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PREDICTING OF CARBON BALANCE OF OIL PALM PLANTATION IN TROPICAL PEATLANDS USING TROPP-CAT MODEL APPROACH

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ABSTRACT

We can accsess true the data of Tropical Peatland Plantation - Carbon Assessment Tool (Tropp-CAT) model using Microsoft Excel sofware. This model evaluated and predicted the loss of soil carbon and CO_2 emissions from tropical peat lands. This research was using the carbon balance calculations following the Tropp-CAT model steppeds, by adding the carbon stocks above and below ground data on oil palm plantations on peatlands. Total carbon stored in the local research area for 733.95 ha is 17394.17 t CO_2. Stocks carbon was calculated for palm oil 11, 16, 18 and 21 years is 12.732, 17.906, 20.507, 20.5737 t CO_2 ha^{-1} $year^{-1}$ respectly. Stocks carbon was calculated for peat at a depth 0-30 and 0-60 cm is 1 469.50 and 3 270.06 t CO_2 ha^{-1}respectly. Rainfall average is 122 mm $year^{-1}$ with 8 days of rain. High ground water level in the main trend and the branch respectively -61.24 and -60.86 cm with emissions rate 43.96 and 44.12 t CO_2 ha^{-1} respectively. Calculation of water content at a depth of 0-30 and 30-60 cm respectively 379% and 419%. The moisture content of the soil influence the CO_2 and CH_4 emissions. The higher water content of soil, affected lowest emissions peat soil. Research for the primer and secondary drainase based on moisture content was 1.272,46 and 1.150, t CO_2 ha^{-1}. The conclution is: (1) oil palm aging increased carbon sequestered and a net absorption of CO_2 from the atmosphere by plants, (2) soil is greater than the release of CO_2 due to emissions.

INTRODUCTION

Peatlands play role in global carbon cycle with carbon storage of 469-486 Gt. Tropical peatland is a balance among three components: hydrological, ecological and landscape morphological components. A change in those three components will indirectly change the balance of carbon in the peatlands[9]. The use of peatlands for oil palm plantation in South East Asia is rumored to be the biggest deforestation and CO_2 emission to atmosphere. The annual increase in oil palm plantation can reach up to 50-100,000 ha. For 20 years (1990-2010) the use of peatlands has increased more than 6 times than that of mineral soil of 3.5 times [21, 12]. [11] reported that oil palm plantation in Indonesia will cause deforestation of one percent per year in the next 20 years. According to [15] the average loss rate of C uptake due to conversion of peatlands into plantations is 20 times. The loss came from emission of burning, the change in aboveground biomass and oxidation of peatlands. The high conversion of peatlands for oil palm plantation is related to the high demand of CPO in global market. Normatively, Indonesia has the right to reduce poverty and to increase job opportunity, welfare and foreign exchange [24]. Therefore, the use of peatlands has two contradicting sides. In one side, it is a need that able to bring economic advantage and welfare for common people, reduce poverty and decrease unemployment. On the other side, however, it causes environmental damage with no convincing scientific evidence to be found yet.

Literature study indicates that data on CO_2 emission prediction in peatlands is varied where each researcher present different data although they used the same method. The same method applied for different areas will result in different data. The differences in data and method are related to the difficulty to reach peat dome, high cost for both laboratory and field analysis and unrepresentative sampling. Therefore, modeling approach will be a helpful prediction tool to obtain accurate data with less cost. To find out the carbon balance in tropical peatlands, this research used modified TROPP-CAT model. The model is a prediction tool to estimate the loss of carbon (C) and carbon dioxide (CO_2) from tropical peatlands under land management change [5]. TROPP-CAT has been applied for simulation in oil palm and acacia plantations as well as peatland forest sites to predict emission due to the change in land use in the future.

The research aimed to: (1) quantitatively analyze above- and below ground stored and emitted carbon in peatlands of oil palm plantation and (2) analyze carbon balance using modified TROPP-CAT model.

MATERIALS AND METHODS

The research was conducted in oil palm plantation that administratively located in GasibSubdistrict, Siak Regency, Riau Province for two months. The plantation area is ±6.562 ha with oil palm plant age of 6 – 21 years. Geographically, the research location is located in latitude and longitude of 10^{0}16'30"- 00^{0}20'49" S and 100^{0}54'21"-102^{0}10'59"E. The average annual rainfall is 73.9 – 551.4 mm/month and 15 days of rain. The average minimum and maximum temperature are 23.7^{0}C and 31.6^{0}C, respectively with average solar radiation from January to June is 52% and relative humidity is 75.8% [3].

Sampling procedure and data collection, as can be seen in Table 1, were primary and secondary data. Secondary data was from previous researches, doctorate dissertation and data of PT Kimia TirtaUtama (PT. KTU, 2011) conducted in the research area.

Table 1. Primary and Secondary Data Collection on Carbon Balance

Type of Data	Variable	Method	Allocation
A. Primary Data	Identification of land use history,	Interview	Calculation of stored and emitted carbon at land clearing
	Vegetation	Direct measurement	Calculation of aboveground biomass
B. Secondary Data	Administrative and geographical location, land area		Supporting data
	Climatological data		Supporting data
	Soil survey data from PT Kimia TirtaUtama (KTU)		Calculation of above- and below ground biomass and emission

DATA ANALYSIS

Research variables were sample area, peat type and depth, carbon content or percent of C (Walkley& Black method), bulk density and water level of peat layer. The estimation of carbon stock was calculated based on a research from [14]. The calculation of stored carbon was conducted using a method used by [1] and [15]. The calculation of carbon balance was conducted mathematically using modified TROPP-CAT model [5] through 7 (seven) stages (Table 2). The prediction of oil palm biomass calculation referred to allometric equation for biomass of all tress or tree components (such as, stalks and leaves) by calculating biophysical factors, such as diameter of tree at chest height and tree height [7]. Carbon balance was calculated by calculating above- and below ground carbon stock correlated with those of carbon emitted.

Table 2.Stages of Model in TROPP-CAT Method

Entry	Information Needed	Data Collection	Calculation
Stage-1	The history of the change in land use, Is the plantation was primary or secondary forest?Is the site was burnt before planting?	Interview with CSR and local people and field observation. Secondary data was research result of Nurhayatiet al, (2010) Rochmayantoet al, (2010); Prakosaet al, (2012) and Warenet al, 2012	Carbon stock and emission
Stage-2	The condition of climate, rainfall and days of rain	PT. KTU (2011); Secondary data was the research result of Malhi*et al*, (2009);Frolkinget al, (2011)	Ground water level and carbon emission
Stage- 3	Identification of peatland condition: peat type and depth	PT KTU (2011)	Below ground carbon stock
Stage- 4	Relationship between water table level and CO_2 emission	Secondary data was the research result of Husain *et al*, (2014)	Carbon emission
Stage- 5	Calculation of aboveground biomass	Direct measurement (non-destructive)	Stored carbon
Stage- 6	Identification of physical properties of peatland (pH, KTK/cation exchange capacity).	PT KTU (2011)	Carbon emission
Stage- 7	Result	Stage 1 - 6	Carbon balance

Ecological data for carbon balance calculation was greatly influenced by the history of the change in land use gained from field observation and interview with local people in the area of HGU (*HakGuna Usaha*/Cultivation Rights Title) and with the company. The calculation of carbon balance was also influenced by climatological data, such as the average annual rainfall and days of rain obtained from the company.

RESULT AND DISCUSSION

Result of survey by PT. Kimia TirtaUtama (KTU) in 2011 for land evaluation reported that the plantation area is 6.562 ha and consists of mineral soil of 3.843 ha (58.6%) and peatland of 2.719 ha (41.4%). Types of peatland are raw peat (fibric) of 80 ha, medium peat (hemic) of 2.546 ha and mature peat (sapric) of 93 ha. Based on field identification and the availability of secondary data in the research location, of the peatland area of 2.719 ha, 733.95 ha (27%) was used as the research location. Type of landform location is backswamp and the shape is flat and slightly concave with slope of 0-1%. The depth of peat is 3-5 M; peat maturity of hemic/sapric in soil layer of 0-30 cm and 30-60 cm. The age of oil palm trees is 10-12 years.

The use of TROPP-CAT model

Stage-1

Stage-1 was the result of interview with people who live around the plantation area (in clave) and with the company. Peatland used for plantation was secondary forest. Findings in the field show remains of tree trunks caused by logging with narrow planting space and rare. Therefore, it was assumed that peatland clearing for oil palm plantation was secondary forest burnt with light burning. Research from [20] found that carbon stock in secondary peat swamp forest was 306.41 t CO_2 ha^{-1}. The residue of carbon stock from light burning was 239.06 t CO_2[19]. Research from [17] found that the average of emission for burnt sapric peat was 10.395 ppm CO_2 (1039.5 t CO_2 ha^{-1}) and hemic peat was 10.678 ppm CO_2 (1067.8 t CO_2 ha^{-1}). Simulation of oil palm (*Elaeisguineensis*) planting for 100 years with clearing through burning has resulted in total emission of 2400-3000 t CO_2 ha^{-1}[27].

Stage-2

Pattern of rainfall in peatland is the dominant control in ecosystem process, such as clean primary production. Figure 1 shows that the highest rainfall is in November of 346 mm and July of 281mm. The longest days of rain is occurred in November and April for 17 and 15 days of rain, respectively.

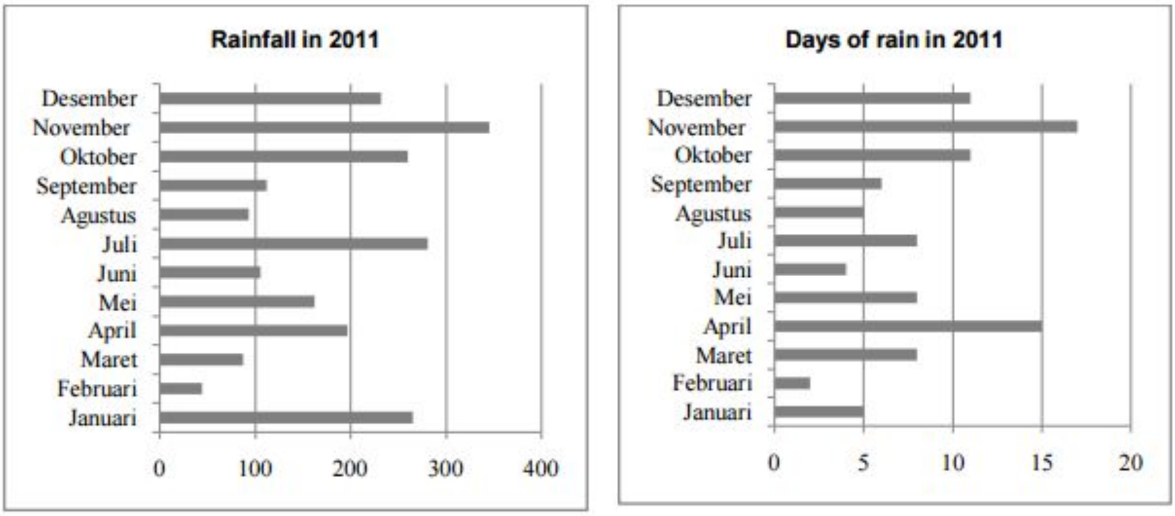


Figure 1 Trend of rainfall and days of rain in 2011

Research by [13] and [6] found that, in general, water deficit would not occur if the rainfall is above 100 mm but it would if the rainfall is under 100 mm. These researches were conducted in February, March and August where the rainfall was 44 mm, 87 mm, and 93mm, respectively. The measurement of water level in peatland was conducted in 16 observation locations with the depth of 0-30 and 30-60 and was calculated based on % volume. The measurement resulted in water level of 75.8% and 83.8% (PT. KTU, 2011). Calculation based on weight resulted in water level of 379% at a depth of 0-30 cm and 419% at a depth of 30-60%. Groundwater content influences CO_2 and CH_4 emission. The higher the groundwater level, the lower the emission of the peatland. Water level above 250% means that it is hydrophilic in nature. In hydrophilic peatland, the emission of CO_2 will decrease with the increase in soil humidity that bigger than groundwater level (*kandungan air tanah/KAT*). High level of peatland groundwater will decrease the availability of oxygen thus restrain the activity of decomposition bacteria. This decrease in the bacteria activity will directly decrease the release of CO_2 to atmosphere.

In this research, the calculation of emission was based on water level in peatland and used exponential linear regression equation [25]. The equation was: $Y = 41.582e^{-0.007X}$, with $R^2 = 0.6002$. Emission calculation at a depth of 0-30 cm resulted in water level of 379% (% weight) and 419% (% weight) at a depth of 0-60 cm. The result of emission calculation of peatland water level at a depth of 0-30 cm and 0-60 cm in the research location was 15.69 mg CO_2 m^{-2} minute^{-1} ($7.85x10^{-12}$ t CO_2 ha^{-1} hour^{-1} or $6.69x10^{-8}$ t CO_2 ha^{-1}year^{-1}) and 14.19 mg CO_2 m^{-2} minute^{-1} ($7.1x10^{-12}$ t CO_2 ha^{-1} hour^{-1} or $6.05x10^{-8}$ t CO_2 ha^{-1}year^{-1}), respectively. $R^2 = 0,6002$ shows that water content in peatland had influence on emission and the higher the water level, the lower the emission emitted.

Stage-3

According to [2], carbon content in peatland was in the range of 300 to 700 t ha^{-1}. If peatland has thickness of 10m, the carbon stock is around 3,000 to 7,000 t ha^{-1}. Based on the assumption, the depth of peatland in the research location was 3-5 meter, thus total stored carbon was 9,000 – 35,000 t ha^{-1}. The result of calculation based on land area for thickness of 3-5 meter and area of 7,800 ha was 390,000 t.

Type of peatland in the research location was hemic or sapric with a depth of 3-5 M. The estimation of below ground carbon stock in peatland of oil palm plantation can be calculated by determining peat volume and the maturity level of peat. Peat volume is calculated by multiplying the thickness of peat layer by peatland area. Whereas, the determination of bulk density and %-C-organic was conducted directly in field and laboratory. The calculation of carbon content (KC) is calculated using formula: KC = B x A x D x C [1].

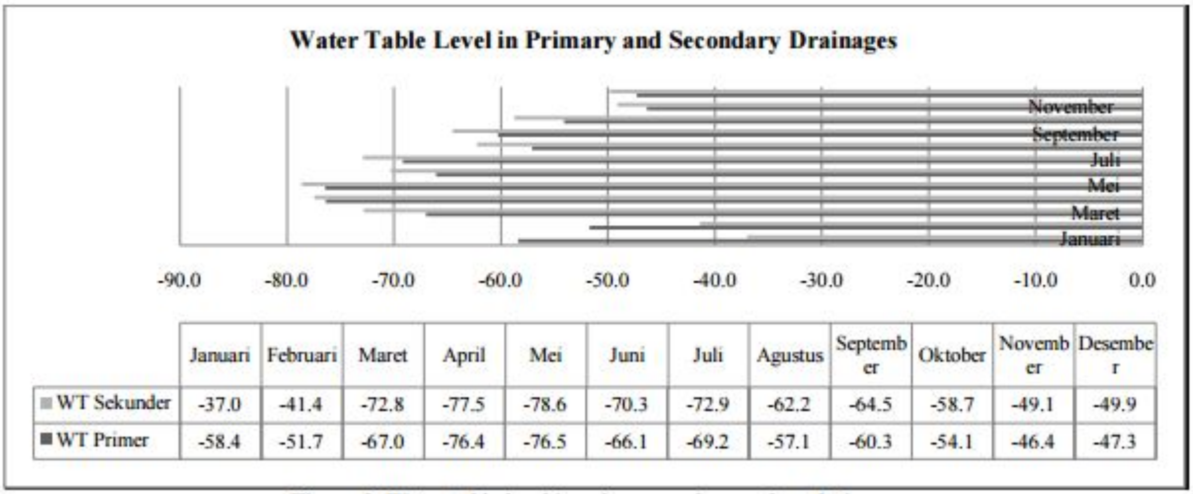
The result of calculation of below ground carbon stock (PT KTU, 2011) for a depth of 0-30 cm and 30-60 cm were, respectively, 1469.50 t C ha^{-1} (5,393.06 t CO_2 ha^{-1}) and 3270.06 t C h^{-1}(12.001,11 t CO_2 ha^{-1}). Sampling was conducted in 16 observation locations. Total stored carbon in the research location for area of 733,95 ha was 3 478.597 t C (12 766.452 t CO_2).

Stage-4

High fluctuation of rainfall in tropical peatland will create soil humidity thus the respiration level of soil will be lower in emitting CO_2 to atmosphere. Researches by [4] and [27] found that forest canopy plays role in carbon sequestration in atmosphere and is beneficial in reducing emission of CO_2 from peatland. Correlating the emission level of CO_2 with the depth of water table should take respiration of above ground root plant into account. A research by [10] in Semenanjung Kampar, Riau showed that below ground CO_2 flux of oil palm (*Elaeisguineensis*) was in the range of 66 ± 25 mg CO_2 ha^{-1} year^{-1}. A research by [22] in peat land of oil palm plantation found that CO_2 flux was in the range of 137.7 ± 73.4 t CO_1ha^{-1}. Research result shows that, significantly, CO_2 flux decreased with the increase in space between oil palm trees. Therefore, it can be concluded that the CO_2 flux was from peat decomposition and root respiration.

The depth of primary drainage in research location (points 50 M, 150 M and 250 M) was 1.5 meter and width of 2 – 3 meter and the secondary drainage (S and U drainages) was 80 cm of depth and 60 cm of width. The measurement of water table level, presented in Figure 2, was conducted weekly in primary and secondary drainages (Data of PT KTU).

The average of water table level in the primary and secondary drainages was 60.90 cm and 61.20 cm, respectively. The calculation of emission based on water table level in the primary and secondary drainages was conducted using exponential regression equation: $Y = 0.593e^{0,015X}$ with $R^2 = 0.3764$[25]. The result of the calculation was 0.542 mg CO_2 m^{-2} minute^{-1} ($2.71x10^{-13}$ t CO_2 ha^{-1} hour^{-1} or $2.31x10^{-9}$ t CO_2 ha^{-1}year^{-1})for primary drainage and 0.544 mg m^{-2} minute^{-1} ($2.72x10^{-13}$ t CO_2 ha^{-1} hour^{-1} or $2.32x10^{-9}$ t CO_2 ha^{-1}year^{-1}) for secondary drainage. $R^2 = 0.3764$ indicates that there was relationship between water table level and CO_2 emission, water table level had contribution of 37% to GRK and the remaining 63% was affected by other factors.



	Januari	Februari	Maret	April	Mei	Juni	Juli	Agustus	September	Oktober	November	Desember
▨ WT Sekunder	-37.0	-41.4	-72.8	-77.5	-78.6	-70.3	-72.9	-62.2	-64.5	-58.7	-49.1	-49.9
■ WT Primer	-58.4	-51.7	-67.0	-76.4	-76.5	-66.1	-69.2	-57.1	-60.3	-54.1	-46.4	-47.3

Figure 2. Water table level in primary and secondary drainages

Stage-5

Tree biomass was calculated using mathematic equation based on diameter and height of stalk with formula: AGB of stalk = $100 \times \pi \times (r \times z)^2 \times h \times \rho$ [14]. Stalk height was measured from the margin of root base of the stalk to the first leave and diameter was measured at chest height [7]. The calculation of leave frond (FBB; Frond Base Biomass) was based on leaves dry weight, spiral in stalk and the percentage of life [8].

Table 3 indicates the result of calculation of AGB (stalk and leave frond) of oil palm at the age of 10, 16, 18 and 21 years, which was 86.03,123.49, 141,43 and 143,87 t CO_2, respectively. Total CO_2 per ha for oil palm at the age of 10,16,18 and 21 was, respectively, 12 732,17 906, 20 507 and 20 573 t CO_2 ha^{-1}.

Table 3.Biomass of oil palm stalk and leave frond (FBB)

N	Age	Tree	CO_2	Leave	CO_2	Total	CO_2	Tree	Total
	year	ton	ton	ton	ton	ton	ton	ha	CO_2ha^{-1}
75	10	16.1	59.16	7.,3	26.9	23.4	86.03	148	12.732
35	16	28.3	104.02	5.3	19.5	33.6	123.49	145	17.906
39	18	28.1	103,10	10.4	38.3	38.5	141.43	145	20.507
39	21	30.1	110.34	9.1	33.5	39.2	143.87	143	20.573

Stage-6

Peatland that has been shifted into oil palm plantation experienced an increase in GRK due to the change in environment, and in turn, it influenced the decomposition process of the peatland. Environmental factors affected the amount of emission of CO_2-equivalent greenhouse gas were ground water level, total acidity, cation exchange capacity, ash level, fiber level and the depth of water table [25].

The calculation of total acidity was conducted using exponential regression with equation: $Y = 0.000001\ e^{-152,16x}$ and $R^2=0.5891$. Regression result shows that the influence of pH on emission was 58%, whereas the remaining 42% was due to other factors. The average pH of peat land (n = 14) was 3.70 and for this pH, emission of GRK was 0.000563mg/m^2/minute or 0.0046 t CO_2 ha^{-1} (2.82×10^{-16} t CO_2 ha^{-1} hour^{-1} or 2.40×10^{-12}t CO_2 ha^{-1}year^{-1}).

Exponential regression was used to calculate KTK with equation: $Y = 122.08\ e^{-0.053x}$ and $R^2=0.5171$. Result of regression with $R^2=0.5171$ shows that the influence of KTK on emission was 51 % and the remaining 49% was influenced by other factors. The average KTK of peat land (n=14) was 73.35. Emission of GRK for KTK was 474.59mg/m^2/minute (2.37×10^{-10} t CO_2 ha^{-1} hour^{-1} or 2.02×10^{-6}t CO_2 ha^{-1}year^{-1}).

Stage-7

Carbon balance of greenhouse gas in tropical peatland is determined by net balance between carbon sequestration in photosynthesis and the release of carbon through ecosystem respiration. Respiration in vegetation is autotrophic respiration resulting in emission of CO_2 from plant foliage and root system. Respiration by soil organism is a decomposition process. The decomposition process could be aerobic or anaerobic from plant litter and peat land. In this process, CO_2 and CH_4 are released. In the research, carbon balance from absorbed and emitted carbon in peatland area of oil palm plantation of 733.95 ha is presented in Table 4.

Various scientific publications and IPCC standard concluded that the replacement of biomass and peatland clearing will emit bigger CO_2 due to pet drying process. The estimation of CO_2 emission with the change in land use from tropical peat swamp forest to oil palm plantation was 19-115 t CO_2-eq ha^{-1} $year^{-1}$.

Table 4 The calculation of absorbed and emitted carbon

Primary peat forest	
Carbon stock	Carbon emission
306.41 t CO_2 ha^{-1}[20]	2000 t CO_2 ha^{-1}[18]
The clearing of primary peat for plantation	
Carbon stock	Carbon emission
254,5 t CO_2 ha^{-1}[13]	2400-3000 t CO_2 ha^{-1}[27] 10.395 t CO_2 ha^{-1} burnt sapric, 1067.8 t CO_2 ha^{-1} burnt hemic, [17]
Oil palm plantation on peatlands	
Carbon stock	Carbon emission
31-101 t C ha-1 [14]	15 t C ha^{-1} $year^{-1}$[9]
Research result	
Carbon stock in peatlands	Carbon emission in peatlands
5.393,06 t CO_2 ha^{-1} (depth of 0-30 cm) 12.001,11 t CO_2 ha^{-1} (depth of 0-60 cm)	2.31×10^{-9} t CO_2 ha^{-1} $year^{-1}$(primary drainage) 2.32×10^{-9} t CO_2 ha^{-1} $tahun^{-1}$ (secondary drainage) 2.4×10^{-12} t CO_2 ha^{-1} $tahun^{-1}$ (pH 3.70) 2.02×10^{-6} t CO_2 ha^{-1} $tahun^{-1}$ (KTK 73.35) 6.69×10^{-8} t CO_2 ha^{-1} $tahun^{-1}$ (water level 379%) 6.05×10^{-8} t CO_2 ha^{-1} $tahun^{-1}$ (water level 419%)
Carbon stock in oil palm	Carbon emission in peatlands
12 732 t CO_2 ha^{-1} (oil palm at the age of 10 years) 17 906 t CO_2 ha^{-1} (oil palm at the age of 16 years) 20 507 t CO_2 ha^{-1} (oil palm at the age of 18 years) 20 573 t CO_2 ha^{-1} (oil palm at the age of 21 years)	47.8 ± 21.3 t CO_2 ha^{-1} (oil palm at the age of 15 years, research result of [16] 137.7 ± 73,4 t CO_2 $ha^{-1}th^{-1}$ (oil palm at the age of 6-15 years, research result of [22]

CONCLUSION

1. The result of AGB (trees and leaves) calculation for oil palm at the age of 10,16,18 and 21 years was 12.732,17.906, 20.507 and 20.573 t CO_2 $ha^{-1}th^{-1}$, respectively. Emission calculation for peatland groundwater level above 379% and 419% resulted in emission level of 6.69 t CO_2 ha^{-1} $year^{-1}$and 6.05×10^{-8} t CO_2 ha^{-1} $year^{-1}$ (at soil depth of 0-30 and 30-60 cm), respectively. Water table level in primary and branch drainages was, respectively, 60.86 cm and -61.24 cm with emission level in primary drainage was 2.31×10^{-9} t CO_2 ha^{-1} $year^{-1}$ and in secondary drainage was 2.32×10^{-9} t CO_2 ha^{-1} $tahun^{-1}$. Emission of GRKfor average pH of 3.74 was 2.4×10^{-12} t CO_2 ha^{-1} $year^{-1}$. Emission of GRKfor average KTK of 73.35 was 2.02×10^{-6} t CO_2 ha^{-1} $year^{-1}$.
2. Carbon balance with modified TROPP-CAT model indicates absorbed carbon through photosynthesis process and peatlands was higher than those of emitted carbon.

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