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Abstract

Drainage for agricultural use on peat soils in the temperate regions of the world releases 3.5 times more CO_2 than similar activities carried out in the tropics, disregarding the use of peat for forestry and for mining purposes. An estimated 4,209 Mt of CO_2 is emitted into the atmosphere in the temperate and boreal regions annually while 1,188 Mt are released in the tropics. Oil palm cultivation on peat in South East Asia accounts for 5.3% of this emission in the tropics or 1.2% of total CO_2 emission from agriculture on peat globally. The study also found that current reports on CO_2 emission on tropical peat has grossly overestimated its emission due to the lack of studies and the lack of knowledge of tropical peat characteristics.

Keywords

Peat, temperate, tropical, oil palm, GHG, CO_2 emission, agriculture

Introduction

Peat is an organic soil where its soil solum is filled with organic materials. In the USDA Soil Taxonomy (USDA, 2010), peat soils are classified as Histosols and are differentiated from mineral soils by having more than half of the upper 80 cm of the soil as organic soil materials. If these organic soil materials of any thickness rest on rock or fragmented materials, then the interstices must be filled with organic materials.

Peat soils are, generally, classified as poor soils for farming. They have both physical and chemical constraints. The physical constraints include the existence of a high water table that needs to be drained before planting can commence. Besides, the waterlogged conditions impede movement and mechanization. In oil palm cultivation, the oil palms lean and require rehabilitation (Lim and Wahyudi, 2010). Nutrient deficiencies, such as, for boron, zinc and copper have also been reported for oil palms grown on peat (Goh and Hardter, 2003).

Despite the limitations posed by peat for agriculture, some agrarian societies have resorted to utilize peat soils for farming, driven by the need to make a living, in the absence of better alternative mineral soils. This has occurred over time in different parts of the world (Oleszczuk et al., 2008). Besides, peat is also used for forestry as well as being extracted for use as energy sources and for horticultural use. It is estimated that about 30 million hectares (ha) of peatland in the world is used for agriculture, another 15 million ha for forestry while less than 5 million ha are mined (Strack, 2008).

The use of peat for agriculture, forestry or for mining purposes alters the flux of the dominant greenhouse gases (GHG) of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The drainage of peatland for agriculture, including oil palm cultivation, releases carbon dioxide into the atmosphere (Hooijer et al., 2006, Oleszczuk et al., 2008, Rieley et al., 2008).

GHG emission from peatland development has garnered interest in recent times since it is now known that the release of GHG accelerates climate change. However, such studies on GHG emission on peat rely much on information gained from knowledge of temperate peat. There are, however, some differences between temperate and tropical peat. As such, there is a certain degree of uncertainty about the validity of postulated results from such studies on CO_2 emission from drained peatland used for agriculture, e.g. for oil palm cultivation, in the tropics.

This study will look into the unique properties of tropical peat and use the information to derive a more realistic estimation of CO_2 emission in the tropics when peatland is drained for agriculture, including oil palm cultivation.

2. Methodology

The information used from the study are obtained from secondary sources. The sources of such information used are mentioned in the text.

3. Results and discussions

3.1Amount of CO_2 emitted in agriculture

The amount of carbon dioxide emitted by draining the various kinds of peatland is shown in Table 1. Based on the results of 32 studies, the amount of CO_2 emitted varies from 2,900 to 62,000 kg $ha^{-1}yr^{-1}$ when peatland is drained for agriculture in the temperate and boreal regions (Oleszczuk et al., 2008). There is a very big variation, of about 21 times difference, in the amount of CO_2 emitted. Such variation can be attributed to crop cover, type of crop grown, variablility between types of bogs and fens, depth of drainage and the length of time it has been drained. The average emission on bogs and fens in the temperate region is, thus, 15,944 kg $ha^{-1}yr^{-1}$ of CO_2.

In the tropics, based on the results of 2 studies, the amount of CO_2 emitted varies from 13,000 to 90,000 kg $ha^{-1}yr^{-1}$. The average amount of CO_2 emitted is, thus, 51,500 kg $ha^{-1}yr^{-1}$. The CO_2 emission in the tropics is, thus, 1.5 - 4.5 times more than that in the temperate and boreal regions when peatland is drained.

Table 1 Amount of CO_2 emitted from drainage of various types of peatland

Types of peatland drained	Locations	Number of studies quoted	Range of CO_2 emission (kg $ha^{-1}yr^{-1}$)	Mean CO_2 emission (kg $ha^{-1}yr^{-1}$)
Bogs	Germany, Russia, Sweden	6	7,300 – 20,000	15,300*
Fens	Germany, Russia, Poland, Sweden, Netherlands, Canada, Finland	26	2,900 – 62,000	16,588*
Peat	Malaysia	1	50,000 – 90,000	70,000**
Peat	Malaysia	1	13,000– 53,000	33,000***

Sources: * Oleszczuk et al (2008) ** Friends of the Earth (2006) *** based on this study

The large amount of CO_2 emission in the tropics for drained peat used for oil palm cultivation has been challenged. Melling (2010) has queried the logic of extrapolating CO_2 emission for tropical regions based on the experience and results obtained on temperate peat. Similarly the uncertainties regarding GHG emissions from tropical peatlands have also been pointed out earlier by Vasander and Jauhiainen (2008).

3.2 Differences in peat soils

Not all peat soils are the same. The Soil Taxonomy (USDA, 2010) recognizes the large variability of peat soils in the world through its soil taxonomic key. Although all peat soils are classified as Histosols at the Order level, there are 5 Suborders and 19 Great Groups that are used to classify peat soils in the world. These are shown in Table 2.

The large variability of peat soils can be classified and placed into one of the large numbers of Subgroups available in the Soil Taxonomy but are not studied here. Even at a high level of classification of the Soil Taxonomy, which is at the Great Groups Level, it is seen that the temperate and boreal peat soils are classified differently from the tropical ones. For example, peat classified within the "Cryo" Great Groups is not found in tropical regions. This stresses the importance of the five factors of soil formation, namely, parent material, climate, relief, organisms and time in peat formation. Climate is drastically different for temperate and tropical

regions. Similarly, there is a big difference in the parent material or vegetation type needed for peat formation between these two regions, with that in the tropics being largely derived from materials obtained from big trees and shrubs while that in the temperate areas are derived from more grassy vegetation (Paramananthan, 2008). Even within a tropical country, such as Malaysia, the soil surveyors have noted the wide range of organic soils and looked at using the right parameters for differentiating them (Tie and Lim, 1991).

Table 2 USDA Soil Taxonomic classification of peat soils and their existence in the world

Suborder and Great Group Levels				
Fibrists	Folists	Hemists	Saprists	Wassists
Cryofibrists [a] Sphagnofibrists [a] Haplofibrists [a,b]	Cryofolists [a] Torrifolists [c] Ustifolists [b,c] Udifolists [a,b,c]	Sulfohemists [b] Sulfihemists [b] Luvihemistsa,[b] Cryohemists[a] Haplohemists [a,b,c]	Sulfosaprists [b] Sulfsaprists [b] Cryosaprists [a] Haplosaprists [a,b]	Frasiwassists [a,b] Sulfiwassists [b] Haplowassists [a,b]

Notes: a = present in temperate and boreal regions

b= present in tropical regions

c= present in arid regions

3.3 Factors affecting GHG emission from peat

GHG emission from peatland used for agriculture is governed by three main factors, namely:

1) The quantity of carbon stored in the peat
2) The degree of drainage of peatland which oxidizes the peat and releases CO_2 and
3) The large emission of CO_2 caused by fires during land clearing operations.

In fact, the amount of CO_2 released from the last two activities is claimed to contribute to about 90% of the total emissions (Friends of the Earth, 2008).

3.3.1Carbon density for Malaysian peat

A carbon density of 60 kg carbon m^{-3} has been used in the calculations of the report of Hooijer et al (2006). Peat soils in the world generally have bulk densities ranging from 0.1 to 0.3 g cm^{-3} depending on their maturity and stage of development. In the MARDI Peat Research Station in

Sessang, Sarawak, Ismail et al (2007) recorded bulk densities for the peat soil in the station prior to land clearing to be 0.07-0.09, 0.06-0.15 and 0.04 - 0.07 g cm^{-3} at the following depths : just below the soil surface, 50 and 100 cm below the soil surface respectively. This equates to a low mean bulk density of 0.08 g cm^{-3} for the peat soil before land clearing.

Higher soil bulk densities are usually found after land clearing. This was the case when Ismail et al (2007) found a higher mean bulk density of the peat soil, with a value of 0.13g cm^{-3} in the Research Station after land clearing operations. In Sarawak, average bulk densities of peat obtained from a Mixed Peat Swamp Forest, Alam Bunga Forest and Padang Alan Forest were 0.12, 0.10 and 0.13 g cm^{-3} respectively (Uyo, 2008). Similar values were also reported by Yew (1982) who found bulk densities of 0.12, 0.14 and 0.17 g cm^{-3} at 0-35cm, 35-120cm and >120cm for a logged over Troposaprist profile in West Malaysia. The carbon contents of the sub-horizons in this profile were 48.1, 53.5 and 51.6 % respectively.

Using an average carbon density of 0.11 g cm^{-3} for the top 1 meter of the peat profile and an average carbon content of 51%, the carbon density of Malaysian peat is 56.1 kg m^{-3}.

3.3.2 Presence of logs and void

Some peat types in Malaysia, particularly those common in Sarawak, contain undecomposed logs and large pieces of wood fragments. Examples of such peat soils are shown in Photos 1 and 2. These large wood fragments do not decompose readily even if the peat is drained and, thus, their immediate contribution to CO2 emission is negligible. Besides, some peat types are not homogeneously filled with peat substrate (Uyo, 2008; Paramananthan, 2008). There are voids or empty spaces within the peat profile which are not filled with peat substrate but are filled with water or air instead. If the large pieces of wood fragments and voids occupy, for example, 55% of the peat profile, then using the example above, the carbon density of the peat is only 25.2 kg m^{-3}. For this kind of peat soil, carbon density has been over-estimated by nearly 2 ½ times when compared to the carbon density of 60 kg m^{-3} given by Hooijer et al (2006).

Figure 1 - Malaysian peat type containing large amounts of wood fragments (photo courtesy of Lah Jau Uyo)

Figure 2 - Profile of Malaysian peat containing large amounts of wood and root fragments (photo courtesy of Lah Jau Uyo).

3.3.3 Drainage of peat causing CO_2 emission

Drainage of peat, as a prerequisite for agriculture, is blamed to be the main culprit in CO_2 emission. It was, thus, claimed that peat land drainage between 60-100 cm results in an annual emission of 50 to 90 tonnes of CO_2 per ha per year when used for oil palm cultivation (Friends of the Earth, 2008). It would, thus, be predicted that over a 25 year period, which coincides with one cycle of oil palm cultivation, an enormously large amount of CO_2 , equivalent to 1,250 to 2,250 tonnes, are emitted per hectare.

Planters in Malaysia generally maintain a water table depth of 50-75 cm for successful cultivation of oil palms (Mohd Tayeb, 2005). With a carbon density of Malaysian peat ranging from 25.2- 56 kg m^{-3}, the CO_2 emission is only 13 - 53 tonnes $ha^{-1}yr^{-1}$, or with a mean of 33 tonnes $ha^{-1}yr^{-1}$,during the initial lowering of water table. There, would, be no further emission of CO_2 in subsequent years since the water table is maintained at this depth throughout the life cycle of the oil palm.

3.3.4 Fires during land clearing

Apart from drainage, this is the next biggest contributor to CO_2 emission. This is a singular event with CO_2 emission dependent on area burned, length of burning and amount of biomass to be burnt. It is not easy to quantify the amount of emissions. Thus, estimations are very variable eg CO_2 emission due to peat fires in Indonesia in 1997 was anything between 3000-9000 megatonnes (Page et al., 2002).

The oil palm industry encourages “zero burning” or “no burning” to be carried out during land clearing. This is being enforced in countries which are concerned about climate change. For example, in Malaysia, zero burning is enforced by laws such as the Environmental Quality Act (1974) and the laws to curtail open burning of waste materials from agricultural activities (Jabatan Alam Sekitar, 1995). However, some states prefer to control burn the areas when the land is initially converted to oil palm. In such cases, the CO_2 emitted should not exceed that contained in the biomass at the time of felling. This is guestimated to be less than 50 tonnes of CO_2 per ha due to the poor aboveground vegetation mass on degraded peat after it has undergone logging. The states that when control burning is carried out, the operators must take great care to ensure that the fires do not spread underground or horizontally but is confined only to the windrows by following rules and regulations stipulated in Natural Resources & Environment Fire Danger Rating System (2004).

3.3.5 In situ field comparisons

In a study carried out by Melling et al., 2007, when the soil CO_2 flux was measured by using a closed chamber technique, it was found that the CO_2 emitted was higher in a forest under peat

than in an oil palm plantation under peat; with values of 2.1 and 1.5 kg C m^{-2} yr^{-1} respectively. This is shown in Table 3. The forest was also found to be a methane source with an emission of 18.34 mg C equivalent m^{-2} yr^{-1}. On the other hand, the oil palm ecosystem was found to be a methane sink with an uptake of 15.14 mg C equivalent m^{-2} $yr^{-1.}$ Higher nitrous oxide emission was also recorded in the oil palm ecosystem compared to the forest, with 1.2 and 0.7 kg N ha^{-1} yr^{-1} respectively.

Table 3 GHG emissions on forest and oil palm ecosystems on peat

Gas flux	Forest	Oil palm
Carbon dioxide (kg C m^{-2} yr^{-1})	+2.1	+1.5
Methane (mg C_e m^{-2} yr^{-1})	+18.34	-15.14
Nitrous oxide (kg N ha^{-1} yr^{-1})	+1.2	+0.7

Notes: + indicates a source; - indicates a sink; C_e is abbreviation for carbon equivalent

This resulted in a total global warming potential (GWP) of 7,850 g CO_2 m^{-2} yr^{-1} for the forest. The GWP of the forest area is much higher than that in the oil palm plantation when the GWP is 5,706 g CO_2 m^{-2} yr^{-1}. This is shown in Figure 1. The GHG emission on an oil palm area in this study, expressed in CO_2 equivalent, is about 12,280 times smaller that the mean CO_2 emission reported by Friends of the Earth (2008). If the CO_2 emission only is considered, then the difference between these two sources is about 12,700 times.

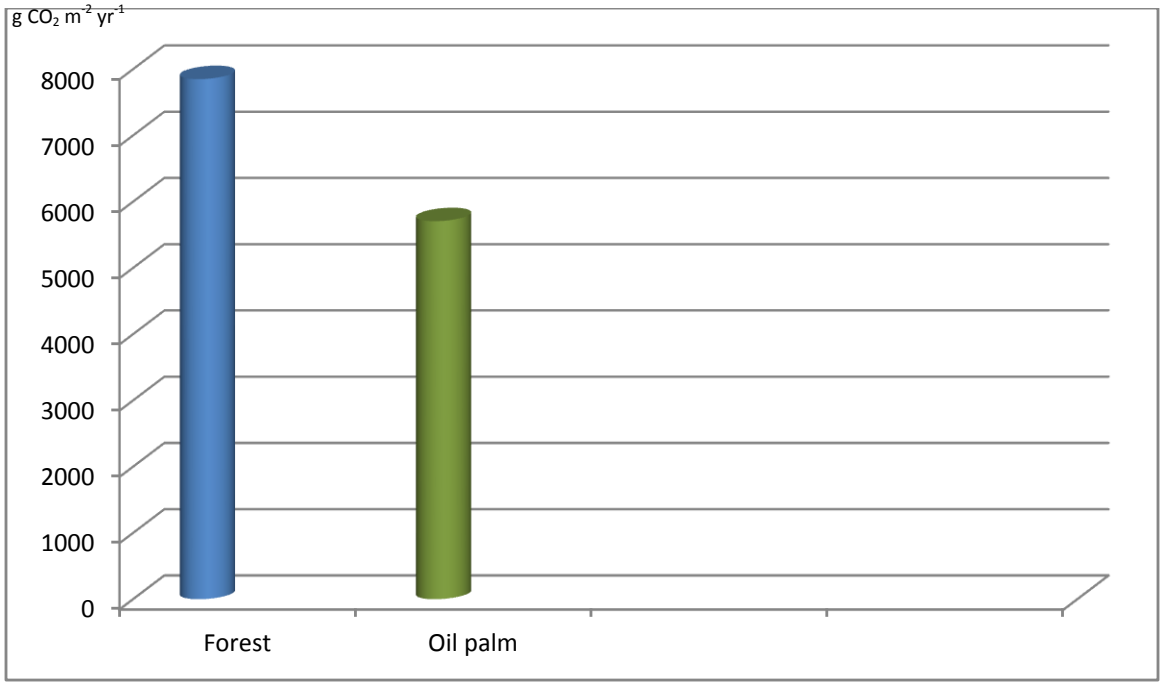

Figure 3 - Total GHG emission from forest and oil palm grown on peat

3.4 Estimation of CO_2 emission from agriculture

Of the 30 million hectares of peatland used for agriculture in the world (Strack, 2008), it is estimated that 264 million hectares are found in the temperate zone while the remaining 36 million hectares are in the tropics. This is based on the assumption that tropical peatland comprises approximately 12% of the global peatland (http://blogs.helsinki.fi/jyjauhia).

The amount of CO_2 emission when peatland is used for agriculture is shown in Table 4. Temperate agriculture on peat emits 4,209 megatonnes per year (Mt yr^{-1}) of CO_2 into the atmosphere; this emission disregards the contribution of peat that is mined or used for forestry. This emission is 1.7 times greater than the total emission of CO_2 for peatland used for agriculture in the tropics. The emission in the latter region, corresponding to tropical regions (Scenario 1) in Table 3, is 2,520 Mt yr^{-1}.

Table 4 estimated CO2 emissions from use of peatland for agriculture in the world

Region	Estimated peat area used for agriculture (million ha)	CO_2 emission (kg $ha^{-1}yr^{-1}$)	Total CO_2 emission (megatonnes yr^{-1})
Temperate	264	15,944*	4,209 (x 3.5)

Tropical (Scenario1)	36	70,000**	2,520 (x 2.1)
Tropical (Scenario 2)	36	33,000***	1,188 (x 1)

Sources: * mean of CO_2 emission from bogs and fens obtained from Table 1

** mean of CO_2 emission obtained from Table 1 as estimated by Friends of the Earth

*** mean of CO_2 emission obtained from Table 1 as estimated in this study

However, it has been pointed out that the emission value of 70 tonnes $ha^{-1}yr^{-1}$ of CO_2 has been grossly overestimated. Scenario 2 in Table 4 gives a more realistic estimate of the CO_2 emission when peatland is converted to agriculture. This is arrived at based on the peat morphology and physical properties of tropical peat, using Malaysian peat as the example. The CO_2 emission in Tropical region (Scenario 2) is 1,188 Mt yr^{-1}. This amount of CO_2 emission from tropical agriculture land use on peat is 3.5 times lower than that emitted from temperate agriculture land use on peat.

3.5 Contribution of oil palm cultivation to CO_2 emission

Indonesia and Malaysia are the world's largest growers of oil palm in the world. Located in South East Asia, with 1.5 million hectares of palm oil grown on peat in Indonesia (http://www.wetlands.org/Whatwedo/Projects/WetlandsandBiofuels/Palmoillandpeatland) and another estimated 400 hectares in Malaysia, the amount of CO_2 emission from this source is estimated to be 62.7 Mt CO_2 annually as seen in Figure 2. This amount is equivalent to 5.3% of the total CO_2 emission from agriculture on peat in the tropics. On a global scale, CO_2 emission from oil palm cultivation on peat constitutes 1.2% of the total CO_2 emission from agriculture on peat.

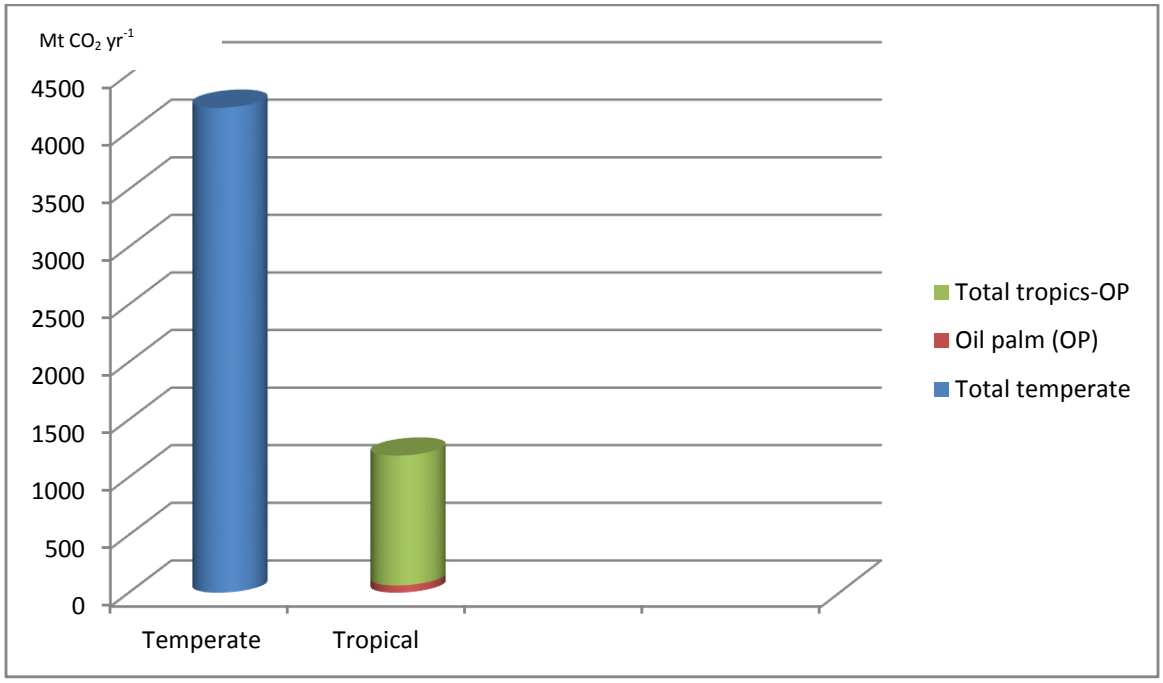

Figure 4 - CO2 emission from agricultural land use types in tropical and temperate zones

4 Conclusions

Peat is present in many parts of the world. Being a versatile material, it has been used since time immemorial and has found many uses. Most of the peat in the world is found in the temperate regions, with tropical peat forming only about 12% of the total area. While large areas are used for agriculture and forestry, smaller areas are mined and the peat used as fuel or as a medium for horticultural practices.

Peat soils throughout the world are not the same. In the USDA Soil Taxonomy, the large variability of peat soils have to be classified differently into 19 Great Groups and many more at the Subgroup level. Tropical peat is different from temperate peat due to the parent (plant) material from which they were derived. Unlike temperate peat, tropical peat often has much woody material, some of which is recalcitrant, and is not easy to break down or decompose. The presence of logs within the profiles also creates voids which are filled with water or air. As a result, tropical peat can have lower bulk densities and lower carbon stocks.

The drainage of peatland for agriculture results in carbon dioxide emission into the atmosphere. Carbon dioxide is a greenhouse gas and its release when peat is used for agriculture is of concern. Knowledge on GHG emission from temperate peat has been used to extrapolate GHG emission on tropical peat used for oil palm cultivation. Since temperate and tropical peats are different, such extrapolations pose uncertainties as to their accuracy and validity.

There is a large scarcity of information on GHG emission on peat drainage for agriculture in the tropics. There is also a big contrast, exceeding 12,000 times difference, in the range of values reported for CO_2 emission from peat areas cultivated with oil palm.

A CO_2 emission range of 50,000 to 90,000 kg ha^{-1} yr^{-1} is often quoted for CO_2 emission from peat areas cultivated with oil palm. When the mean emission figure of 70,000 kg ha^{-1} yr^{-1} is recalculated by considering the unique features of Malaysian peat, this study has estimated the emission to be 33,000 kg ha^{-1} $yr^{-1.}$ On the contrary, there is a wealth of information on CO_2 emission for temperate peat. The average CO_2 emission in temperate areas is 15,944 kg $ha^{-1}yr^{-1.}$ The CO_2 emission in the tropics is, thus, 2 to 4 times, higher than that in the temperate region.

It is estimated that 264 million hectares of temperate peat are used for agriculture, compared to 36 million hectares in the tropics; disregarding peatland used for forestry and those that are mined. 4,209 Mt of CO_2 are emitted annually when peat is drained for agricultural land use in the temperate region. This emission is 2.1 to 3.5 times higher than that obtained from similar activities carried out on peat soil in the tropics.

CO_2 emission from peat drainage for oil palm cultivation in South East Asia is estimated to be 62.7 Mt and constitutes 5% of total CO_2 emission for tropical agriculture on peat. On a global scale, it contributes to only 1.2% of the total CO_2 emission from agriculture on peat.

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Abbreviations

C	carbon
C_e	carbon equivalent
CH_4	methane
cm	centimeters
CO_2	carbon dioxide
GHG	greenhouse gas
GWP	global warming potential
ha	hectare
kg	kilogram
m	metre
Mt	megatonne
N	nitrogen
N_20	nitrous oxide
yr	year