Sensible heat flux of oil palm plantation: Comparing Aerodynamic and Penman-Monteith Methods

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Abstract. Oil Palm (*Elaeis guinensis* Jacq) has a unique morphological characteristics, in particular it has a uniform canopy. As the plant become older, its canopy coverage will completely cover the surface and influence characteristics of its microclimate. Sensible heat flux estimation of oil palm plantation could be used to identify the contribution of oil palm in reducing or increasing heat to its surrounding environment. Determination of heat flux from oil palm plantation was conducted using two methods, Aerodynamic and Penman-Monteith. The result shows that the two methods have similar diurnal pattern. The sensible heat flux peaks in the afternoon, both for two and twelve years oil palm plantations. Sensible heat flux of young plantation is affected by atmospheric stability (stable, unstable and neutral), and is higher than that of older plantation, with mean values of 0.52 W/m² (stable), 43.53 W/m² (unstable), 0.63 W/m² (neutral), with standard deviation of 0.50, 28.75 and 0.46 respectively. Sensible heat flux estimated by Penman-Monteith method in both young and older plantation was higher than the value determined by Aerodynamic method with respective value of 0.77 W/m² (stable), 45.13 W/m² (unstable) and 0.63 W/m² (neutral) and 0.34 W/m² (stable), 35.82 W/m² (unstable) and 0.71 W/m² (neutral).

1. Introduction

Oil Palm (*Elaeis guinensis* Jacq) is a plantation crop from West Africa, which can grow well in the humid tropics like Indonesia. It has a unique morphological characteristics, in particular it has a uniform canopy [1]. As the plant become older, its canopy coverage will completely cover the surface and influence characteristics of its microclimate, including the absorption of solar radiation, wind speed, air temperature, and relative humidity as well as other elements of microclimate.

Sensible heat flux is the energy required to heat the air, in addition to the heat flux was also associated with an increase and decrease in temperature and serves to keep the temperature of the environment in order to maintain at the optimum interval [2]. Several methods have been developed to Determine the value of heat flux feels one of them with the estimate or calculate the gradients of temperature and humidity at or near PBL *(Planetary Boundary Layer)*, this research compared two methods, Aerodynamic and Penman-Monteith, identify the contribution of oil palm in reducing or increasing heat to its surrounding environment. Since there is little difference in the needs of weather data and climate data for both methods, so it is important to do a comparison between the two methods. Research aims are to determine the sensible heat flux of different age-oil palm plantation and to compare Aerodynamic and Penman-Monteith Methods.

2. Methods

Measurement of solar radiation, wind velocity, air temperature, soil temperature and relative humidity in 2 year old oil palm plantation (Pompa Air Village) running for 7 months July 2013 – February 2014, sensor of solar radiation installed above oil palm plantation, sensor wind velocity (anemometer), air temperature (thermometer), soil temperature and relative humidity installed at three heights are 2.4 meters, 3.15 meters and 5.8 meters and 12 year old oil palm plantation (PTPN VI) march – October 2014, sensor of solar radiation installed above oil palm plantation , sensor wind velocity (anemometer), air temperature (thermometer), soil temperature and relative humidity installed at three heights are 13 meters, 15.4 meters and 21.7 meters. Measurements in 2 year old oil palm plantation (Pompa Air Village) and 12 year old oil palm plantation (PTPN VI) are research collaboration with *CRC 990 subproject A03, EFForts projects (University of Goettingen)*. Because measurements must be made on the planetary boundary layer, so that the measurements were taken at three heights for both oil palm age.

2.1. Stability atmosphere

$$Ri = \frac{g(\frac{\delta\theta}{\delta z})}{T'(\frac{\delta u}{\delta z})^2} \qquad (1)$$

where g is acceleration due to gravity (9.8 m/s^2), θ_a is the average potential temperature (K) at a height of z1 and z2. These measurements were performed at a position close to the surface (2 years old oil palm plantation, with the highest measurement position 5.8 meters and 12 years old oil palm plantation, with the highest measurement position 21.7 meters) [3].

2.2. Aerodynamic methods

$$H = -\rho_a C_p k^2 \frac{(u_2-u_1)(\theta_2-\theta_1)}{\left[ln\left(\frac{z_2-d}{z_1-d}\right)\right]^2 \varphi_m \varphi_s} \qquad (2)$$

On the atmospheric conditions of stable and unstable or in addition to neutral, formula sensible heat flux (H) in equation (6) must be corrected, because the equation can only be used on the atmospheric conditions of neutral, correction equations can be done by using a correction factor Monin-Obukhov Stability parameter, Monin-Obukhov stability parameters at every condition of atmospheric stability is shown in the following equation [4]:

$\zeta = Ri$ for $Ri < 0$ (3)
$\zeta = Ri/(1\text{-}5Ri)$ for $0 \le R \le 0{,}1$ (4)
$\zeta = 0{,}2$ for $Ri > 0{,}1$ (5)

Monin-Obukhov value of parameter of stability is obtained, then the substitution to the following equation dimensionless wind shear [4]:

$\Phi_s = \Phi m^2 = (1-5\zeta)^{-1/2}$ for $\zeta < 0$ (6)
$\Phi_s = \Phi m = 1-5\zeta$ for $\zeta \ge 0$ (7)

where ρ is the density of air (Kg / m3), Cp is specific heat at constant pressure (1004.2 J / kg / K). and K is the Von Karman constant with a value (0.4). For level measurement is low (2 years old oil palm plantation) use absolute temperature, (T) in units of kelvin and for level measurement of high (12 years old oil palm plantation) use potential temperature (θ) in units of kelvin where θ = T - Γdz, with Γd is *dry adiabatic lapse* rate of -0.00976 K/m.

2.3. Penman-Monteith methods

$$L_E = \frac{\Delta(Rn-G)+ \rho_a C_p(e_s-e_a)/r_a}{\Delta+ \Upsilon[1+\frac{r_s}{r_a}]} \quad (8)$$

where L_E is latent heat flux (MJ m^{-2} day^{-1}), Δ is the slope of the vapor pressure curve (kPa˚C^{-1}), Rn is net radiation (MJ m^{-2} day^{-1}), G is the soil heat flux (W m^{-2}), (e_s - e_a) shows the deficit pressure of vapor of the air, ρa is the average air density at constant pressure, γ is the psychometric constant (kPa˚C^{-1}), Cp is the specific heat capacity of air at constant pressure (1.013x 10^{-3} MJ kg^{-1}˚C^{-1}), ra is the aerodynamic resistance (s m^{-1}) and r_s is canopy resistance (s m^{-1}) [5].

Residual of evapotranspiration using the Penman-Monteith method of equation above, can be used to estimate the sensible heat flux was using the energy balance equation, with the assumptions net radiation (Rn) is distributed to $L_E, H, G\ dan$ S, can use the following equation:

$$R_n - LE - G - H - S = 0 \quad (9)$$

or

$$H = R_n - (L_E + G + S) \quad (10)$$

Where:

H : Sensible Heat Flux (W/m²)
Rn : Net Radiation (W/m²)
L_E : Laten Heat Flux (W/m²)
G : Ground Heat Flux (W/m²)
S : *Storage* (W/m²)

3. Result

3.1 Study area

Pompa Air Village located in the Province of Jambi, Bajubang Sub District, Batang District, located at a latitude of 01^0 52'06" south latitude and 103^0 15'17" east longitude. With a height of between 11-500 meters above sea level, air temperature ranged between 20˚C - 30˚C and annual rainfall between 2265 to 2976 mm [6]. PTPN VI located in the province of Jambi, Kotabaru Sub District. Jambi District located between 01^0 38'19" south latitude and 103^0 34'42" east longitude. With a height of 0-60 meters above sea level. The average air temperature ranged between 22˚C - 32˚C with an annual rainfall average of 2296 mm [7].

3.2 Characteristics micrometeorology

3.2.1 Global radiation

Solar radiation is an energy been derived from thermonuclear process that occurs in the sun. The variation of the average diurnal solar radiation above 2 years old oil palm plantation (Pompa Air Village) and 12 years old oil palm plantation (PTPN VI). Shown in figure 2. From the morning towards midday, The incandescence of the air above 12 years old oil palm plantation is happening faster then the 2 years old oil palm plantation. Although the global radiation on average in the 12 years ol oil palm plantation is lower then the 2 years old oil palm plantation.

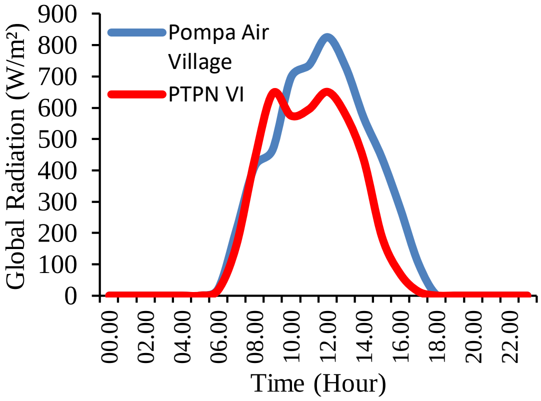

Figure 1. Average diurnal variation of global radiation in 2 year old plantation (Pompa Air Village) and 12 years old plantation (PTPN VI), Jambi

3.2.2 Air temperature and relative humidity

Air temperature is the manifestation of sensible heat flux. Based on figure 2 two research areas show that increasing the height of areas decreases its temperature tend to be declining. Based on theory, the air density near the surface during the day is higher than the layers above it and the acceptance of reflected radiation from the Earth's surface is more, so temperature near the surface is higher than the above layer, because the existence of air turbulence or mass movement such as the high wind speed, causes the mixture of air masses and air temperature tend to be homogeneous, so the difference air temperature between the height is relatively small .

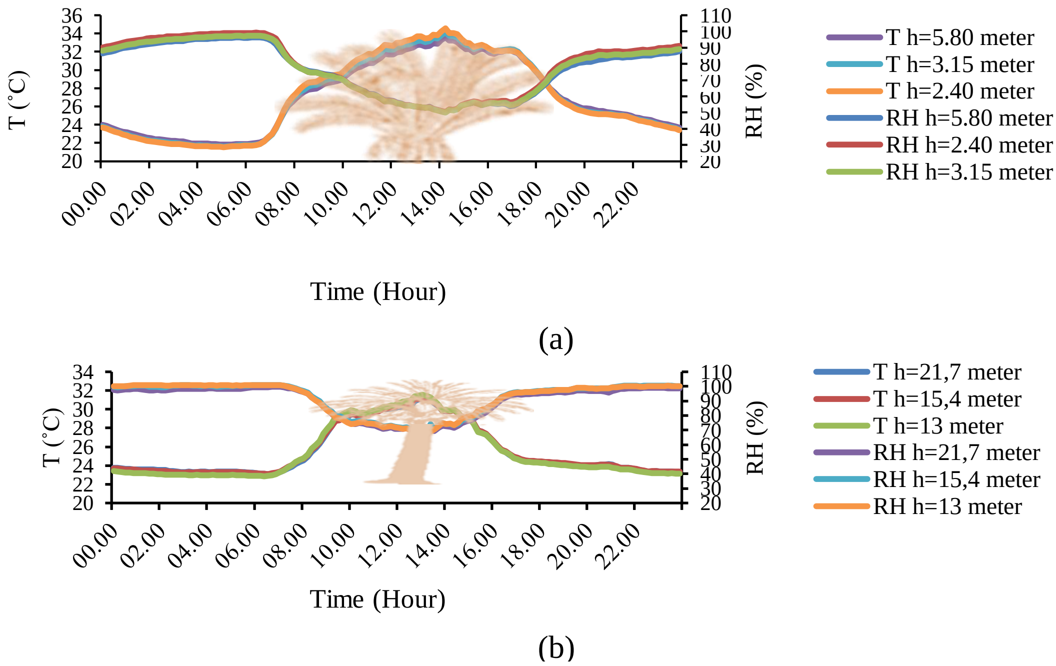

Figure 2. Average diurnal variation of temperature and relative humidity in 2 year old plantation (Pompa Air Village) and 12 years old plantation (PTPN VI), Jambi

3.2.3 Wind speed

Wind speed profile in the area of oil palm plantation, Pompa Air Village measured at height of 2.40 m, 3.15 m and 5.80 m have almost same diurnal variation. The same is also shown by the wind speed profile in the region of PTPN VI measured at a height of 13 meters, 15.4 m and 21.7 m. Based on figure 5, maximum wind speeds in the oil palm plantation of age 2 years (Pompa Air Village) happens at 12.00 WIB with a value 2.56 m/s and the maximum wind speed in the oil palm plantation of age 2 years (PTPN VI) happens at 13.00 WIB with a value 2.3 m/s. The higher altitude will increase the wind speed, because at the height near land surface the movement of air will be hampered by the existence of friction between the surface of the style that is caused by the interaction between the surface by the air above it, so experiencing barriers in the form of friction, that cause wind speed declining.

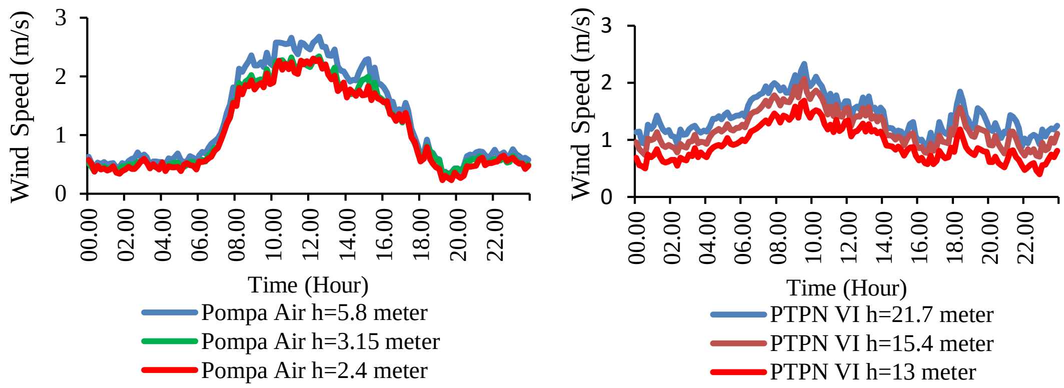

Figure 3. Average diurnal variation of wind speed on oil palm plantations (a) the age of 2 years (Pompa Air Village) and (b) the age of 12 years (PTPN VI)

3.3 Roughness characteristic parameters

Roughness characteristics parameters can be determined by three parameters, there are the zero-plane displacement (d), friction velocity (u *) and roughness length (z_0) [8] is obtained from the profile wind speed, because surface roughness can be known through data analysis wind speed at the top of the canopy on the state of the atmosphere is neutral [9], because the atmospheric conditions of neutral assumed to be able to represent the roughness condition in all conditions of atmospheric stability and the neutral condition, shear stress that occurs purely because of friction with the roughness parameters and no flux of vertical mass or buoyancy such as unstable atmospheric conditions [10].

Zero-plane displacement (d) is a function of the height and density and the mechanical state of the plant [11, 12]. Based on calculations, the value of the zero-plane displacement (d) of oil palm (Pompa Air Village) is lower than the oil palm plantations (PTPN VI) with value of 2.08 meter and 12.44 meter respectively. Zero-plane displacement (d) will be higher if the the roughness length increases and when it near the height of the canopy [4].

Table 1. The average zero-plane displacement (d), friction velocity (u *) and roughness length (z_0) in oil palm plantations age 2 years (Pompa Air Village) and age 12 (PTPN VI) Jambi

Location	Heigh (m)	d (m)	u* (m/s)	z_0 (m)
Pompa Air Village	2.5	2.08	0.03	0.0006
PTPN VI	13	12.44	0.17	0.006

The value of friction velocity (u*) and roughness length (z0) on 2 year old oil palm plantation (Pompa Air Village) and 12 year old oil palm plantation (PTPN VI) are different (Table 1). The value of friction velocity (u*) tends to increase with increasing wind speed [13].*Stability of atmosphere*

Based on the Richardson number (RI), there are three categories of atmospheric stability: neutral (Ri ± 0.01), stable (Ri < 0:01) and unstable (Ri > 0:01). The results show that the atmospheric stability in the plantation Pompa Air Village (3a) and PTPN VI Jambi (3b) are neutral, stable and unstable. However, for the stability of the atmosphere in the neutral condition it is very rare. Although the neutral atmospheric conditions at both areas are relatively small, the data in these conditions can be used to determine the roughness characteristic parameters (figure 4). That's because the atmospheric stability at neutral condition is considered to be representative of condition of roughness in all conditions of atmospheric stability, logarithmic wind profile and also lack of influence bouyancy, so purely the influence from surface characteristics itself [10].

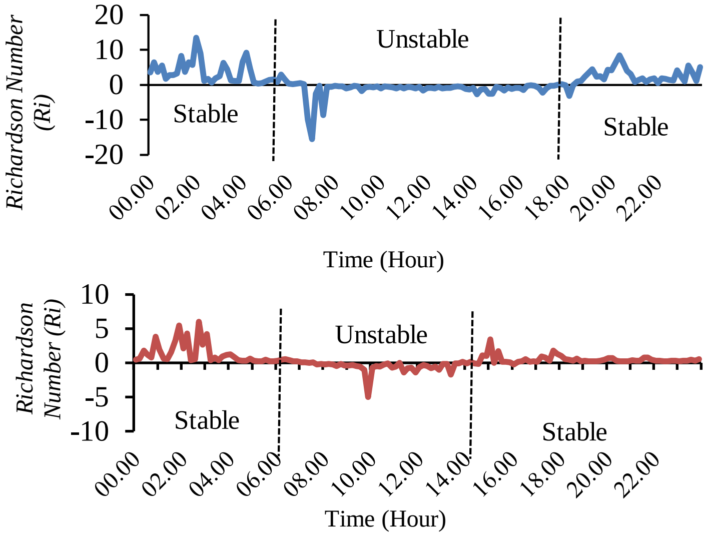

Figure 4. Variation diurnal of Richardson Number in oil palm plantations (a) the age of 2 years (Pompa Air Village) and (b) the age of 12 years (PTPN VI)

3.4 Sensible heat flux profile

Sensible heat flux is the energy required to heat the air. Expression of sensible heat flux is the temperature. Heat flux was a heat transfer that could be felt through the air from one place to another. The flux density is expressed as energy per unit time per unit surface area (W/m^2). Estimation of oil palm in reducing heat to its surrounding environment. Figure 1 shows similar diurnal variations. The peak of sensible heat flux happen in the afternoon, both for two and twelve years oil palm plantations. Sensible heat flux of young palm plantation is higher than the older plantations, with mean value 0.52 W/m^2 (stable), 43.53 W/m^2 (unstable), 0.63 W/m^2 (neutral), with standard deviation of 0.50, 28.75 and 0.46 respectively and the old plantation is 0.29 W/m^2 (stable), 35.38 W/m^2 (unstable) dan 0.47 W/m^2 (neutral), with standard deviation of 0.54, 23.39 and 0.46 respectively (table 1). Sensible heat flux estimated by Penman-Monteith method in both study areas was higher than the value estimated by Aerodynamic method with respective value of 0.77 W/m^2 (stable), 45.13 W/m^2 (unstable) dan 0.63 W/m^2 (neutral), with standard deviation of 0.96, 29.61 and 0.91 respectively dan 0.34 W/m^2 (stable), 35.82 W/m^2 (unstable) dan 0.71 W/m^2 (neutral), with standard deviation of 0.20, 24.31 and 0.90 respectively (table 2).

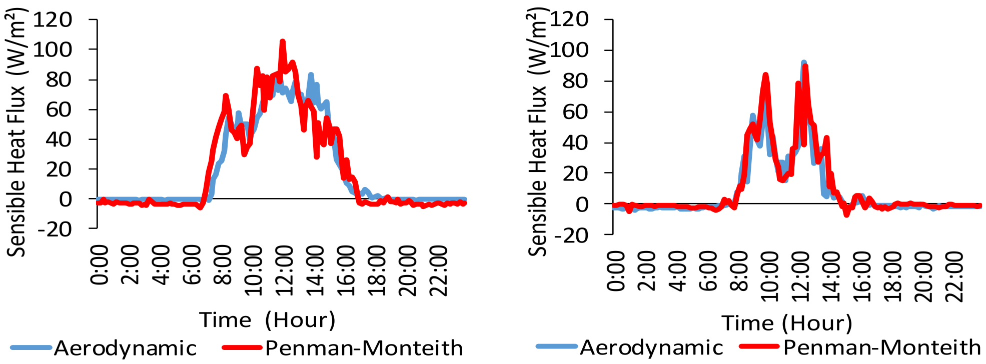

Figure 5. Sensible heat flux variation of oil palm plantation (a) age 2 years (Pompa Air Village) and (b) age 12 years (PTPN VI) by aerodynamic and Penman-Monteith methods.

Table 2. Average diurnal sensible heat flux of oil palm plantation in each situatuion of atmospheric stability in Pompa Air Village and PTPN VI, Jambi

Method	Pompa Air Village (2 years old) W/m²	Standard Deviation	PTPN VI (12 years old) W/m²	Standard Deviation
Aerodynamic				
Stable	0.27	0.24	0.24	0.88
Unstable	41.94	27.9	34.95	22.47
Neutral	0.27	0.01	0.23	0.02
Penman-Monteith				
Stable	0.77	0.76	0.34	0.20
Unstable	45.13	29.61	35.82	24.31
Neutral	0.73	0.91	0.71	0.90
Average				
Stable	0.52	0.50	0.29	0.54
Unstable	43.53	28.75	35.38	23.39
Neutral	0.63	0.46	0.47	0.46

RMSE (Root Mean Square Error) showed 8.9 between the method of Penman-Monteith and aerodynamic for plantation Pompa Air Village Jambi and 3.4 for observation at the plantation PTPN VI, can be said to be a match between the method Penman-Monteith with aerodynamics in both areas, which can also be seen from a high correlation coefficient between the two methods (r = 1 to the Village Pump and 0.99 for PTPN VI) and Agreement Index score between the two methods at two research sites close to the value 1. So the methods of aerodynamic and Penman-Monteith are a perfect fit to estimate the heat flux was (table 3)

Table 3. Statistical calculation of sensible heat flux by Aerodynamic and Penman-Monteith Methods

	Pompa Air Village	PTPN VI
Average of Sensible Heat Flux:		
Penman-Monteith	20.03	9.93
Aerodinamik	20.02	8.43
RMSE	8.9	3.4
I.A (*Index of Agreement*)	0.98	0.99
r^2	0.92	0.98
R	1.00	0.99

4. Conclusion

Sensible heat flux estimation using aerodynamic and penman-monteith methods show a similar diurnal variation in 2 years and 12 years aged oil plantation. Penman-monteith method show a higher estimation than aerodynamic method and 2 years aged oil plantation show a higher estimation than 12 years aged oil plantation. Sensible heat flux of young plantation is affected by atmospheric stability (stable, unstable and neutral), and is higher than that of older plantation. Sensible heat flux estimated by Penman-Monteith method in both young and older plantation was higher than the value determined by Aerodynamic method.

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