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Estimation of Oil Palm Total Carbon Fluxes Using Remote Sensing

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ABSTRACT

Net primary production (NPP) is one of the approaches used to estimate the amount of carbon sequestration by plants. This research aims to estimate the total carbon flux exchanged from different ages of oil palm using remote sensing. The study site was at the PTPN VI Batang Hari, Jambi, Sumatra, Indonesia. The amount of carbon sequestration by oil palm plantations at PTPN VI Batang Hari, Jambi can be estimated using remote sensing based on the light use efficiency (LUE) model. The results showed that the oil palm age affects the amount of carbon sequestrated. The lowest Net primary production value was found at one year of planting 4.28 $gCm^{-2}day^{-1}$, and the highest was 9.38 $gCm^{-2}day^{-1}$ at 20 years of planting. The model LUE output was validated using Eddy covariance data and the results showed a low error and a high accuracy rate with RMSE = 0.05 $gCMJ^{-1}$, R^2 = 92%, and p-value = 0.04. We concluded that the LUE model can be used with high accuracy to estimate the amount of carbon absorption of oil palm when direct measurement is unavailable.

KEYWORDS
fraction absorbed photosynthetically active radiation, gross primary production, leaf area index, light use efficiency, net primary production

INTRODUCTION

Forests are ecosystems that have the ability to absorb CO_2 and high carbon reserves and act as a counterbalance to the concentration of CO_2 in the atmosphere. Tropical natural forests can absorb CO_2 around 163.5 tCO_2 per ha per year with carbon reserves of around 76 to 214 tC per ha and based on the characteristics and conditions of forests in a certain area can reach more than 500 tC per ha (Syam'ani et al., 2012). However, land conversion can quickly turn forests into sources of CO_2 emissions in the atmosphere. More than 75% of CO_2 emissions in Indonesia caused by land conversion (Carlson et al., 2012). Yeyen et al., (2018) mentioned that the largest land conversion in recent decades was for oil palm plantations. IFCA, (2007) stated that more than 70% of oil palm plantations in Indonesia have replaced forests and produced emissions from above-ground biomass of 588 million tC (~2117 million tCO_2) into the atmosphere during the period 1982-2005.

Based on previous research, oil palm plants also have the ability to absorb and store carbon. Based on research by Kii et al., (2020), oil palm can absorb CO_2 of 86.5 tCO_2 per ha per year for 25 years, which is the typical life span of oil palm plantations. The difference in the value of oil palm's ability to sequestrate carbon is influenced by several factors, namely environmental factors where oil palm plants grow and the approach and complexity of the model used (Kii et al., 2020). Estimating CO_2 absorption by an oil palm plantation can be done with a net primary production (NPP) value approach. NPP was defined as a simple mathematical calculation to determine how much CO_2 plants absorb and retain in photosynthesis (Kii et al., 2020).

Table 1. Data and research data sources.

Data	Year	Source
Precipitation	2015	Climate tower PTPN VI Batang Hari, Jambi
CO_2 flux	2015	Climate tower PTPN VI Batang Hari, Jambi
Relative humidity	2015	Climate tower PTPN VI Batang Hari, Jambi
Air temperatures	2015	Climate tower PTPN VI Batang Hari, Jambi
Global radiation	2015	Climate tower PTPN VI Batang Hari, Jambi
Solar radiation	2015	Climate tower PTPN VI Batang Hari, Jambi
Landsat 5 TM	2005	earthexplorer.usgs.gov
Landsat 7 ETM+	2009	earthexplorer.usgs.gov
Landsat 8 OIL-SHOTS	2019	earthexplorer.usgs.gov
Boundary area of study	1999, 2002, 2004	PTPN VI Batang Hari, Jambi

The NPP calculations estimated using the eddy covariance method on a flux tower (Biudes et al., 2021). However, the eddy covariance method was spatially limited due to high costs, limited technical equipment and infrastructure requirements, and requires a relatively homogeneous area as well as turbulent atmospheric conditions. Therefore, the application of remote sensing as an additional method to the eddy covariance method can be used to estimate NPP on a regional scale. This is because in addition to being representative of a specific location, remote sensing can also be used for areas that do not have meteorological data and eddy covariance flux towers (Biudes et al., 2021). Also, in accordance with June et al., (2006) to determine NPP and CO_2 absorption in an ecosystem on a large scale can be done with an approach using remote sensing technology and geographic information systems.

According to Larasati et al., (2012), there were 3 models that used to estimate NPP values, namely climate models, process models (June et al., 2006), and LUE models. The LUE model is a model that responsive with changes in environmental conditions or can be used to determine the effect of climate change predictions on the NPP of a plant (June et al., 2006). Using remote sensing, the LUE model has been widely applied to estimate NPP values at scale in different ecosystems (Gómez-Giráldez et al., 2019). This study aims to estimate the total carbon flux exchanged by oil palm plantations at various plant ages using remote sensing.

RESEARCH METHODS

Study Area

The study area was PT Perkebunan Nusantara VI Batang Hari, Jambi, Sumatra Island, Indonesia. PT Perkebunan Nusantara VI (PTPN VI) located in sub-plot 23 (01°41'35.0" LS and 103°23'29.0" BT), which was one of the flattest with a land area of 2,025 ha and equipped with an eddy covariance system. Most of the oil palm plants in PTPN VI Batang Hari, Jambi were planted in 1999 and 2002, with a land area of 600 ha and 1.400 ha, respectively. In addition, one small area of oil palm was planted in 2004, with a land area of 25 ha.

Tools and Data

We used ArcMap 10.3 software, Microsoft Word, Minitab, and Microsoft Excel for data processing and analysis. The data used in this study include Landsat satellite imagery data of 5 TM, 7 ETM+, and 8 OLI-TIRS with a spatial resolution of 30 m as well as micrometeorological data 2015 obtained from the climate tower of PTPN VI Batang Hari, Jambi using Eddy covariance with an interval of 30 minutes, and a map of the regional boundary (.shp) of PTPN VI Batang Hari, Jambi. The data used in this study are presented in Table 1.

Satellite Imagery Correction and Calibration

The radiometric correction was performed to convert digital numbers into spectral radiance (USGS, 2019).

$$L_\lambda = M_L \times Q_{cal} + A_L \tag{1}$$

Where L_λ was spectral radiance ($Wm^{-2}\ sr^{-1}\ \mu^{m-1}$), M_L was radiance multiplicative scaling factor for the band (radiance_mult_band_n from the metadata), Q_{cal} was level 1 pixel value in DN, and A_L was radiance additive scaling factor for the band (radiance_add_band_n from the metadata). Calibration of Landsat 7 ETM+ and 8 OLI-TIRS satellite imagery with Landsat 5 TM was performed to equate the spectral radiance band used on different images. The image calibration process was carried out at sample points taken basedon the spectral radiance range, which was the lowest to highest radiance spectral value in each band used.

Imagery Autographing

The data cutting of Landsat satellite imagery was carried out using a map of the regional boundaries

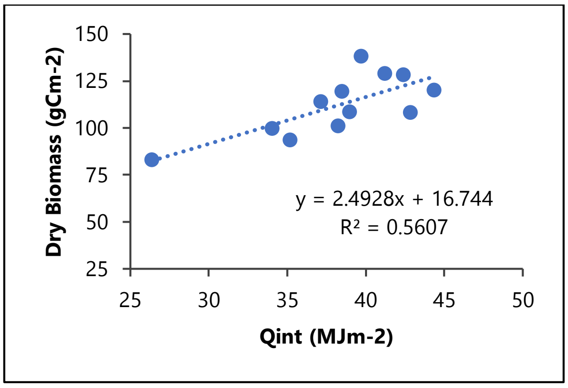


Figure 1. Correlation between accumulated intercept-ted radiation with increase in biomass (oil palm).

(shape file format, shp) of PTPN VI Batang Hari on oil palm areas for 2004, 2002, and 1999 planting years.

Data cutting of Landsat 5 TM satellite imagery (2005) obtained results in the form of study areas aged 1, 3, and 6 years. Data on Landsat 7 ETM+ (2009) satellite imagery and 8 OLI-TIRS (2019) were obtained from study areas aged 5, 7, 10, 15, 17, and 20 years.

Determining the Value of Photosynthetically Active Radiation (PAR)

The calculation of the photosynthetically active radiation (PAR) value (MJm-^{2}day^{-1}) in this study used observational data in 2015, which was processed from Eddy covariance tower data which was assumed to be the same at all ages of oil palm plants. Equation 2 was used to determine the PAR value (Prasad et al., 2002).

$$\mathrm{PAR} = 50\% \times \mathrm{Global\ Radiation} \tag{2}$$

Where PAR was photosynthetically active radiation.

Determining Gross Primary Production (GPP) Observations

According to Zhou et al., (2009) the correlation between NEE and GPP, and R_{eco} can be seen in the Equation 3 and 4.

$$\mathrm{NEE_{obs}} = \mathrm{GPP_{obs}} + \mathrm{Reco_{obs}} \tag{3}$$

$$\mathrm{GPP_{obs}} = \mathrm{NEE_{obs}} - \mathrm{Reco_{obs}} \tag{4}$$

Where $\mathrm{NEE_{obs}}$ was net ecosystem exchange (gCm^{-2}) observation data, GPP was gross primary production (gCm^{-2}) observation data, and R_{eco} was ecosystem respiration data (gCm^{-2}) observation which was considered equal to night-time NEE values.

Determining Light Use Efficiency (LUE) Observation and Model

The LUE value in this study was obtained from the calculation of 2015 field data processed from the Eddy covariance tower (Reis and Ribeiro, 2020).

$$\mathrm{LUE_{obs}} = \frac{\mathrm{GPP_{obs}}}{\mathrm{PAR}} \tag{3}$$

The LUE model was an observational LUE that corrected using environmental factors such as precipitation, air temperature, relative humidity, and global radiation or it can also be referred to as corrected LUE.

Determining the Value of Leaf Area Index (LAI)

Estimated the LAI values of oil palm using remote sensing with a spectral radiance NIR approach obtained from the regression equation between LAI hemispheric photography techniques using remote sensing with a coefficient of determination (R^2) of 0.85 and RMSE of 0.52 (Kanniah et al., 2012).

$$\mathrm{LAI} = -0.156 \times \mathrm{srNIR} + 16.95 \tag{4}$$

Where LAI was the leaf area index and srNIR was the spectral radiance of near infrared band. The LAI value of oil palm was needed in estimating the NPP value of oil palm cultivation to determine the amount of accumulated radiation interception by oil palm at PTPN VI Batang Hari, Jambi, Sumatra Island, Indonesia.

Determining the Value of fraction Absorbed Photosynthetically Active Radiation (fAPAR)

Based on the Beer-Lambert law, the calculation of the fAPAR value of oil palm plantations can be derived from the LAI value, with k being the extinguishing coefficient influenced by the age of the plant (Kanniah et al., 2014; Kii et al., 2020).

$$\mathrm{fAPAR} = 1 - \mathrm{e}^{(-\mathrm{k}\times\mathrm{LAI})} \tag{5}$$

Where k was the palm oil extinction coefficient (1-3 years = 0.24, 4-6 years = 0.30, and 7-12 years = 0.47).

Determining the Value of Gross Primary Production (GPP)

June et al., (2006) stated that all carbon absorbed by vegetation during the photosynthesis process was called Gross Primary Production (GPP) with units of tons of carbon per hectare per year. The calculation of the GPP value can be conducted using the light use efficiency (LUE) model with the following equation (June et al., 2006; Kii et al., 2020; Zhang et al., 2017).

$$\mathrm{GPP} = \mathrm{LUE} \times \mathrm{fAPAR} \times \mathrm{PAR} \tag{6}$$

Determining the Value of Net Primary Production (NPP) and Autotrophic Respiration

Net primary production (NPP) was the value of gross primary production (GPP) minus autotrophic respiration (Sugiarto et al., 2008). The autotrophic respiration value used in this study was 45% of the GPP value (June et al., 2006; Hall and Beaulieu, 2013).

$$\mathrm{Ra} = 0{,}45 \times \mathrm{GPP} \tag{7}$$

$$\mathrm{NPP} = \mathrm{GPP} - \mathrm{Ra} \tag{8}$$

Model Light Use Efficiency (LUE) Validation

Validation analysis was performed between the model and observational LUE values. The validation analysis used in this study was Root Mean Squared Error (RMSE), coefficient of determination (R^2), and p-value (Aziz et al., 2022).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n}(\text{LUE}_{\text{model}}(i) - \text{LUE}_{\text{obs}}(i))^2}{n}} \qquad (9)$$

Where the $\text{LUE}_{\text{model}}$ was the LUE corrected by precipitation, the LUE_{obs} was the LUE calculated based on the dry biomass per accumulation of interception radiation, and n was the number of samples.

The correction between LUE and precipitation was conducted to determine the effect of precipitation as a significant correction factor on the LUE value so that the model LUE was closed to the true LUE. The correction was done using the regression equation generated from the scatter plot with the largest coefficient of determination and p-value < 0.05.

RESULTS AND DISCUSSION

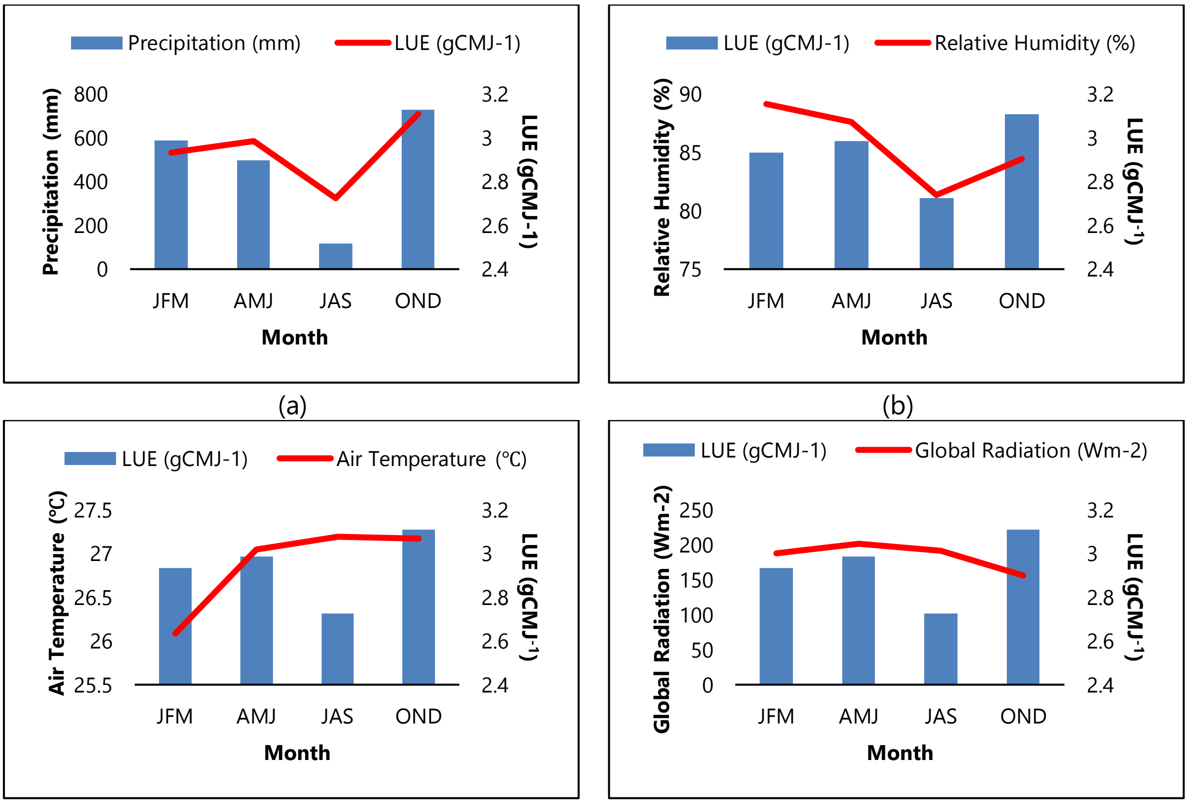
Light Use Efficiency (LUE) of Oil Palm Crops

The relationship between accumulated radiation interception and dry biomass of oil palm plants (Figure 1) had a positive and strong linear correlation, illustrated by a coefficient of determination value of 56.07%. This suggests that the accumulation of radiation interception significantly influences the dry biomass of plants. The greater the accumulation of radiation interception of oil palm plants, the more it will increase the production of dry biomass of oil palm plants.

The LUE of oil palm cultivation at PTPN VI Batang Hari, Jambi showed average LUE value of 2.93 gCMJ^{-1}, lowest average LUE value in July to September (2.72 gCMJ^{-1}), and highest in October to December (3.11 gCMJ^{-1}) (Figure 2). The value follows the research results of Kii et al., (2020), which ranged from 1.8 gCMJ^{-1} to 3.27 gCMJ^{-1} in the same study area. Fluctuations of LUE values were influenced by climatic factors such as precipitation, relative humidity, air temperature, and global radiation fluctuating during 2015 depicted in Figure 2.

The highest accumulated precipitation per three months was 728 mm, occurred from October to December, and the lowest was 116 mm from July to September (Figure 2a). The highest average relative humidity per three months at PTPN VI Batang Hari, Jambi in 2015 was 89% from January to March, and the lowest was found in July to September, which was 81% (Figure 2b). The highest average three-month air temperature occurred in July to September at 27.2°C, and the lowest occurred in January to March at 26.08°C (Figure 2c). High air temperature, low relative humidity, and low precipitation caused low LUE values of oil palm. This condition caused the availability of groundwater and soil moisture to decrease, then it caused a water deficit, so plant growth and dry biomass of plants were quite low (Biudes et al., 2021).

As seen in Figure 2d, the average global radiation per three months at PTPN VI Batang Hari, Jambi in 2015 decreased when entering July to December, with the



(a) (b)

(c) (d)

Figure 1. Light use efficiency (LUE) pattern as influenced by (a) precipitation, (b) relative humidity, (c) air temperature, and (d) global radiation at PTPN VI Batang Hari, Jambi 2015.

Table 2. The value of the coefficient of determination (R^2) between climate elements and the LUE of oil palm cultivation at PTPN VI Batang Hari, Jambi.

Predictan	Predictor	R^2	p-value	Equation
Light use efficiency (LUE)	Relative Humidity	22%	0.532	LUE = 1.084 + 0.02164 × Relative Humidity
	Temperature	0.05%	0.977	LUE = 3.123 - 0.0069 × Temperature
	Precipitation	92%	0.043	LUE = 2.655 + 0.000587 × Precipitation
	Global Radiation	34%	0.413	LUE = 3.821 - 0.004798 × Global Radiation

highest average being in April to June which was 201 Wm^{-2} and the lowest was from October to December, with 156 Wm^{-2}. Within this period, LUE decreased with decreasing global radiation and vice versa, except from October to December, when LUE increased when global radiation was low. The low global radiation from October to December was due to the El-Nino phenomenon in 2015, which caused smog events in Jambi Province including our study site. This caused a decrease in radiation entering the earth's surface due to being blocked by gases and aerosols in the atmosphere.

The regression analysis results showed that seasonal precipitation had a higher degree of correlation with LUE than other parameters (Table 2). This was illustrated by the value of the coefficient of determination of precipitation with LUE (R^2 = 92%) greater than the coefficient of determination of LUE with other parameters. The value of LUE significance also reinforces the degree of correlation with precipitation (p-value = 0.043) which was less than it faults tolerance value (p-value < 0.05) than the p-value of other parameters. This indicated that precipitation was a climatic factor that can significantly affect the LUE value compared to other parameters. The low correlation of relative humidity, air temperature, and radiation to the LUE value of oil palm in this study was due to air temperature, relative humidity, and radiation at PTPN VI Batang Hari, Jambi had small variations during the 3-month so that the effect on LUE of oil palm was small and insignificant.

Figure 3 showed the difference in patterns between the value of the observational LUE and the LUE of the oil palm planting model at PTPN VI Batang Hari, Jambi. The difference in results occurs from January to March and April to June. Based on Figure 3, the LUE of the model from January to March (3.01 $gCMJ^{-1}$) was greater than in April to June (2.95 $gCMJ^{-1}$). In contrast to the model LUE, the observed LUE value from January to March (2.93 $gCMJ^{-1}$) was smaller than from April to June (2.99 $gCMJ^{-1}$). In addition, there was a difference in LUE values from October to December, namely 3.11 $gCMJ^{-1}$ (LUE obs) and 3.09 $gCMJ^{-1}$ (model LUE) with the same pattern. This was because the LUE value of the model had been corrected using the precipitation value so that the distribution pattern of the model LUE results follows the actual precipitation distribution pattern.

The Correlation of Leaf Area Index (LAI) and fraction Absorbed Photosynthetically Active Radiation (fAPAR) to the Age of Oil Palm

The color changes in the Landsat imagery extraction results in Figure 4 showed the spatial distribution of LAI and fAPAR values of oil palm cultivation varies whit the age of oil palm. The lowest estimated LAI value was found at one year of age at 2.32 and the highest at 20 years of age at 3.75 with an average LAI over 20 years of 3.17 (Figure 4a). The lowest

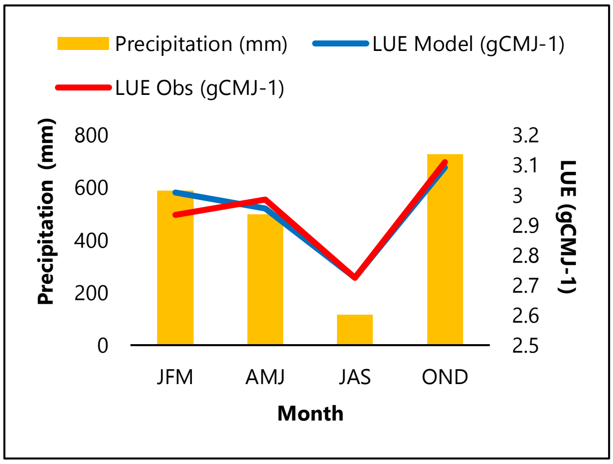
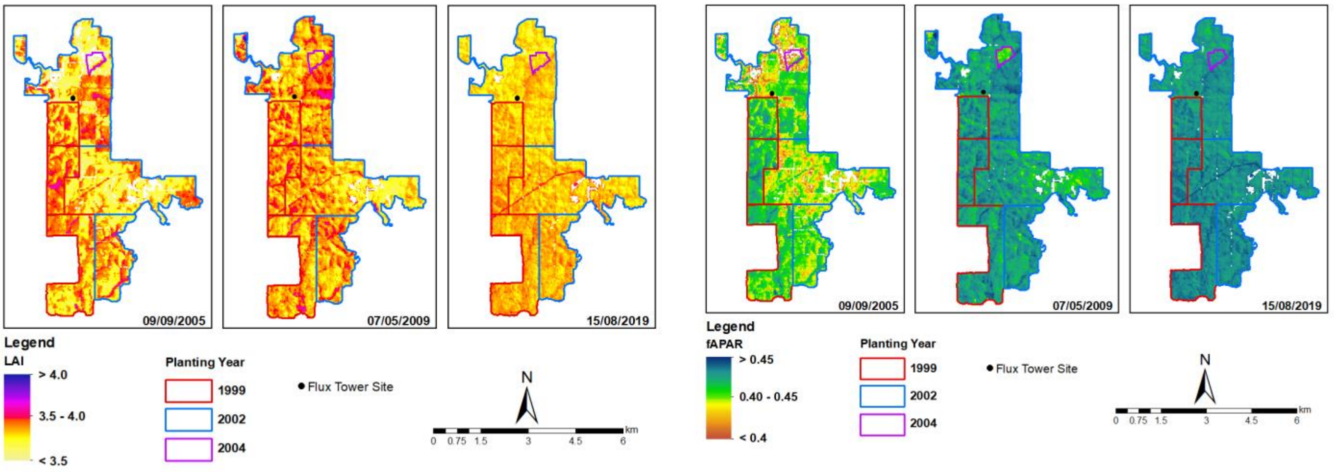


Figure 2. Patterns of model light use efficiency (LUE) an observations LUE of precipitation.



(a) (b)

Figure 3. Distribution values of (a) leaf area index (LAI) and (b) fraction absorbed photosynthetically active radiation (fAPAR) of oil palm PTPN VI Batang Hari, Jambi.

fAPAR was observed at one year of age at 0.38 and the highest at 20 years of age at 0.82 with an average fAPAR over a 20-year period of 0.67 (Figure 4b).

The estimation of the average LAI and fAPAR values of oil palm was appropriate based on the research of Tan et al., (2014) which resulted in LAI values of oil palm ranging from 0.57 to 5.17 and fAPAR had a range of values between 0.04 to 0.94. The fAPAR value range indicates the same oil palm conditions as the LAI range. The higher the canopy density of the oil palm, the greater the LAI of the oil palm so that the canopy oil palm absorbs more radiation. This follows the results of research conducted by Kii et al., (2020), the more productive the age of the oil palm, the absorption capacity of PAR increases and begins to decrease as the plant ages.

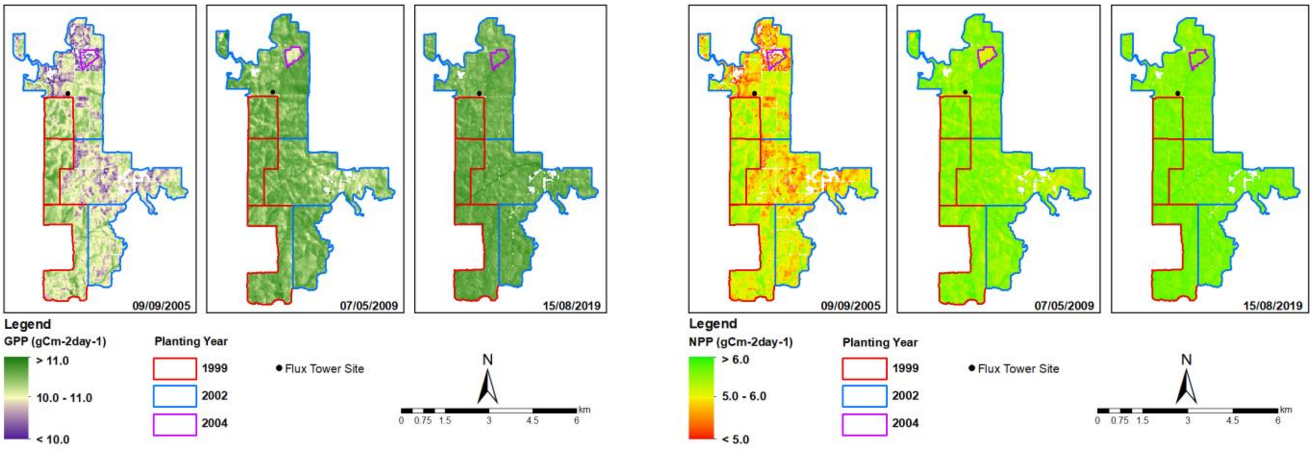
Dynamics of Gross Primary Production (GPP) and Net Primary Production (NPP)

The distribution of the GPP value of oil palm plantations shows different results at each age of the oil palm crop (Figure 5a). One-year-old oil palm plants had the lowest GPP value of 7.78 gCm^{-2}day^{-1} and the highest GPP value was found in 20-year-old oil palm plants at 17.05 gCm^{-2}day^{-1}. This value was higher than the results of research by Tan et al., (2014) in Malaysia it was 7.93 and 8.07 gCm^{-2}day^{-1}. In addition, the results of the GPP value of this study were also higher than the results of research conducted by Kii et al., (2020) in the same study area (PTPN VI Batang Hari, Jambi) which was 11.74 gCm^{-2}day^{-1}. This was because the LUE and PAR values used as calculation inputs in this study were assumed to be the same for all plant ages. The variation in GPP values against the ages of different crops in oil palm crops was influenced by differences in LAI values which directly affect fAPAR values at the same age (Kii et al., 2020).

NPP ranges from 4.28 to 9.38 gCm^{-2}day^{-1} with an average of 7.60 gCm^{-2}day^{-1} (Figure 5b). The highest average NPP value of oil palm was found at the age of 20 years (9.38 gCm^{-2}day^{-1}) and the lowest was found at the age of one year (4.28 gCm^{-2}day^{-1}). In this study, NPP at the age of 10 years (8.82 gCm^{-2}day^{-1}) was greater than the results of a study previously conducted by Kii et al., (2020), 6.47 gCm^{-2}day^{-1}, and Kanniah et al., (2014), 2.65 gCm^{-2}day^{-1}. Accorded to Kii et al., (2020), the difference in NPP values of oil palm plantations was influenced by environmental factors where oil palm grows, such as nutrients, water, light, and climatic factors, as well as the approach and complexity of the model used. Estimated the NPP value of oil palm on a regional scale was important determine the-

Table 3. Validation of model light use efficiency (LUE) results against observational LUE.

Time	Precipitation (mm)	LUE Obs (gCMJ^{-1})	LUE Model (gCMJ^{-1})	RMSE (gCMJ^{-1})	R^2	p-value
January-March	587	2.93	3.01	0.05	0.92	0.04
April-June	499	2.99	2.95			
July-September	116	2.72	2.72			
October-December	728	3.11	3.09			
Average	483	2.93	2.94			



(a) (b)

Figure 4. Distribution values of (a) GPP and (b) NPP of oil palm PTPN VI Batang Hari, Jambi.

role of oil palm cultivation in the global carbon cycle and climate change. The high NPP value of oil palm cultivation showed that the oil palm crop had a fairly good and optimum potential in carbon sequestration. The higher GPP and NPP values of oil palm cultivation, the greater potential for carbon absorption and storage of oil palm crops.

Light Use Efficiency (LUE) Validation

Validation analysis between the model LUE values and observational LUE using Eddy covariance data per three months during 2015 found in PTPN VI Batang Hari, Jambi (Table 3) showed an increase in LUE with increasing precipitation. Based on the results of statistical tests, p-value of < 0.05 (0.04), RMSE of 0.05 gCMJ^{-1}, and coefficient of determination of 92% were obtained. This showed that the model LUE had a low error rate, so the model LUE result was accurate with the observational LUE results. Based on the results of these statistical tests, the LUE model can be used to estimate the amount of carbon sequestration of oil palm crops when direct measurements were unavailable.

LUE values on different types of vegetation were presented in Table 4. Based on Table 4, LUE values in various previous studies had been estimated using different approaches, vegetation types, and climatic factors of different study areas. This follows the statement of Arkebauer et al., (1994) state that several factors affect the LUE value, such as environmental climatic conditions and different vegetation types.

CONCLUSIONS

Oil palm had a fairly good and optimum potential in carbon sequestration with an average NPP value of oil palm cultivation over a 20-year period of 7.60 gCm^{-2}day^{-1}. The pattern of NPP value distribution to the age of oil palm follows the pattern of distribution of GPP values which LAI and fAPAR influence. The estimation of NPP values uses a precipitation-corrected LUE and PAR model approach that was assumed to be the same at all plant ages. The results of the model LUE validation show that the LUE of the model result was close to the observational LUE result. The model LUE had a low error rate, so the model LUE results are accurate with the observational LUE results with a p-value of < 0.05 (0.04), RMSE of 0.05 gCMJ^{-1}, and a coefficient of determination of 92%. This suggests that LUE models affected by precipitation can be used to estimate the carbon sequestration capabilities of oil palm crops when direct measurements are unavailable.

Table 4. light use efficiency (LUE) values across different types of vegetation.

Vegetation	Study Area	LUE (gCMJ^{-1})	Source
Oil palm	PTPN VI Batang Hari, Jambi	2.78	(Kii et al., 2020)
Oil palm	Papua New Guinea	1.22	(Huth et al., 2014)
Palm oil (Eddy Covariance flux tower)	Tropics	2.14	(Tan et al., 2012)
Oil palm	Peninsular Malaysia	1.68	(Kanniah et al., 2014)
Tropical rainforests	Indonesian	0.99	(Ibrom et al., 2008)
Evergreen forest	High Latitude	1.2	(Garbulsky et al., 2010)
Evergreen forest	Subtropical	0.8	(Garbulsky et al., 2010)
Tundra	Cherski (Russia)	0.4	(Garbulsky et al., 2010)

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REFERENCES

Arkebauer, T.J., Weiss, A., Sinclair, T.R., Blum, A., 1994. In defense of radiation use efficiency: a response to Demetriades-Shah et al. (1992). Agric. For. Meteorol. 68, 221–227. https://doi.org/10.1016/0168-1923(94)90038-8.

Aziz, M., Rizvi, S.A., Sultan, M., Bazmi, M.S.A., Shamshiri, R.R., Ibrahim, S.M., Imran, M.A., 2022. Simulating Cotton Growth and Productivity Using AquaCrop Model under Deficit Irrigation in a Semi-Arid Climate. Agric. 12, 1–18. https://doi.org/10.3390/agriculture12020242.

Biudes, M.S., Vourlitis, G.L., Velasque, M.C.S., Machado, N.G., Danelichen, V.H. de M., Pavão, V.M., Arruda, P.H.Z., Nogueira, J. de S., 2021. Gross primary productivity of Brazilian Savanna (Cerrado) estimated by different remote sensing-based models. Agric. For. Meteorol. 307, 108456. https://doi.org/10.1016/j.agrformet.2021.108456.

Carlson, K.M., Curran, L.M., Asner, G.P., Pittman, A.M., Trigg, S.N., Marion Adeney, J., 2013. Carbon emissions from forest conversion by Kalimantan oil palm plantations. Nat. Clim. Chang. 3, 283–287. https://doi.org/10.1038/nclimate1702.

Garbulsky, M.F., Peñuelas, J., Papale, D., Ardö, J., Goulden, M.L., Kiely, G., Richardson, A.D., Rotenberg, E., Veenendaal, E.M., Filella, I., 2010. Patterns and controls of the variability of radiation use efficiency and primary productivity across terrestrial ecosystems. Glob. Ecol. Biogeogr. 19, 253–267. https://doi.org/10.1111/j.1466-8238.2009.00 504.x.

Gómez-Giráldez, P.J., Aguilar, C., Caño, A.B., García-Moreno, A., González-Dugo, M.P., 2019. Remote sensing estimation of net primary production as monitoring indicator of holm oak savanna management. Ecol. Indic. 106, 105526. https://doi.org/10.1016/j.ecolind.2019.105526.

Hall, R.O., Beaulieu, J.J., 2013. Estimating autotrophic respiration in streams using daily metabolism data. Freshw. Sci. 32, 507–516. https://doi.org/10.1899/12-147.1.

Huth, N.I., Banabas, M., Nelson, P.N., Webb, M., 2014. Development of an oil palm cropping systems model: Lessons learned and future directions. Environ. Model. Softw. 62, 411–419. https://doi.org/10.1016/j.envsoft.2014.06.021.

Ibrom, A., Oltchev, A., June, T., Kreilein, H., Rakkibu, G., Ross, T., Panferov, O., Gravenhorst, G., 2008. Variation in photosynthetic light-use efficiency in a mountainous tropical rain forest in Indonesia. Tree Physiol. 28, 499–508. https://doi.org/10.1093/treephys/28.4.499.

IFCA., 2007. Reducing Emission from Deforestation and Forest Degradation in Indonesia. REDD. Consolidation Report. Departemen Kehutanan-IFCA.

June, T., Ibrom, A., Gravenhorst, G., 2006. Integration ff NPP Semi Mechanistic - Modelling, Remote Sensing and CIS in Estimating CO2 Absorption of Forest Vegetation in Lore Lindu National Park. Biotropia (Bogor). 13. https://doi.org/10.11598/btb.2006.13.1.217.

Kanniah, K.D., Tan, K.P., Cacknell, A.P., 2012. 2012 IEEE International Geoscience & Remote Sensing Symposium: proceedings: July 22-27, 2012, Munich, Germany. IEEE.

Kanniah, K.D., Tan, K.P., Cracknell, A.P., 2014. Estimating primary productivity of tropical oil palm in Malaysia using remote sensing technique and ancillary data, in: Neale, C.M.U., Maltese, A. (Eds.),. p. 92391K. https://doi.org/10.1117/12.2067012

Kii, M.I., June, T., Santikayasa, I.P., 2020. Dynamics Modeling of CO2 in Oil Palm. Agromet 34, 42–54. https://doi.org/10.29244/j.agromet.34.1.42-54

Larasati, R., June, T., Dewi, S., 2012. Peran Cagar Biosfer Cibodas dalam Penyerapan CO2. J. Penelit. Sos. dan Ekon. Kehutan. 9, 66–76. https://doi.org/10.20886/jpsek.2012.9.2.66-76

Prasad, V.K., Kant, Y., Badarinath, K.V.S., 2002. Estimation of potential GHG emissions from net primary productivity of forests — a satellite based approach. Adv. Sp. Res. 29, 1793–1798. https://doi.org/10.1016/S0273-1177(02)00112-6.

Reis, M.G. dos, Ribeiro, A., 2020. Conversion factors and general equations applied in agricultural and forest meteorology. Agrometeoros 27. https://doi.org/10.31062/agrom.v27i2.26527.

Sugiarto, Y., June, T., Sapto P, B., 2008. Estimation of Net Primary Production (NPP) Using Remote Sensing Approach and Plant Physiological

Modelling. Agromet 22, 183. https://doi.org/10.29244/j.agromet.22.2.183-199.

Syam'ani, Agustina, A.R., Nugroho, Y., 2012. Cadangan Karbon di Atas Permukaan Tanah pada Berbagai Sistem Penutupan Lahan di Sub-Sub DAS Amandit. Jurnal Hutan Tropis 13, 148–158.

Tan, K.P., Kanniah, K.D., Cracknell, A.P., 2014. On the upstream inputs into the MODIS primary productivity products using biometric data from oil palm plantations. Int. J. Remote Sens. 35, 2215–2246. https://doi.org/10.1080/01431161.2014.889865.

Tan, K.P., Kanniah, K.D., Cracknell, A.P., 2012. A review of remote sensing based productivity models and their suitability for studying oil palm productivity in tropical regions. Prog. Phys. Geogr. Earth Environ. 36, 655–679. https://doi.org/10.1177/0309133312452187.

USGS., 2019. Landsat 8 (L8) Data Users Handbook. 1-106.

Yeyen, Muin, S., Fahrizal, 2018. Persepsi Masyarakat terhadap Konversi Lahan menjadi Perkebunan Kelapa Sawit di Desa Nanga Tayap Kecamatan Nanga Tayap Kabupaten Ketapang. Jurnal Hutan Lestari 6, 742-751.

Zhang, Y., Xiao, X., Wu, X., Zhou, S., Zhang, G., Qin, Y., Dong, J., 2017. A global moderate resolution dataset of gross primary production of vegetation for 2000-2016. Sci Data 4, 170165. https://doi.org/10.1038/sdata.2017.165.

Zhou, L., Zhou, G., Jia, Q., 2009. Annual cycle of CO2 exchange over a reed (Phragmites australis) wetland in Northeast China. Aquatic Botany 91, 91–98. https://doi.org/10.1016/j.aquabot.2009.03.002.