Greenhouse gas emission of agricultural inputs on peat soil at corporate and smallholder oil palm farmers

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Abstract Greenhouse gas emission rate in peat soil under oil palm plantation comes to attractive interest to control the environment. Revealing the indirect emission of the applied input of oil palm cultivation in peat soil in the area, would contribute on the improvement of the greenhouse gas emission data exposure. The objective of this study was to determine greenhouse gas emissions generated from the oil palm cultivation applied inputs. Field observation was conducted in Labuhan Batu, North Sumatra, Indonesia, in 2013-2014, at both corporate and smallholder farmers as well. CO₂-eq emission of the applied agricultural inputs was calculated by means of MILCA- JEMAI© application software. CO₂ equivalent emissions from applied inputs of corporate peatland oil palm plantation was calculated based on data in 2012 amounted to 1013.7 kg CO₂-eq ha⁻¹ year⁻¹. On smallholder farmers, it showed a 40 lower emission rate but with higher variability at 604 ± 238 kg CO₂-eq ha⁻¹ year⁻¹. At the oil palm corporate, inorganic fertilizer application contributed a higher emission rate, followed by fuel use and pesticide applications. CO₂-eq emission rate at smallholder farmers showed a similar pattern for inorganic fertilizer use. However, it showed higher emission from pesticide application rather than fuel use.

Keywords: carbon footprint, fertilizer efficiency, emission variability, carbon sequestration, peat soil culture

1. Introduction
Peat ecosystems are the highest source of carbon reserves and carbon absorbers, whereas the 19.8 million hectares in Indonesia [1] store 37 million tons of carbon reserves, so cultivating peatland requires more particular attention to suppressing carbon loss. This land-use causes changes in the value of carbon reserves and emissions caused by the cultivation process. Although there is evidence about the carbon regenerating process for storage as peat soil[2, 3], the degradation as an emission source is to be paid for particular attention. Most emission hotspots of peat soil for oil palm plantation are peat oxidation, including peat fire incidence[4, 5, 6], land clearing, fertilizer embodied emissions, and field emission[7]. The consideration of pesticide embodied emission level has generally not enough significant contribution due to the relatively lower application dosage in the field.
The emission of CO₂ gas in peat soil plays the most meaningful interest, which its emission rate in the field at 30º reached about 50-100 times higher than CH₄ [8]. The annual emission rate of CH₄ in the tropical peat, however, showed a very broad variability in value ranging from approximately 5-100 kg C-CH₄ ha⁻¹[9]. Environmental soil moisture status is a major consideration taken into the methane emission account [8]. The CO₂-emission also shows higher variability from year to year, wherein long term the CO₂ emission goes to lower rate measurements, where after 5 years of cultivation time, its CO₂ emission flux reaches at the ranging value of 24-41% compared to the first 5-year planting time[10]. It is also confirmed, the deeper peat soil emitted CO₂ approximately 2-4 times higher than the shallow peat soil [11]. The oil palm culture emission rate in peat soil generally ranged from 693-2000 kg C ha⁻¹ [12, 13]. Moreover, the carbon loss will be improved through the carbon regenerating process. including carbon sequestration in the peat soil, so that minor negative balance in peat soil year by year in dynamic trends values, in which there were also found that in a few years there was no negative emission balanced recorded [14]. The value of CO₂ soil flux could reach 2.8 tons C ha⁻¹ year⁻¹ at the high density of tree covers the area and only 1.6 tons C ha⁻¹ year⁻¹ at the lower density tree covers [15]. The emissions rate of nitrous oxide from the decomposition of peat soil could be much higher than the emission contributed by nitrogen fertilizer application due to soil moisture and water level control [16]. The emission rate of nitrous oxide in peat soil at oil palm culture was found in the value of 12.8-26.6 kg N₂O ha⁻¹ year⁻¹ [17, 18], which is equivalent to CO₂ emission in a rate of 1047-2176 kg C ha⁻¹ year⁻¹. High levels of nitrogen fertilizing enrich NH₄⁺ and NO₃⁻ content in the soil, which can increase N₂O emissions. The denitrification process involves anaerobic facultative bacteria, which are capable of using NO₃⁻ in the respiration process in low oxygen conditions or anaerobic conditions. To exemplify the carbon status in the oil palm cultivation in peat soil, the identification of carbon reserves in oil palm plantation is required to estimate the carbon balancing, so that estimation of sustainability of the oil palm plantation in the area could be better to evaluate.

Another contributor to the Greenhouse Gas Emission (GGE) of the oil palm culture in peat soil is the embodied emission sourced from applied agricultural inputs. In this study, the application of agricultural inputs material as fertilizer, pesticides, and fuel consumption will be observed and evaluated to justify the status of its contribution to emission from the oil palm culture. This study aimed to identify and compare the GGE of applied agricultural cultivation inputs in peatland in oil palm plantations at smallholder farmers and oil palm corporate.

2. Materials and methods

The research was conducted from September 2013 to March 2014 in the plantation owned by a corporate company and smallholder farmers in Labuhan Batu Regency, North Sumatra. This tropical peat soil showed an acidic characteristic and peat depth ranging 3.6-5.1 m. Higher variability values were found at the soil peat depth, surface water level, availability phosphate content, and ash content of the peat at 10-20 cm soil depth. The surface water variability drove the rate of peat soil subsidence, where the lower surface water level increased the subsidence acceleration rate [19]. The oil palm plants were 10-12 years old. Sampled smallholder farmers in this study commonly occupied an area ranging 2-10 hectares per individual located around the company’s plantation. The whole sampling area covered an extending radius of about 4 km. Local geographical information and main soil characteristics are presented in Table 1.

Besides, the assessment results of total carbon stock in the area were conducted to draw attention to the baseline circumstances related to the long-term carbon loss due to the emission. The carbon stock total in the peat soil depth of 150 cm was 1216-1276 tons ha⁻¹ and in the depth of 362-512 cm was 3416-4113 tons ha⁻¹ (Figure 1).
Table 1. Local geographical information and main soil characteristics.

| Descriptor               | Unit  | Value       |
|--------------------------|-------|-------------|
| Annual rainfall          | mm    | 2009        |
| Gradient slope           | %     | <3          |
| Altitude                 | m asl | ±12         |
| Peat depth               | cm    | 362-512     |
| Surface water level      | cm    | 10-45       |
| Soil pH                  | -     | 3.6-4.4     |
| C-org                    | %     | 51.2-52.8   |
| N-Total                  | %     | 1.4-1.5     |
| Available P (Bray 1)     | ppm   | 94.1-141.1  |
| Ash content in 10-20 cm soil depth | % | 5.9-12.9 |

Figure 1. The total peat soil carbon stock at the study location at the 150 cm and 362-512 cm soil depth.

After characterization of relevant local geographical information and main soil characteristics, the information about applied input data of the oil palm cultivation methods was collected. The data comprised applied fertilizer, pesticides, and fuel consumption until harvested in the field. Five groups of smallholder farmers categorized by plantation living settlement location were appointed for the data collection and observation.

Emissions of applied agricultural inputs were indirectly calculated using the Multiple Interface Life Cycle Assessment (MILCA) software of Japan Environmental Management Association for Industry (JEMAI) version 1.1.6 with IDEA database 1.2.6. The results of applied inputs and GGE rate were analyzed using the T-test.

3. Results and discussions

Applied inputs for the oil palm cultivation in the peat soil area showed the higher variability in the smallholder farmers, which some of them used no urea fertilizer. In case that the farmers used the urea fertilizer, the application dosage was higher up to 388% than the company application standard. The company applied urea fertilizer only 48 kg ha\(^{-1}\) year\(^{-1}\). However, the company applied complete fertilizer and other inputs, so that the kind of inputs at the company was generally much more integrated and diverse in mineral, ameliorants, pesticides, and fuel consumption. Nitrogen fertilizer as required macronutrients as the main source of agricultural field emission was confirmed.
[20, 21]. Hence the carbon footprint of the fertilizer showed an impressively higher value [22, 23]. However, the major contributor to field emission is mainly due to land-use conversion or land-use change [7]. The inventory data of applied inputs for oil palm cultivation in peat soil is presented in Table 2.

**Table 2.** The inventory data of applied inputs for oil palm cultivation in peat soil per year.

| Input                           | Unit     | Company | Farmer | Note |
|---------------------------------|----------|---------|--------|------|
| Empty Fruit Bunch (EFB)         | kg ha⁻¹  | 13949   | 14080  | ns   |
| Population                      | plant ha⁻¹| 143.0   | 142.6  | ns   |
| Plant old                       | years    | 12.0    | 10.2   | ns   |
| Urea fertilizer                 | kg ha⁻¹  | 48.6    | 76.4   | ns   |
| NPK fertilizer                  | kg ha⁻¹  | 73.6    | 70.2   | ns   |
| Rock Phosphate                  | kg ha⁻¹  | 0.0     | 18.3   | ns   |
| MOP                             | kg ha⁻¹  | 103.8   | 43.6   | ns   |
| NPK+Kieserite                   | kg ha⁻¹  | 94.7    | 43.8   | *    |
| Borate                          | kg ha⁻¹  | 7.1     | 2.8    | ns   |
| MgO                             | kg ha⁻¹  | 0.0     | 0.0    |      |
| CuSO₄                           | kg ha⁻¹  | 1.6     | 2.9    | ns   |
| Dolomit                         | kg ha⁻¹  | 0.0     | 32.5   | *    |
| Organic fertilizer              | kg ha⁻¹  | 3.0     | 10.8   | ns   |
| Herbicide                       | kg ha⁻¹  | 0.2     | 0.7    | ns   |
| Fungicide                       | kg ha⁻¹  | 0.0     | 0.0    | -    |
| Insecticide                     | kg ha⁻¹  | 0.8     | 0.0    | *    |
| Gasoline-fuel                   | litres   | 24.0    | 12.0   | *    |
| Diesel-fuel**                   | MJ***    | 4179.7  | 0      | *    |

*significant different at p=0.05; ns=not significant
**Including for transportation, water pump, generator
***Conversion base on Annex III Energy Content of Transport Fuels Directive 2009/28/EC

The estimated total carbon reserve in the peat soil at the company’s oil palm plantations area with a peat depth of 437.5 ± 75 cm was 4113 ± 697 tons C ha⁻¹, while the total carbon reserves at smallholder farmers a peat depth of 425.0 ± 29 cm was averagely 3416 ± 227 tons C ha⁻¹. These reserves would secure the peat’s existence due to the genesis dynamics and degradation least for the next hundred years in the future[1, 2], which would be more sustainable with biodiversity planting management for regenerating and conservation function[24].

**Table 3.** Greenhouse Gas Emission (GGE) and carbon footprint of the oil palm company and smallholder farmers

| Input Emission:               | Unit           | Company | Farmer | Note |
|-------------------------------|----------------|---------|--------|------|
| Total fertilizer              | kg CO₂-eq ha⁻¹ year⁻¹ | 675.2   | 604.9  | ns   |
| Pesticide                     | kg CO₂-eq ha⁻¹ year⁻¹ | 19.5    | 13.8   | ns   |
| Fuel Consumption              | kg CO₂-eq ha⁻¹ year⁻¹ | 319.0   | 6.9    | *    |
| Total                         | kg CO₂-eq ha⁻¹ year⁻¹ | 1013.7  | 625.6  | *    |
| Input emission: CO₂           | kg CO₂-eq ha⁻¹ year⁻¹ | 623.6   | 561.9  | ns   |
The carbon emission of applied fertilizer inputs at the company plantation was averagely not differentiable with the smallholder farmers. Higher variability of the farmers' fertilizer application rates contributed higher standard deviation values at approximately 36% of the median value. The company's peatland oil palm plantations emitted carbon from fertilizer at the total value of 675.2 kg of CO₂-eq followed by the fuel use at 319 kg of CO₂-eq ha⁻¹ year⁻¹ and lastly pesticides 19.5 kg CO₂-eq ha⁻¹ year⁻¹. The emission from pesticide application of both management systems showed no significant value averagely ranging from 13.8-19.5 kg CO₂-eq ha⁻¹ year⁻¹. However, due to the higher use of fuel consumption by the company, emissions sourced from fuel were significantly also higher at the rate of 319 kg CO₂-eq year⁻¹, which is a remarkable rate compared to the fuel emission of the smallholder farmers, that reached only 6.9 kg CO₂-eq ha⁻¹ year⁻¹. Fossil fuel inputs of the oil palm company included fertilizer transport to the field and harvesting transport of Fresh Fruit Bunch (FFB) to the mill.

Besides them, company worker transport and mobilization, transport of fertilizer, the use of water pumps in nurseries, and the use of fuel for electric generators were also calculated in the company fuel consumption. On the other side, the smallholder farmers lived close to the plantation area. They used mainly simple motorcycles to the plantation. Harvested FFB of the farmers at the plantation was bought directly by FFB collector buyer at the field so that the farmer has no fuel consumption after harvest in the field.

The emission value of applied inputs in the company plantation reached a total of 1013.7 kg CO₂-eq ha⁻¹ year⁻¹ with EFB-Carbon-footprint from the applied inputs with the value of 0.061 kg CO₂-eq kg⁻¹ EFB. Those values were higher than those of the smallholder farmers, which reached only 604.7 kg CO₂-eq ha⁻¹ year⁻¹ and 0.038 ± 0.011 kg CO₂-eq kg⁻¹ EFB, respectively. The better carbon footprint of applied input in both systems was also confirmed, that in the Roundtable Sustainable Palm Oil (RSPO) certified plantation showed not better than at the uncertified plantation[16]. The carbon footprint for Crude Crude Palm Oil (CPO) products in Sumatra was 4.8 kg CO₂-eq kg⁻¹ CPO[25]. However, an uncontrolled canalization system at an uncertified plantation or smallholder farmers produces much higher emissions than emissions contributed by applied input[25, 26].

4. Conclusion

CO₂ equivalent emissions from applied inputs of corporate peatland oil palm plantation based on data in 2012 amounted to 1013.7 kg CO₂-eq ha⁻¹ year⁻¹. On smallholder farmers, it showed a 40 lower emission rate but with higher variability at 604 ± 238 kg CO₂-eq ha⁻¹ year⁻¹. At the oil palm corporate, inorganic fertilizer application contributed a higher emission rate, followed by fuel use and pesticide applications. CO₂-eq emission rate at smallholder farmers showed a similar pattern for inorganic fertilizer use. However, it showed higher emission from pesticide application rather than fuel use.
References
[1] Xu J, Morris PJ, Liu, J and Holden, J 2018 *Catena* **160** 134–140
[2] Hapsari KA, Biagioni S, Jennerjahn TC, Reimer PM, Saad A, Achnopha Y, Sabiham S and Behling H 2017 *Quat Sci Rev* **169** 173–187
[3] Dommain R, Couwenberg J, Glaser PH, Joosten H and Suryadiputra INN *Quat Sci Rev* 97 1–32
[4] Cattau, ME, Harrison ME, Shinyo I, Tungau S, Uriarte M and DeFries R 2016 *Glob Environ Chang* **39** 205–219
[5] Agusta H, Nisya FN, Handoyo GC, Santoso N, Risdiyanto I, Wawan and Krisantini 2019 *IOP Conf Ser Earth Environ Sci* **209** 012052
[6] Carmenta, R, Zabala, A, Daeli, W and Phelps, J 2017 *Glob Environ Change* **46**, 50–59
[7] Bessou C, Chase LDC, Henson I, Abdul-Manan AFN, Milà i Canals L, Agus F, Sharma M and Chin M 2014 *J Clean Prod*** 73** 136–145
[8] Sjögersten S, Aplin P, Gauci V, Peacock M, Siegenthaler A and Turner BL 2018 *Geoderma* **324** 47–55
[9] Wong GX, Hirata R, Hirano T, Kiew F, Aeries EB, Musin KK, Waili JW, Lo KS and Melling L 2018 *Agric For Meteorol* **256**–257 353–361
[10] Dohong, A, Aziz, AA and Dargusch P 2017 *Land use policy* 69349–360
[11] Kiew F, Hirata R, Hirano T, Wong GX, Aeries EB, Kemudang K, Waili JW, Lo KS, Shimizu M and Melling 2018 *Agric For Meteorol* **248** 494–501
[12] Itoh M, Okimoto Y, Hirano T and Kusin K 2017 *Sci Total Environ* **609** 906–915
[13] Ishikura K, Hirano T, Okimoto Y, Hirata R, Kiew F, Melling L, Aeries EB, Lo KS, Musin KK, Waili JW, Wong GX and Ishii Y 2018 *Agric Ecosyst Environ* **254** 202–212
[14] Dohong A, Aziz AA and Dargusch P 2018 *Anthropocene* **22** 31–39
[15] Skiba U, Hergoualc’h K, Drewer J, Meijide A and Knohl A 2020 *Curr Opin Environ Sustain* **47** 81–88
[16] Schmidt J and De Rosa M 2020 *J Clean Prod* **277** 124045
[17] Oktarita S, Hergoualc’h K, Anwar S and Verchot LV 2017 *Environ Res Lett* **12** 104007
[18] Kusin FM, Akhir NIM, Mohamat-Yusuff F and Awang M 2015 *Atmosfera* **28**, 243–250
[19] Ritzema H, Limin S, Kusin K, Jauhiainen J and Wösten, H 2014 *Catena* **114** 11–20
[20] Lourenço KS, Cantarella H, Soares JR, Gonzaga LC and Menegale PL de C 2021 *Geoderma* **404** 115258
[21] Scrucca F, Ingrao C, Maalouf C, Moussa T, Polidori G, Messineo A, Arcidiacono C and Asdrubali F 2020 *Environ Impact Assess Rev* **84** 106417
[22] Chojnacka K, Kowalski Z, Kulczycka J, Dmytryk A, Górecki H, Ligas B and Gramza M 2019 *J Environ Manage* **231** 962–967
[23] Hasler K, Bröring S, Omta SWF and Olfs HW 2015 *Eur J Agron* **69** 41–51
[24] Blackham GV, Webb EL and Corlett RT 2014 *For Ecol Manage* **324** 8–15
[25] Walling E and Vaneckhaute C 2020 *J Environ Manage* **276** 2020 111211
[26] Lam WY, Kulak M, Sim S, King H, Huibregts MAJ and Chaplin-Kramer R 2019 *Sci Total Environ* **688**, 827–837