Seasonal analyses of carbon dioxide and energy fluxes above an oil palm plantation using the eddy covariance method

Anis Ibrahim[1], Yusri Yusup[1], and Haniff Harun[2]

[1] Environmental Technology, School of Industrial Technology, Universiti Sains Malaysia (USM), Pulau Pinang, Malaysia.
[2] Biology Department, Malaysian Palm Oil Board (MPOB), Bangi, Selangor, Malaysia.

Introduction

Palm oil is a major agricultural product of the Southeast Asia region. The oil palm tree is a very productive tropical C3 plant, a plant that uses Calvin cycle for fixing CO_2 in the air and produces three carbon molecules of 3-phosphoglyceride acid (3-PGA). Hence, oil palm can substantially absorb CO_2 from the atmosphere. Studies have also shown that rainfall (or monsoon season) influences oil palm productivity. Long-term direct measurements of CO_2 uptake by oil palm plantations can enable us to understand the effects of monsoon seasons on oil palm CO_2 absorption and productivity. Regarding ecosystem-wide energy balance, sensible heat (H) and latent heat (LE) are significant determinants of energy released or absorbed from the oil palm ecosystem, which is also related to productivity through the transpiration process. Using the eddy covariance method, we attempt to understand the relationship between CO_2 uptake and monsoon season and to assess LE and H fluxes over oil palm canopies.

Methodology

A 30-m tower mounted with an eddy covariance (EC) system was installed at the MPOB (Malaysian Palm Oil Board) Research Station in Keratong, Pahang, Malaysia (2°47'20.10"N, 102°55' 57.89"E), in a 17 years old oil palm plantation from September 2013 to October 2016 (Figure 1). Oil palm canopy height was 17.3 m.

Instrument	Measured Variables	Unit
3D sonic anemometer (CSAT3, Campbell Scientific)	Sensible heat flux (H)	W/m²
	Wind speed (u, v, w)	m/s
	Soil Temperature (T_s)	K
Open-path CO_2/H_2O infrared gas analyzer (LI7500A, LI-COR)	Latent heat flux (LE)	W/m²
	CO2 flux	µmol/m²/s
	Density (ρ)	kg/m³
Air temperature and RH sensors (HMP155, Vaisala)	Air temperature (T_a)	K
	Relative humidity (RH)	%
Wind speed and direction sensor (5103V, RM Young)	Wind speed (U)	m/s
	Wind direction	° (North)
Rain gauge (TR-525M)	Precipitation	mm
Net radiometer (CNR4)	Net radiation (Rn)	W/m²

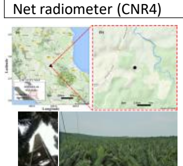

Figure 1. Location of EC tower (2°47'20.10"N, 102°55' 57.89"E) and view of the oil palm canopy

Energy Balance Closure (EBC)

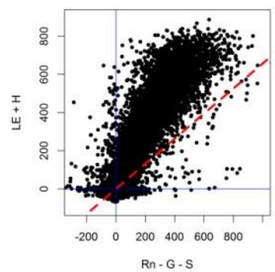

Figure 2. Energy balance closure analysis

Figure 2 indicates that the surface energy fluxes (LE + H exceeds available energy (Rn – G – S). The energy balance ratio (EBR) was 0.66 with R^2 value 0.82. However, researchers frequently reported that (LE + H) were underestimated by 10 – 30%, which stem from unaccounted processes such as advection, neglected energy sink or even sampling error.

Results

Diurnal CO_2 Flux, LE and H Fluxes

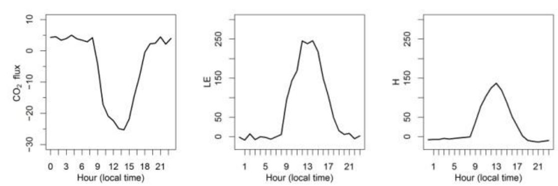

Figure 3. The diurnal linkages between CO_2 flux, LE and H.

Seasonal Rainfall

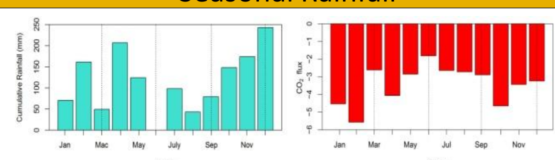

Figure 4. Seasonal variation of net monthly CO_2 exchange and rainfall over the 17-year-old oil palm plantation.

Monthly CO_2 Flux

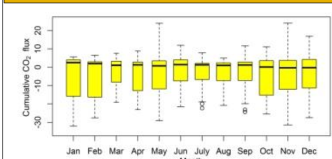

Figure 5. Monthly averaged boxplots of CO_2 flux for the entire duration of the analysis.

Net Radiation

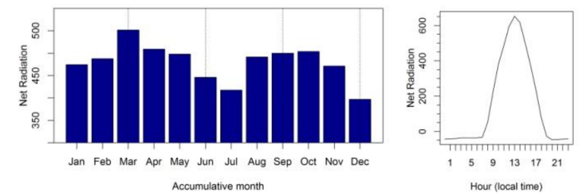

Figure 6. Monthly and diurnal variations of net radiation (W m^{-2})

Discussion

- EBC gave a slope between LE and H and total incoming energy of 0.65 with an R^2 = 0.82 and EBR = 0.66. (Figure 2)
- At the diurnal scale, CO_2, LE, and H exhibited an apparent daily trend where CO_2 flux was at its minimum −3.59 µmol m^{-2} s^{-1} in the mid-afternoon and maximum – 0.004 µmol m^{-2} s^{-1} in the morning while LE and H behaved conversely to CO_2 flux. (Figure 3)
- The average CO_2 flux was – 0.37 µmol $m^{-2}s^{-1}$, which indicates that the oil palm plantation was a strong sink. At the seasonal time scale, CO_2 fluxes did not show any apparent trend except that during the Northeast Monsoon (Dec – March) when the highest variability of the monthly means of CO_2 occurred. (Figure 4)
- The annual average of rainfall was 1400 mm. The highest rainfall event was during the Northeast Monsoon. Rainfall increases soil respiration and weakens photosynthesis. Decreased CO_2 uptake is clearly seen at the beginning of the wet season or Nov – Dec (Figure 4) in which CO_2 flux was low. In January, the rainfall reduced, which caused greater uptake of CO_2. However, in the Southeast Monsoon (Jun – Sep), the result contradicts this phenomenon while both of the inter-monsoon seasons coincided well.
- Net radiation shows consistency with seasons. Maximum net radiation occurred in the first inter-monsoon (Mar – May) season. (Figure 6)
- At the seasonal time scale, CO_2 fluxes did not show any noticeable trend except that in the first three months of the Northeast Monsoon (Dec – March) in which CO_2 uptake increased with RN.

Conclusion

The CO_2 fluxes varied with rainfall but showed no apparent trend with monsoon seasons. The CO_2 diurnal analysis shows an expected pattern, where maximum absorption was at about noon (11:00 – 13:00 local time) when LE and H were also at their maximum.

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