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CARBON DIOXIDE AND METHANE EMISSION FROM COMPACTED TROPICAL PEAT SOIL

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By

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CARBON DIOXIDE AND METHANE EMISSION FROM COMPACTED TROPICAL PEAT SOIL

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Chair : Prof. Che Fauziah Ishak', PhD
Faculty : Agriculture

Tropical peatland stores a large amount of carbon (C) and is an important C sink. In Malaysia, 25% of the peatland area has been converted to oil palm plantation where drainage, compaction and groundwater table control are pre-requisite. To date, relationship between land compaction and C emission from tropical peatland is limited. To understand the effect of compaction on soil C emission from tropical peatland, a laboratory soil column incubation study was conducted. Peat soil used in this study was classified as hemist and collected from a Mixed Peat Swamp forest. Soil were then packed and compacted in columns made of polyvinyl chloride (PVC) pipes to three different soil bulk densities (BD); 0.14, 0.18 and 0.22 g cm^{-3}. Soil CO_2 flux, CH_4 flux, DOC concentration and soil redox potential (E_h) from the soil columns were measured weekly for 12 weeks. Total soil porosity and moisture retention of each soil BD at field capacity were also determined using another set of peat sample packed into 100 cm^3 soil core ring. Field measurement of soil CO_2 flux and CH_4 flux at oil palm plantation, where the soil BD ranges from 0.20 to 0.24 g cm^{-3} were also monitored for one year for comparison and validation against the soil column approach using result from BD 0.22 g cm^{-3}. Soil porosity decreased while moisture retention increased proportionally with increasing soil BD. Total porosity was greater for BD 0.14 (91%), followed by BD 0.18 (87%) and BD 0.22 (83%). In contrast, volumetric moisture content at field capacity were greater at soil BD 0.22 (80%), followed by 0.18 (74%) and 0.14 (64%). Results from soil column incubation showed that soil CO_2 fluxes were greater for compacted peat and tend to increase when water infiltration become slower with time, until when the soil is at or near the saturation point, soil water content becomes a limiting factor for soil CO_2 fluxes. On contrary, CH_4 fluxes were not affected by the changes in water infiltration

rates and compaction reduced soil CH_4 fluxes by about 22%. Total CH_4 flux for 12 weeks incubation was highest at soil BD 0.14 (461 mg C m^{-2}) followed by BD 0.22 (363 mg C m^{-2}) and BD 0.18 (360 mg C m^{-2}). Total DOC concentration also significantly higher by almost two times at soil BD 0.14 (8588 mg L^{-1}) compared to soil compacted to BD 0.18 (4912 mg L^{-1}) and BD 0.22 (4930 mg L^{-1}). Soil E_h which act as indirect indicator for the oxygenation status, shows no significant correlations with both CO_2 flux (r=0.16–0.45) and CH_4 flux (r=0.01–0.24). This study indicated that the modification of physical properties (like soil porosity and moisture retention) after compaction affects the water movement and gaseous transport in the soil profile, thus influences the C emission from peat soil. However, further improvement on the experimental soil column set-up are required as comparison with *in-situ* field monitoring showed that CO_2 fluxes from soil column incubation were slightly smaller than the field measurement.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

EMISI KARBON DIOKSIDA DAN METHANA DARI TANAH GAMBUT TROPIKA YANG DIPADATKAN

Oleh

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Tanah gambut tropika menyimpan sejumlah besar karbon (C) dan merupakan penstoran C penting. Di Malaysia, 25% daripada kawasan tanah gambut telah ditukar kepada ladang kelapa sawit di mana kawalan saliran, pemadatan dan kawalan air bawah tanah (GWT) adalah prasyarat. Sehingga kini, hubungan antara pemadatan tanah dan pelepasan C dari tanah gambut tropika telah jarang dikaji. Untuk memahami kesan pemadatan tanah ke atas pelepasan C dari tanah gambut tropika, kajian inkubasi kolum tanah telah dijalankan di makmal. Tanah gambut yang dikategorikan sebagi hemik telah diambil dari Paya Campuran Gambut (Mixed Peat Swamp). Tanah tersebut telah dipadatkan didalam paip polyvinyl chloride (PVC) kepada tiga ketumpatan pukal tanah (BD) yang berlainan; 0.14, 0.18 dan 0.22 g cm^{-3}. Fluks CO_2 tanah, fluks CH_4, kepekatan DOC dan potensi redoks tanah (E_h) dari kolum tanah diukur setiap minggu selama 12 minggu. Jumlah keliangan tanah dan pengekalan kelembapan setiap BD tanah juga ditentukan menggunakan satu lagi sampel gambut yang disampel menggunakan bekas teras tanah berisipadu 100 cm^3. Pengukuran lapangan di ladang kelapa sawit, di mana tanah BD berkisar antara 0.20 hingga 0.24 g cm^{-3} dipantau selama satu tahun untuk perbandingan dan pengesahan keputusan kajian kolum tanah dari BD 0.22 g cm^{-3}. Pori keliangan tanah berkurangan sementara pengekalan kelembapan tanah meningkat secara berkadaran dengan peningkatan BD tanah. Pori keliangan tanah lebih besar di tanah BD 0.14 (91%), diikuti oleh BD 0.18 (87%) dan BD 0.22 (83%). Sebaliknya, kelembapan tanah di keupayaan medan lebih besar di tanah BD 0.22 (80%), diikuti oleh 0.18 (74%) dan 0.14 (,64%). Hasil daripada percubaan inkubasi kolum tanah menunjukkan bahawa fluks CO_2 tanah lebih tinggi pada gambut yang dipadatkan dan cenderung meningkat apabila penyusupan air menjadi lebih perlahan dengan masa, sehingga ketika tanah berada di tahap atau hampir pada titik tepu, kandungan air tanah menjadi faktor pembatas untuk fluks CO_2 tanah. Sebaliknya, fluks CH_4 tidak terjejas oleh perubahan kadar penyusupan air dan pemadatan mengurangkan fluks CH_4 sekitar 22%. Jumlah fluks CH_4 selama 12

minggu inkubasi adalah tertinggi di tanah BD 0.14 (461 mg C m^{-2}) diikuti oleh BD 0.22 (363 mg m^{-2}) dan 0.18 (360 mg C m^{-2}). Jumlah kepekatan DOC juga lebih tinggi dengan hampir dua kali ganda pada tanah BD 0.14 (8588 mg L^{-1}) berbanding dengan tanah yang dipadatkan kepada BD 0.18 (4912 mg L^{-1}) dan BD 0.22 (4930 mg L^{-1}). E_h tanah yang secara tidak langsung berfungsi sebagai penentu status oxygen tidak menunjukkan hubung kait yang ketara dengan fluks CO_2 (r=0.16–0.45) dan fluks CH_4 (r=0.01–0.24). Kajian ini menunjukkan bahawa pengubahsuaian sifat-sifat fizikal (seperti keliangan tanah dan pengekalan kelembapan) selepas pemadatan memberi kesan kepada pergerakan air dan pengangkutan gas dalam profil tanah sehingga mempengaruhi pelepasan C dari tanah gambut. Walau bagaimanapun, kajian ini memerlukan penambahbaikan lanjut pada lajur tanah eksperimen yang dibentuk disebabkan perbandingan dengan pemantauan di lapangan menunjukkan bahawa fluks CO_2 dari inkubasi kolum tanah sedikit lebih rendah daripada pengukuran lapangan.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Tropical peatland stores a large amount of carbon (C) and is an important C sink. The largest area of tropical peatland (56%) is in Southeast Asia (Page et al., 2011), most of which are located in Indonesia, Malaysia, Brunei, and Thailand (Joosten, 2009; Posa et al., 2011). In Malaysia, peatland cover an area about 2.6 million hectares (Mutallib et al., 1992) of which Sarawak support the largest area (69.1%) followed by Peninsular Malaysia (26.1%) and Sabah (4.76%). In their natural state, peat soil is regarded as a problematic soil mainly due to its physical and chemical properties, making the cultivation of agricultural crops difficult (Andriesse, 1988; Melling et al., 2008). Among the physical and chemical properties of peat are high ground water table, high porosity, low bulk density and bearing capacity, high acidity and low fertility.

Peatlands in Malaysia were largely undeveloped until the 1980s (Meittinen et al., 2016). In Malaysia, large-scale utilization of peatland for agriculture was initiated in 1983 by cultivating pineapple, followed by planting of rubber and oil palm (Md.Sharif et al., 1986). Unlike pineapple which thrives well on peat, rubber and oil palm experienced low yields during the initial years of planting on peat, due to weak root anchorage, and poor nutrient retention in soil. These problems occurred due to insufficient knowledge on the structure and hydrology of peatlands. With rapid progression of peat research, development of proper peatland management strategy to maximize the crop production on peatlands has been made possible. The industrial plantation on tropical peatland in both Malaysia and Indonesia are dominated by a large-scale oil palm and pulp wood plantation. Over the past two decades, approximately 25% of peatlands area in Malaysia which is mostly concentrated in Sarawak has been converted to agriculture, most notably for oil palm plantation (Padfield et al., 2015). Page et al. (2011) estimated the area of oil palm on peat in Malaysia have increased from 0.38 Mha in 2000 to 0.53 Mha in 2010.

The oil palm industry is the fourth largest contributor to the Malaysian economy. In 2011, the oil palm industry contributed RM 80.3 billion worth of export earnings which is equivalent to 61.8% of the overall export value of all commodities in Malaysia (Kamalrudin and Ramli, 2014). The oil palm industry has been a major contributor to Malaysia's export earnings and acts as a great booster in promoting socio-economic development, eradicating poverty and providing direct employment (Teoh, 2000; ETP, 2012; Alam et al., 2015). Oil palm has become the most important and economic security crop in Malaysia. Although cultivation of oil palms on tropical peatland has brought economic and social benefits to the country, it has also attracted global attention as cause of global warming and climate change. Currently, the main and on-going debate concerning plantation agriculture in tropical peatlands is the impact of the conversion on the stability of the large amount carbon stored and its potential emission to the atmosphere (Hooijer et al., 2010; Murdiyaso et al., 2010).

1.2 Justification of Study

High amount of carbon (C) stored in the tropical peatland is a result of a combination of simultaneous organic matter input from above ground vegetation and slow but progressive decomposition of organic matter under waterlogged, anaerobic condition. Cultivation of oil palm on peat requires drainage, which lowers the water level typically to a depth of 50-70 cm, to improve the oil palm growth. Lowering of water level also creates aerated zone, thus increase peat oxidation and promotes soil organic matter decomposition resulting in the large C losses from peat. Following drainage, common practice is to perform mechanical compaction using heavy machinery before oil palm planting take place. Generally, mechanical compaction brings the soil particles closer together and reduces the larger pore size into smaller pore. This result in decrease in the total soil porosity, soil aeration, water infiltration rate and hydraulic conductivity while increase in soil bulk density, soil strength and volumetric water content (Pengthamkeerati et al., 2005; Nawaz et al., 2013).

Increase in bulk density of peat soil provides better anchorage of oil palm tree, reduces rate of fertilizer leaching, increase the nutrient supply and thus optimizes the plant growth and higher crops yield. In addition to the improvement of crop production, increases of water retention capacity due to greater proportion of small pores in compacted peat (Silins and Rothwell, 1998) is also hypothesized to counteract the changes in water and oxygen (O_2) contents initially induced by the peat drainage (Rothwell et al., 1996). Greater water retention ensures higher soil moisture content were maintained above the groundwater table (GWT), thereby affecting the soil C emission (Kluge et al., 2008; Iiyama et al., 2012). High soil moisture reduced the gases diffusion (i.e., O_2 and CO_2), since diffusion is approximately 10,000 slower in pore space filled with water than in air. The O2 availability in the soil has been associated with aerobic microbial activities that control the rate of SOM decomposition. Therefore, compaction is hypothesized to influence the dynamic of C emission from drained peatland through both soil moisture content and gas diffusivity.

However, knowledge on the effect of peat soil compaction towards C emission is extremely limited as most previous work had focused mainly on the impact of drainage in peat soil. In addition, most of the literatures on soil compaction are based on the work conducted on mineral soil. Therefore, considering the benefits of compaction to palm production and its possible reduction in soil C emission, more research is required in this area for the sustainable management of tropical peatlands. Soil C emission from peatland can be assessed using incubation experiment and field monitoring. Comparing with field monitoring, which is easily affected by environmental conditions, incubation experiment can provide controlled condition and thus may have an advantage to investigate the effect of compaction on soil C emission. However, in most study using incubation experiment, the results obtained are not directly transferrable to field scales. Utilization of both techniques is important for validation and comparison.

1.3 Objectives

The general objective of this study is to determine the effect of soil compaction on carbon (C) emission from tropical peatland. For this purpose, essentially the study involved these specific objectives:

1. To investigate the soil C emission from laboratory soil column study with three different soil bulk densities of 0.14 g cm^{-3}, 0.18 g cm^{-3} and 0.22 g cm^{-3} (Soil C emission is assessed in the form of CO_2 flux, CH_4 flux and dissolved organic carbon, DOC).

2. To investigate the relationship of soil CO_2 and CH_4 flux with oxygen availability in the soil column, using soil redox potential (E_h) data.

3. To compare CO_2 and CH_4 flux from soil column incubation with field flux data at oil palm plantation site, with soil bulk density of 0.22 g cm^{-3}.

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LIST OF PUBLICATIONS

Nur Azima Busman, Ishak, CF., Sulaiman, M.F., Maie, N. and Melling, L., 2018. Effect of soil compaction on soil CO_2 flux from tropical peatland. Proceedings of the 10th International Symposium on Plant-Soil Interaction Interactions at Low pH, 25-29 June 2018, Putrajaya, Malaysia, pp.124-125.

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