural waters. *Analitica. Chemica. Acta.*; 1962, 27: 31-36. DOI: 10.1016/S0003-2670(00)88444-5
[23] Stevenson FJ. Humus Chemistry: Genesis, Composition, Reactions. 2nd Edn., John Wiley and Sons, New York, ISBN: 0471594741, 1994, pp: 24-58.
[24] Susilawati K. Ahmed OH, Nik Muhamad AB Khanif MY. Simple method of purifying humic acids isolated from tropical hemists (peat soil). *Am. J. Applied Sci.*; 2008, 5: 1812-1815. http://www.scipub.org/fulltext/ajas/ajas5121812-18 15.pdf
[25] Fierer, N., Schimel, J.P., and Holden, P.A. (2003). Variations in microbial community composition through two soil depth profiles. *Soil Biology and Biochemistry, 35*, 167-176
[26] Eilers, K.G., Debenport, S., Anderson, S., and Fierer, N. (2012). Digging deeper to find unique microbial communities: the strong effect of depth on the structure of bacterial and archaeal communities in soil. *Soil Biology and Biochemistry, 50*, 58-65
[27] Blume E, Bischoff M, Reichert JM, Moorman T, Konopka A, Turco RF (2002). Surface and subsurface microbial biomass, community structure and metabolic activity as a function of soil depth and season. Appl Soil Ecol 20:171–181