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Increasing smog haze and its impact on oil palm evapotranspiration and gross primary production during the 2015 fire: special discussion on diffuse radiation

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Abstract*. In 2015, several regions in Indonesia experienced drought which coincided with the El Nino phenomenon. A drought in Indonesia followed by fires has resulted in oil palm plantations in Jambi being covered by smog haze. The fire phenomenon has a major impact on the weakening of the radiation that enters the earth's surface due to the closure of the atmosphere by thick smog haze that it affects gross primary production (GPP) and evapotranspiration of oil palm. This study aims to analyze the intensity of smog based on diffuse radiation and analyze the relationship and pattern of GPP and evapotranspiration to diffuse radiation during the occurrence of smog in 2015.* PM_{10} *concentration as a representation of aerosols in the atmosphere on atmospheric transmissivity is negatively correlated with r = -0,8 and p-value = 0,0016. The high diffuse radiation is directly proportional to the atmospheric conditions covered by smog. When the smog cover in the atmosphere was at its peak in October 2015, most of the incoming solar radiation was diffuse radiation. The diffuse fraction with GPP and evapotranspiration was also negatively or inversely correlated. Both have a significant relationship with p-value < 0,05 and r = -0,93 for GPP and r = -0,88 for evapotranspiration. Based on the magnitude of the correlation coefficient, diffuse radiation with GPP has a closer relationship than evapotranspiration.*

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INTRODUCTION

Indonesia is known as an archipelagic country located at the equator, so it is said to be a tropical country. As a country that belongs to the Asia Pacific region, Indonesia will be exposed to various climatic conditions and extreme climatic events. The climate in the region is strongly influenced by changes in sea surface temperature, wind circulation, and rainfall, so it is very likely to experience climate variability that leads to the development of the El Nino Southern Oscillation (ENSO), namely, El Nino and La Nina (Kamil and Omar 2017). In 2015, several regions in Indonesia experienced drought, which coincided with the El Nino phenomenon. El Nino is a phenomenon resulting from the interaction between the ocean and the atmosphere in the equatorial region of the central and eastern Pacific oceans, which has a return period of 2–7 years. El Nino causes an increase in rainfall in the East-Middle Pacific and a decrease in rainfall in several tropical regions, including Indonesia. The decrease in rainfall to below normal eventually led to droughts in several areas in Indonesia, including southern Sumatra (South Sumatra Province, including Riau, Jambi, Lampung), Java, Bali, West Nusa Tenggara, and East Nusa Tenggara.

Drought in Indonesia was followed by various impacts, such as fires in Sumatra. Fires have caused several areas in Indonesia and even the countries around the fire location to be covered by smog haze, including settlements and oil palm plantations. Oil palm can grow with rainfall of about 1.500–2.000 mm per year without a defined dry season. Therefore, oil palm is categorized as a tropical plant. Oil palm requires constant solar radiation, which is about 5 hours per day, to be able to produce well. Based on this, weather and climate observations and their impact on water and carbon components will be very important for oil palms (Kamil and Omar 2017).

The phenomenon of fires has not only an impact on human health but also an impact on the micrometeorological component of oil palm. The reduced solar radiation that enters the surface due to the closed atmosphere by thick smog will affect the balance of oil palm growth. As one of the conditions for optimal growth, climatic conditions, including rainfall and solar radiation, play an important role because they affect production potential. The decrease in solar radiation due to smog cover in the atmosphere will disrupt the biogeochemical process of oil palm plants, namely the balance of carbon dioxide exchange between the plant atmosphere and Gross Primary Production (GPP). Oil palm plants have the potential as CO_2 absorbers. This is related to the high production of plant biomass and the dynamic expansion of plantation areas, so it plays a very important role in environmental balance. Oil palm plantations can absorb CO_2 net of 64,5 tons CO_2 per hectare per year (Henson 1999). GPP was developed as an approach for estimating biomass and calculating carbon stocks stored in plants.

Similarly, drought stress is a follow-up impact of the El Nino phenomenon, which will have an impact on the water balance of oil palm plantations, including evapotranspiration. It is important to analyze the water demand for oil palm plantations. Evapotranspiration is one component of the water balance as an indicator to determine the water demand for oil palm. Evapotranspiration describes the process of water loss from a land-use through evaporation from the soil surface and transpiration from the plant surface (June *et al.* 2018). Therefore, evapotranspiration is closely related to the management of water resources, land resources, and crops or agriculture in general. This study was conducted to analyze the intensity of smog haze based on diffuse radiation in 2015 and to analyze the relationship and pattern of gross primary production (GPP) and evapotranspiration on diffuse radiation during the 2015 fire.

METHOD

Research Location and Time

The research was conducted from November 2021 to February 2022, with data processing and interpretation carried out at the Agrometeorology Laboratory, Department of Geophysics and Meteorology, Bogor Agricultural University.

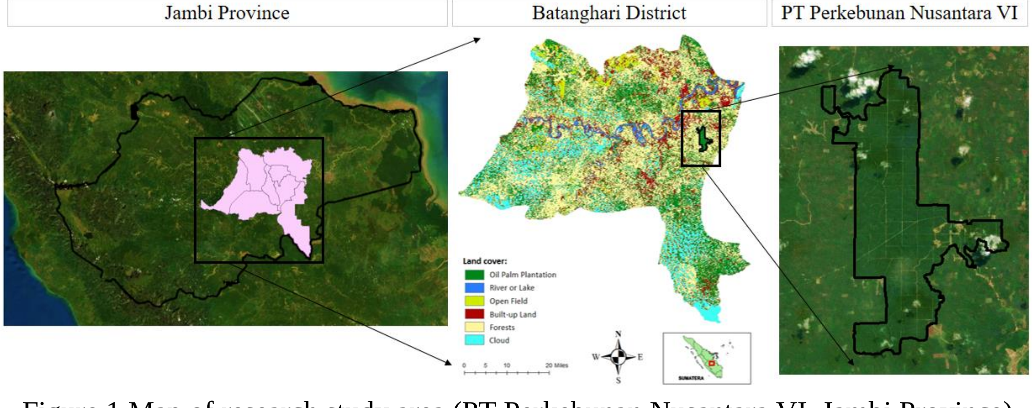

Figure 1 Map of research study area (PT Perkebunan Nusantara VI, Jambi Province)

The study area used in this study is located at PT Perkebunan Nusantara VI (PTPN VI), which is located in Batanghari Regency, Jambi Province (Figure 1). PTPN VI is the study area in this research because PTPN VI is an extensive oil palm plantation and is equipped with measuring instruments such as the Eddy tower and micrometeorological tower and has experienced forest and land fires that caused haze cover in 2015.

Method of Collecting Data

This research is a type of descriptive research with secondary data collection methods or data obtained from other sources that carry out direct measurements. The source of observation data comes from the eddy tower and the micrometeorology tower supported by the IPB-CRC 990-EFForTS. Another data source is the Breathing Earth System Simulator (BESS) model, which is based on remote sensing. This data has previously been validated using observation data.

$$\text{NEE} = \text{Fc} = \overline{w' \rho_c'}$$

$$\text{R}eco = \int \text{NEE}_{\text{night}}\,\text{dt}$$

$$\text{GPP} = \text{NEE} + \text{R}eco$$

Fc : CO_2 fluxes representation of *Net Ecosystem Exchange* (NEE) ($mg/m^2/s$)
w' : The mean vertical wind component deviation (m/s)
$\rho c'$: Average displacement of carbon density (mg/m^3)
Reco : Ecosystem respiration

$$u^*(z) = \frac{k\,(z-d)}{\varphi_m\,(\zeta)}\frac{\partial u}{\partial z}$$

k : Von Karman constant (0,41)
zo : Roughness length (m)
uo* : Friction velocity on the canopy (m/s)
u*(z) : Friction velocity at height z (m/s)
$\partial u/\partial z$: Wind speed gradient (s-1)

Gross Primary Production (GPP) data has been validated with GPP data processed using primary CO_2 flux data (Equation 1), as well as evapotranspiration data which has been validated with evapotranspiration data processed using the aerodynamic method (Equation 4) with the required parameters including air temperature, wind speed, humidity, with three different altitudes, as well as air pressure data.

Data Analysis Method

The data analysis method used in this research is quantitative data analysis method. Data analysis was carried out by analyzing the relationship between the smog phenomenon and GPP, and oil palm evapotranspiration which were analyzed based on diffuse radiation. Data analysis was carried out by plotting the time, both daily and monthly. In addition, statistical analysis was also carried out to see the close relationship between the two variables and validate the data. Data analysis was carried out using various tools such as Microsoft Excel and Rstudio. Most of the calculations to get the parameters to be analyzed are done by Microsoft Excel, a small part is done in Rstudio. All data visualization is done at Rstudio.

RESULT AND DISCUSSION

Global Radiation Analysis and Diffuse Radiation

Rainfall analysis was carried out to see the pattern of rainfall during 2015 at PTPN VI Batanghari. Rainfall data is observational data obtained from the micrometeorology tower. Based on 2015 monthly rainfall data (Table 1), since May 2015, the rainfall began to decline to the lowest peak in September. According to the Schmidt-Ferguson climate classification, the dry period occurs when the rainfall is less than 60 mm/month. Rainfall intensity is an important factor for the development of female flowers, midrib growth, and fruit bunch production of oil palm plants; female flowers will be formed more in the rainy season with sufficient rainfall, while male flowers will form when the plant experiences a deficit in water availability (Agustiana *et al.* 2018).

Table 1 The data used in the study

Observation data		
Parameter	**Source**	**Temporal Resolution**
CO_2 fluxes	Eddy Tower	30 minutes (2015)
Rainfall	Micrometeorology Tower	30 minutes (2015)
Air temperature		
Wind speed		
Humidity		
Pressure		
Diffuse radiation		
Global radiation		
Particulate Matter 10	Meteorology, Climatology and Geophysics Agency (BMKG)	Weekly (2015)
Remote sensing data (model)		
Evapotranspiration	Breathing Earth System Simulator (BESS) Model	Daily (2015)
Gross Primary Production (GPP)		

Solar radiation is divided into two main components, namely direct radiation, and diffuse radiation. Direct radiation is solar radiation received from the sun without being scattered by the atmosphere, while diffuse radiation is radiation received from the sun after changing direction due to scattering in the atmosphere (Gana *et al.* 2014). Calculation of the radiation balance (Rn in W/m^2) is the difference between short wave radiation (Rs) and longwave radiation (Rl) that enters the earth's surface (↓) with short wave radiation and long wave that comes out (↑) from the earth's surface.

$$Rn = Rs\downarrow + Rl\downarrow - Rs\uparrow - Rl\uparrow$$

The calculation of diffuse radiation is obtained from mathematical calculations between global and direct radiation because global radiation is the total direct and diffuse radiation that enters the earth (Sumbung and Letsoin 2012).

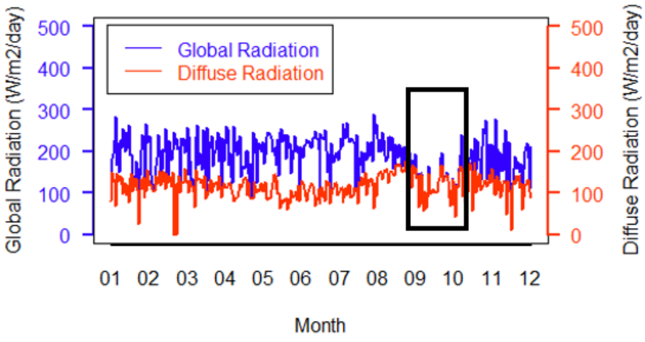

Figure 2 Daily pattern of global radiation and diffuse radiation during 2015 (smog haze period is marked with a bold rectangle)

The graph above shows the daily pattern of global radiation and diffuse radiation during 2015 (Figure 2). Based on the graph above, when fires occur, the global radiation amount decreases and is almost the same as the diffuse radiation (the part marked with a black box), meaning that most of the incoming solar radiation is diffuse radiation. This is due to the reduction in global radiation entering the surface due to the obstruction of gases and aerosols in the atmosphere. The amount of diffuse radiation is higher when the atmosphere is cloudy than when the atmosphere is cloudy or sunny (Ogbulezie *et al.* 2017). This is because the atmosphere in a clean condition indicates that the gas and aerosol content is less than when the atmosphere is in a cloudy state. When the amount of diffuse radiation that reaches the earth's surface is less than or equal to 25% of the global radiation, then the sky conditions at that time can be said to be clear (Khan and Ahmad 2012). The highest diffuse radiation occurred on November 5, 2015, which was 187,7 W/m^2/day. The beginning of the increase in diffuse radiation occurred in early September, at the time of the beginning of the fires.

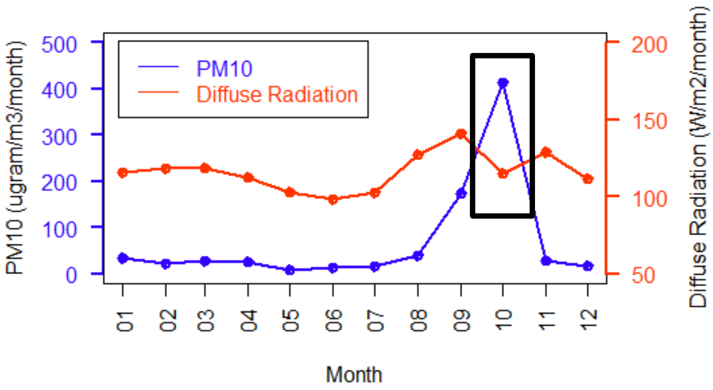

Figure 3 Monthly pattern of PM_{10} concentration and diffuse radiation in 2015 (smog haze period is marked with a bold rectangle)

The picture above is the monthly pattern of the average PM_{10} in Jambi against diffuse radiation in 2015 (Figure 3). Particulate matter is defined as small particles consisting of solid or liquid droplets suspended in the air (Davidson *et al.* 2007). Based on the figure, the peak of concentration PM_{10} occurs with a significantly decreasing in average diffuse radiation as of October or coincided with fire. The condition before the fire happens shows low concentration and less than 150 µgram/m^3. PM_{10} concentrations were decreased in November due to leaching by rain after the fires.

A decrease in global radiation affects microclimate conditions on the surface, like effects in the movement of an air parcel and surface boundary layer. Atmospheric stability shows the surface boundary layer, which changes due to the warming up and cooling down of surface ground. Atmospheric stability are measured by *Richardson number* (Ri). Ri is used to measure static atmospheric stability based on simple criteria in vertical movement of air parcel due to lifting force (*buoyancy*) as an effect of the difference between an air parcel and its circumstance.

Table 2 Percentage of atmospheric stability during 2015

Atmospheric Stability	***Ri Number***	**On 2015**	**March-April 2015 (Wet Period)**	**September-October 2015 (Dry Period)**
Stable	>0,01	37,4%	8,6%	79,8%
Neutral	-0,01–0,01	32,7%	41,7%	20,0%
Unstable	<-0,01	29,9%	49,7%	0,2%

The percentage of atmospheric stability shows that the dry period occurs similarly to fire event and atmospheric stability much happen in stable condition (Table 2). These can happen due to the lack of sun radiation that comes on earth's surface, so that air parcels are moving close to equilibrium position or tend to be stable because of decreasing heat (Arya 2001).

Atmospheric Transmissivity Analysis and Diffuse Fraction on Particulate Concentration

Atmospheric transmissivity is the ratio between global radiation and sun radiation at the top of the atmosphere. Therefore, the size of the transmissivity of the atmosphere depends on the sun radiation which reaches the earth's surface. Atmospheric clarity can be seen through the transmissivity pattern of the atmosphere as a comparison between global radiation (H) and sun radiation at the top of the atmosphere on the earth's surface (Ho), called extraterrestrial radiation.

$$\text{Atmospheric transmissivity} = \frac{\mathrm{H}}{\mathrm{Ho}}$$

The diffuse fraction shows how much sun radiation is refracted as a result of being blocked by gases and aerosols in the atmosphere. The diffuse fraction can be obtained by comparing the diffuse radiation (Hd) with the global radiation (H).

$$\text{Diffuse fraction} = \frac{\mathrm{Hd}}{\mathrm{H}}$$

Atmospheric transmissivity with the diffuse fraction has a reverse comparison. The higher the transmissivity of the atmosphere, the lower the value of the diffuse fraction. The large amount of sun radiation that has been successfully transmitted to the earth's surface indicates low refraction of sun radiation by the atmosphere. The diffuse fraction at the time of fires reached more than 0,8, coinciding with the increase in particulate concentrations due to forest (Steigler *et al.* 2019). The figure below shows the relationship between PM_{10} concentration on the diffuse fraction and atmospheric transmissivity. The relationship between PM_{10} concentration and the diffuse fraction is positive with r = 0,85 and p-*value* = 0,00048, meaning that the higher the PM_{10} concentration in the atmosphere, the higher the diffuse fraction (Figure 4). The relationship between PM_{10} concentration and atmospheric transmissivity occurs in the opposite direction, which is negatively correlated with r = -0,8 and p- *value* = 0,0016.

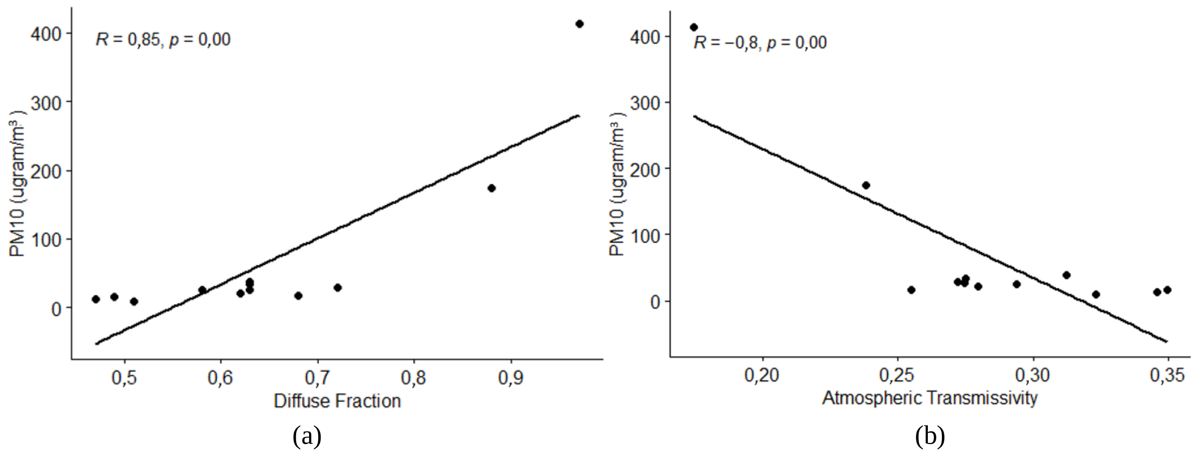

Figure 4 Correlation between PM_{10} concentration with diffuse fraction (a) correlation between PM_{10} concentration with atmospheric transmissivity (b) on 2015

Analysis of Evapotranspiration and GPP of Solar Radiation

Sun radiation is the main energy which very important for all physical processes on earth. Sun radiation acts an important role in the process of plant photosynthesis and the water balance on the earth's surface. Covered surfaces dominated by vegetation will certainly use more radiation to be used as energy to evaporate water and carbon exchange processes compared to if the land surface cover is residential or non-vegetated (Arya 2001). Atmospheric conditions covered by smog can also reduce Photosynthetically Active Radiation (PAR) as part of the global radiation, which acts in the photosynthesis process (Yamasoe *et al.* 2006). GPP calculates the rate at which carbon is captured from the atmosphere by plants as a result of gross photosynthesis, which is a major component of the carbon balance between the biosphere and the atmosphere. Below is a graph showing the relationship between GPP and PAR in 2015.

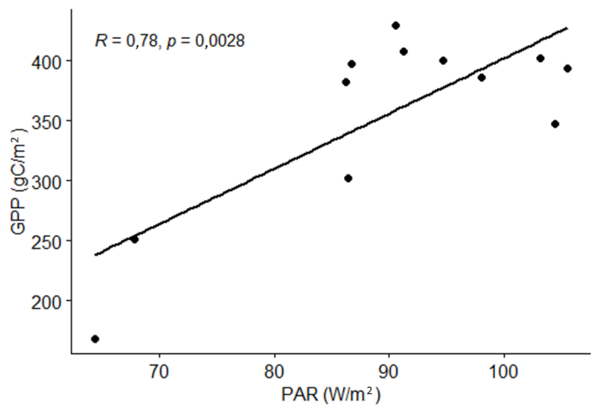

Figure 5 Correlation between PAR with GPP during 2015

GPP estimation is important because GPP is one of the variables which affects the carbon cycle, and GPP also makes an important contribution to Net Primary Productivity (NPP), total biomass, and yield of an area (June *et al.* 2006). PAR radiation is correlated with sun radiation which enter the surface of the plant canopy. PAR value can be assumed as 50% of solar radiation coming to the surface (Prasad *et al.* 2002). A high PAR value will affect the increase in GPP, because GPP is a representation of carbon fixation during photosynthesis, where it requires energy of sun radiation. The higher the PAR absorbed by the plant canopy, the higher the energy possessed by the plant is carrying out photosynthesis or carbon fixation from the atmosphere.

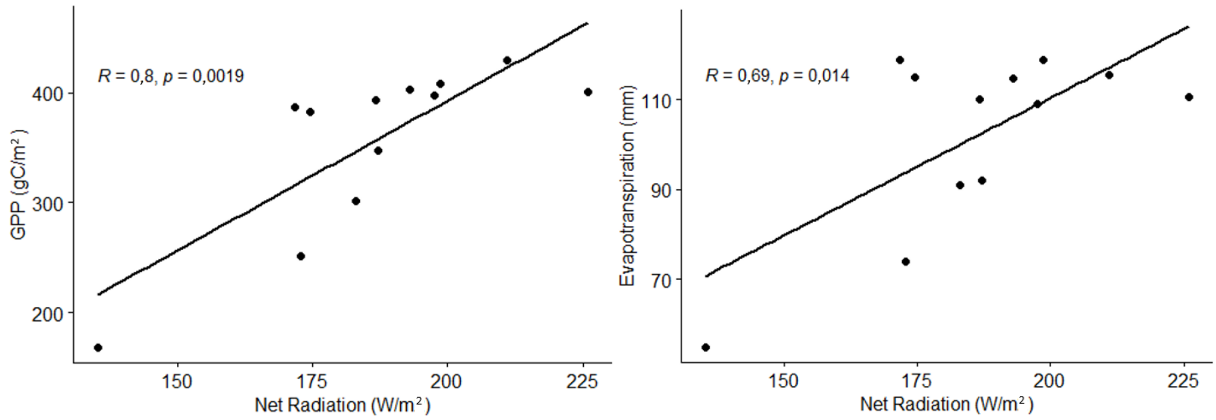

Figure 6 Correlation between GPP with monthly net radiation (a) correlation between evapotranspiration with monthly net radiation (b) on 2015

Evapotranspiration analysis for oil palm plantations is important because it is related to the water balance of vegetation. The daily pattern of evapotranspiration describes how much the loss rate of surface water (soil, water sources, and vegetation) into the atmosphere which occurs every day. Figures 5a and 5b show the relationship between net radiation with GPP and evapotranspiration. Net radiation is obtained from the calculations in equation (5). Two parameters show a significant relationship indicated by *p-value* $< 0,05$ with r = 0,80 for GPP and r = 0,69 for evapotranspiration. GPP and evapotranspiration to net radiation show a positive linear relationship, where the higher the sun radiation, the higher the GPP and evapotranspiration (Amarakoon *et al.* 2000). Therefore, it can be said that GPP and evapotranspiration are strongly influenced by the net radiation or radiation balance that reaches the earth's surface.

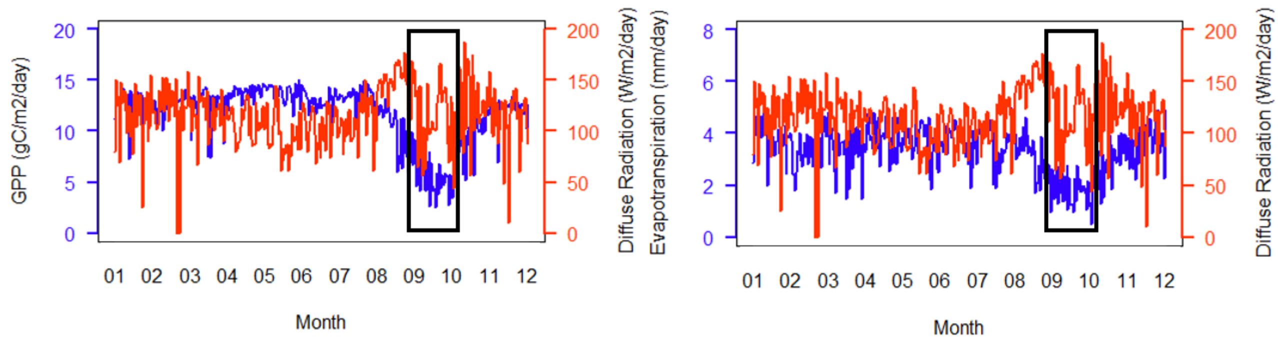

Figure 7 Daily pattern of GPP with diffuse radiation (a) daily pattern evapotranspiration with diffuse radiation (b) on 2015 (smog haze period are marked with a bold rectangle)

The daily pattern of GPP and evapotranspiration (Figure 7) shows a decrease when a fire occurs. This is due to the high concentration of aerosols in the atmosphere, resulting in weak solar radiation reaching the plant canopy (June *et al.* 2006). The greater the diffuse radiation received by oil palm plants, the lower the GPP and evapotranspiration values. The decrease in GPP can be interpreted that the greater concentration of CO_2 released into the atmosphere due to the decreased photosynthetic activity of plants or even does not occur at all. Similar to evapotranspiration which decreases because there is no energy to evaporate water on the surface or in plants, low evapotranspiration values can be interpreted as a dry environment. The lowest evapotranspiration value occurred on October 27, 2015 at 0,49 mm/day and the lowest GPP value occurred on October 11, 2015 at 2,53 gC/m^2/day.

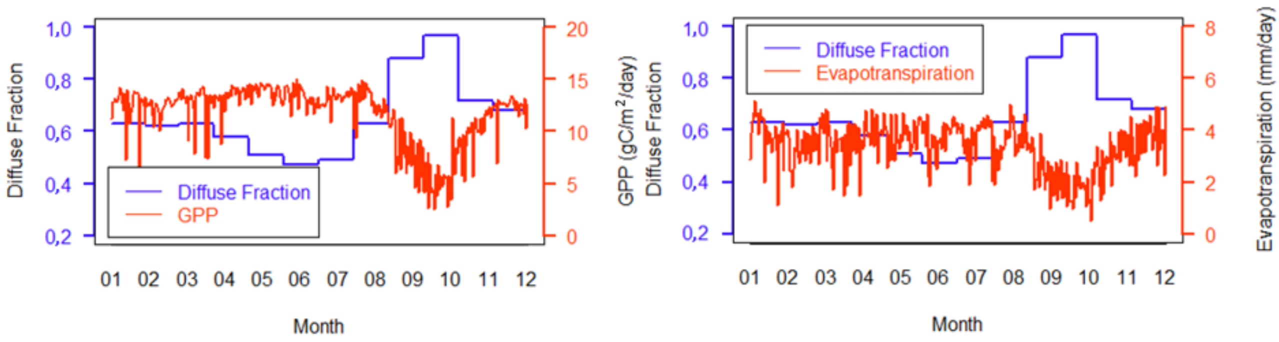

Figure 8 Daily pattern of GPP and monthly diffuse fraction (a) daily pattern of evapotranspiration and a monthly diffuse fraction (b) on 2015

The diffuse fraction represents how much the proportion of diffuse radiation in the global radiation received by the plant canopy (Figure 8). When the atmosphere was covered by thick smog haze due to fire occurrences from September to mid-November 2015, the diffuse fraction began to increase until it reached its highest peak of 0,97 in October 2015. The opposite occurred in GPP, and evapotranspiration was decreasing. This can be interpreted that the greater the diffuse fraction, the less evaporation of water on the surface of the land and plants, and the less CO_2 absorbed by oil palm plants. Plant transpiration and photosynthesis have a strong relationship because the stomata in plants are a pathway for absorbing CO_2 and releasing water vapor by transpiration. In general, a high GPP value will be followed by high evapotranspiration. But in reality, climatic conditions such as rainfall, soil temperature, or air temperature often make GPP not always followed by high evapotranspiration.

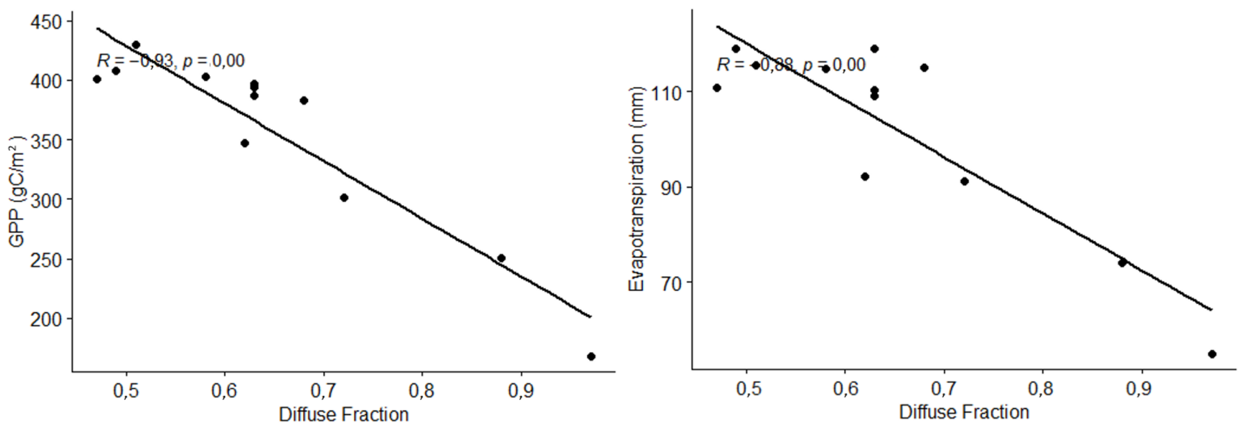

Figure 9 Correlation between GPP and monthly diffuse fraction (a) correlation between evapotranspiration and a monthly diffuse fraction (b) on 2015

Figure 9 shows the relationship between the diffuse fraction with GPP (Figure 9a) and evapotranspiration (Figure 9b). Based on the graph, the relationship between the diffuse fraction and GPP and evapotranspiration is inversely related, as explained in the previous paragraph. Both have a significant relationship with p-value < 0,05 and r = -0,93 for GPP with a diffuse fraction and r = -0,88 for evapotranspiration with a diffuse fraction. Based on the result of the correlation coefficient, GPP with diffuse radiation has a greater value than the relationship between evapotranspiration and diffuse fraction. This is in accordance with research conducted by Knohl and Baldocchi (2008), that canopy photosynthesis shows an almost identical relationship with the diffuse fraction. The impact of changes in the diffuse fraction on the respiration process in the soil, leaves, and stems is smaller than changes in photosynthesis. As the diffuse fraction increases, the efficiency of water use decreases due to a higher reduction in photosynthesis compared to transpiration.

Statistic Analysis for Data Validation

Based on the results of statistical analysis, the data simulated by the Breathing Earth System Simulator (BESS) model and observation data from the eddy tower and the micrometeorology tower at PTPN VI Batanghari, Jambi, showed a significant relationship, with a p-*value* = 0,001 and r = 0,56 in the wet period and p-*value* = 0,001 and r = 0,56 in the wet period and p-*value* = 0,01 and r = 0,45 on the dry period for evapotranspiration (Table 3).

Table 3 Result of statistic analysis on GPP between BESS data with observation data

Evapotranspiration				
Period	**r**	**p-*value***	**RMSE**	**Regression equation**
Wet	0,56	0,001	0,88 mm/day	y = 0,4089x + 2,4233
Dry	0,45	0,010	2,93 mm/day	y = 0,2274x + 1,8331
***Gross Primary Production* (GPP)**				
Period	**r**	**p-*value***	**RMSE**	**Regression equation**
Wet	0,49	0,004	2,96 $gC/m^2/day$	y = 0,1688x + 10,6392
Dry	0,39	0,030	4,51 $gC/m^2/day$	y = 0,2774x + 6,5380

And then, p-*value* = 0,005 / r = 0,49 in the wet period and p-*value* = 0,03 / r = 0,39 in the dry period for GPP (Table 3). During the dry period, the model output was slightly underestimated from the observational data. This was due to the influence of environmental conditions, one of which was the smog haze from fires. This effect will certainly affect the simulated value of the BESS model because BESS is a satellite image-based model, so it will be very sensitive to its accuracy level with atmospheric conditions or cloud cover.

CONCLUSION

Smog intensity due to fires in Jambi on 2015 was positively correlated with the diffuse fraction. This is indicated by the positive relationship between PM_{10} concentration and the positive result of diffuse fraction with r = 0,85 and p-*value* = 0,00048, meaning that the higher the PM_{10} concentration in the atmosphere, the higher the diffuse fraction. The relationship between PM_{10} concentration and atmospheric transmissivity occurs in the opposite direction, which is negatively correlated with r = -0,8 and p-*value* = 0,0016. Diffuse radiation is of high value when atmospheric conditions are covered by gases and aerosols because more solar radiation will be refracted. When the smog haze cover in the atmosphere was at its peak on October 2015, the amount of global radiation was even almost the same as the amount of diffuse radiation that entered the earth's surface. This shows that when the smog haze occurs, the incoming solar radiation is dominated by diffuse radiation due to reduced global radiation.

The decreasing of global radiation that enters the earth's surface will certainly have an impact on vegetation land cover, one of which is oil palm plantations. Sun radiation is energy that is very important for processes that exist in plants, such as photosynthesis and transpiration. GPP and evapotranspiration which decreased during fires, were caused by the decrease of sun radiation received by the plant canopy. GPP and evapotranspiration are inversely compared to the diffuse fraction, it can be interpreted that the larger the diffuse fraction, the less evaporation of water on the land and plant surfaces and the less CO_2 absorbed by oil palm plants. Plant transpiration and photosynthesis have a strong relationship because the stomata in plants is a way for absorbing CO_2 and releasing water vapor by transpiration.

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REFERENCES

Agustiana S, Wandri R, Asmono D, Herlinda S. 2018. Performa tanaman kelapa sawit pada musim kering di Sumatera Selatan; pengaruh defisit air terhadap fenologi tanaman. Prosiding Seminar Nasional Lahan Suboptimal; 18-19 Oktober 2018; Palembang, Indonesia. Palembang: Universitas Sriwijaya. p 67–73; [Accessed 2022 Feb 28]. http://conference.unsri.ac.id/index.php/lahansuboptimal/article/view/1279.

Amarakoon D, Chen A, McLean P. 2000. Estimating daytime latent heat flux and evapotranspiration in Jamaica. *Agricultural and Forest Meteorology*. 102:113–124.

Arya SP. 2001. *Introduction to Micrometeorology*. California (CA): Academic Press.

Davidson CI, Phalen RF, Solomon PA. 2007. Airborne particulate matter and human health: a review. *Aerosol Science and Technology*. 39(8):737–749.

Gana NN, Rai JK, Momoh M. 2014. Estimation of global and diffuse solar radiation for Kebbi, North-Western, Nigeria. *International Journal of Scientific and Engineering Research*. 5(1):1654–1661.

Henson IE. 1999. Comparative ecophysiology of oil palm and tropical rain forest. *Oil and Environment*. 9–39.

June T, Dewi NWSP, Meijide A. 2018. Perbandingan Metode Aerodinamik, Bowen Ratio dan Penman-Monteith dalam penentuan evapotranspirasi pertanaman kelapa sawit. *Agromet*. 32(1):11–20.

June T, Ibrom A, Gravenhorst G. 2006. Integration of NPP semi mechanistic-modelling, remote sensing and GIS in estimation CO2 absorption of forest vegetation in Lore Lindu National Park. *BIOTROPIA*. 13:22–36.

Kamil NN, Omar SF. 2017. The impact of el nino and la nina on Malaysian palm oil industry. *Oil Palm Bulletin*. 74:1–6.

Khan MM, Ahmad MJ. 2012. Estimation of global solar radiation using clear sky radiation in Yemen. *International Research Journal of Engineering Science, Technology and Innovation (IRJESTI)*. 1(9):228–237.

Knohl A, Baladochhi DD. 2008. Effects of diffuse radiation on canopy gas exchange processes in a forest ecosystem. *Journal of Geophysical Research*. 113:1–17.

Ogbulezie JC, James UO, Chukwujindu NS. 2017. A review of regression models employed for predicting diffuse solar radiation in North-Western Africa. *Tr Ren Energy*. 3(2):160–206. doi:10.17737/tre.2017.3.2.0042

Prasad VK, Kant Y, Badarinath KVS. 2002. Estimation of potential GHG emissions from net primary productivity of forest: a satellite based approach. *Adv Space Res.* 29:1793–1798.

Steigler C, Meijide A, Fan Y, Ali AA, June T, Knohl A. 2019. El Niño–Southern Oscillation (ENSO) event reduces CO_2 uptake of an Indonesian oil palm plantation. *Biogeosciences.* 16:2873–2890.

Sumbung FH, Letsoin Y. 2012. Analisa dan estimasi radiasi konstan energi matahari melalui variasi sudut panel fotovoltaik SHS 50 WP. *Jurnal Ilmiah Mustek Anim Ha.* 1(1):55–65.

Yamasoe MA, von Randow V, Manzi AO, Schafer JS, Eck TF, Holben BN. 2006. Effect of smoke and clouds on the transmissivity of photosynthetically active radiation inside the canopy. *Atmos Chem. Phys.* 6:1645–1656.