The greenhouse gas and energy balance of a commercial oil palm plantation in tropical lowland Jambi province (Sumatra, Indonesia)

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1 Background

In the past decades Indonesia has experienced substantial land-use changes from forests to oil palm (*Elaeis guineensis* Jacq.) plantations due to the world's high demand for cheap vegetable oil.

Oil palm expansion affects ecosystem properties and functions such as biodiversity, microclimate, carbon pools and greenhouse gas balance. However, there is still limited information on the annual CO_2 budgets of oil palm plantations at the ecosystem scale. Further, the overall high rate of nitrogen-based fertilization in oil palm plantations, and related emission of nitrous oxide (N_2O) raises concern over potential long-term impact of oil palm agricultural practices on climate. With respect to climate change, changes in precipitation pattern and increase in the magnitude and frequency of extreme events such as El Niño Southern Oscillation (ENSO) may severely stress oil palm which may lead to a reduction in carbon and water uptake rates.

2 Study aim

- Quantify the full greenhouse gas balance (N_2O, CO_2, CH_4) and surface energy budget, as well as microclimate of a large scale, mature commercial oil palm plantation in the tropical lowlands of Jambi province (Sumatra, Indonesia).
- Gain an understanding of oil palm greenhouse gas budget and its drivers, global warming potential, surface energy exchange, as well as oil palm response to meteorological extremes such as El Niño-Southern Oscillation (ENSO).

3 Materials and methods

Study site:

The study site is located in a large scale, mature commercial oil palm plantation in the tropical lowlands of Jambi province on Sumatra, Indonesia (1°41'35.0" S, 103°23'29.0" E, 76 m a.s.l.). The oil palm plantation covers approx. 2000 ha and oil palms were planted between the years 1999 and 2004. Average oil palm height is approx. 13 m.

Fig. 1: Climate measurement tower (**A**), top-of-tower view (**B**), below-canopy structure (**C**).

Measurement setup and measured parameter:

Parameter	Sensor	Instrument height or depth
N_2O fluxes and water vapor	N_2O/CO Analyzer (Los Gatos Research Inc.)	22 m
Water vapor & CO_2 fluxes	LI7500A (LI-COR Inc.)	22 m
CH_4 fluxes	Static vented chambers	0 m
Wind speed & direction	uSonic-3 Scientific (METEK GmbH)	22 m
Radiation	CNR4 (Kipp & Zonen)	22 m
PAR	PQS1 (Kipp & Zonen)	22 m
Air temperature & humidity	Thies Clima	22 m
Precipitation	Thies Clima	11.5 m
Soil moisture & temperature	TRIME-PICO32 (IMKO GmbH)	-5 cm

Table 1: Meteorological measurements, instrument type and sensor height or depth.

Scan the QR-code to see a drone video of the plantation

Scan the QR-code to see a drone video of the measurement tower and instruments

Data collection and processing:

- Continuous measurements of CO_2 and H_2O gas exchange, surface energy balance components and meteorological parameters since May 2014 (Meijide et al., 2017), N_2O gas exchange measurements since August 2017
- Eddy covariance measurements: 10 Hz sampling frequency, fluxes were calculated for 30-minute intervals (EddyPro 6.2.0 software), standard flux processing and data quality checks, no gap filling for N_2O fluxes, online gapfilling tool for CO_2 fluxes (Meijide et al., 2017; Stiegler et al., 2019)
- Climatic variables: measured every 15-s and averaged to 10- and 30-minute intervals
- CH_4 fluxes: measurement campaign in 2014 & 2015 with static vented chambers, sample analysis with a gas chromatograph (flame ionization & electron capture detector) (Hassler et al., 2015)

4 Results and discussion

Global warming potential (GWP):

The oil palm plantation is a source of greenhouse gases, with a total global warming potential (GWP) of 720 g CO_2 equivalent m^{-2}. Nitrous oxide (N_2O) plays an important role in the greenhouse gas balance of the plantation due to the high fertilizer application while the role of methane (CH_4) is negligible due to the high mineral content of the soil.

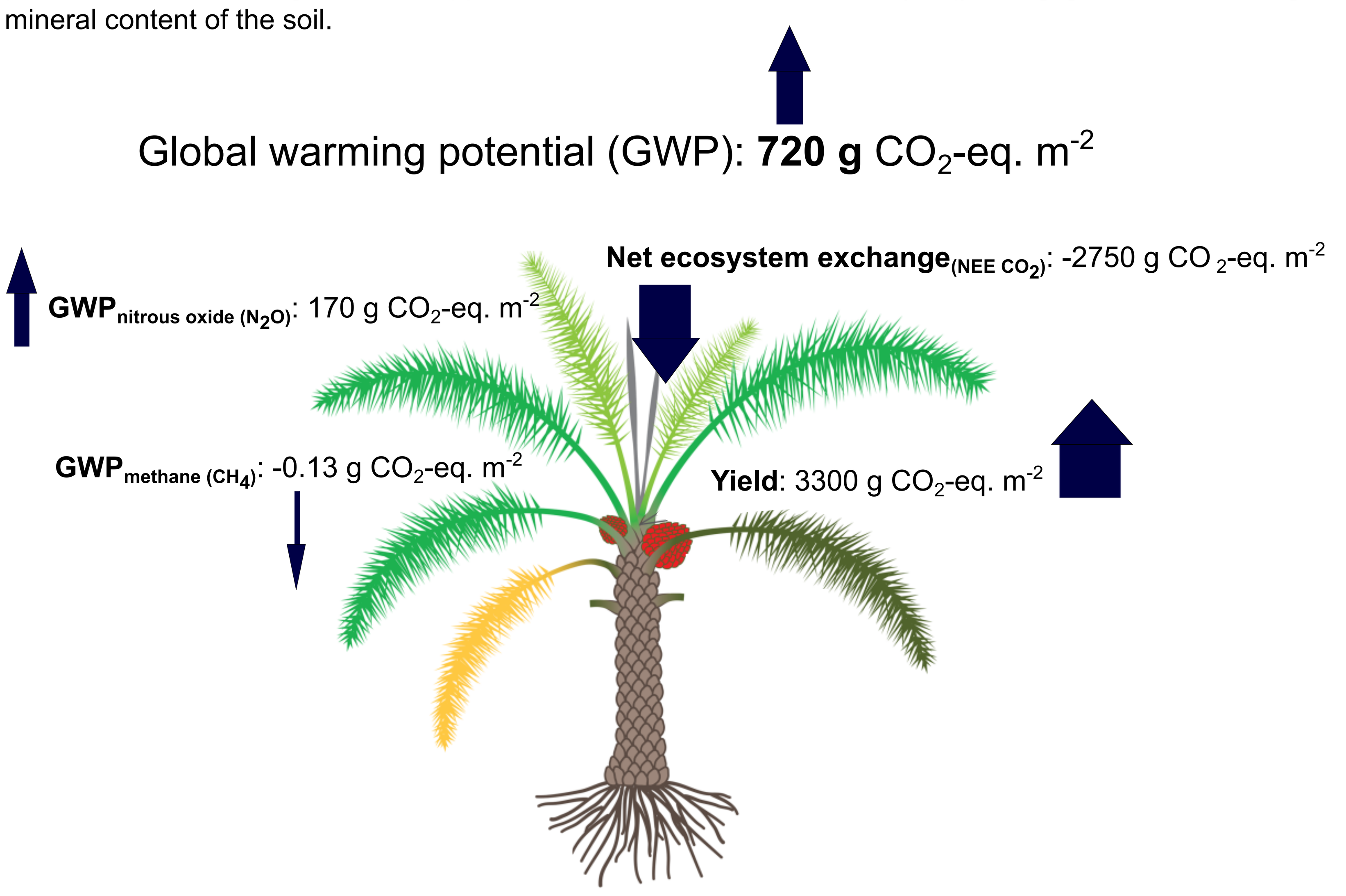

Fig. 2: Global warming potential (GWP) of the oil palm plantation.

Methane (CH_4):

The plantation is a small sink of CH_4. Fluxes of CH_4 are much larger in the peat soils but they cover only 5-10% of the total plantation area.

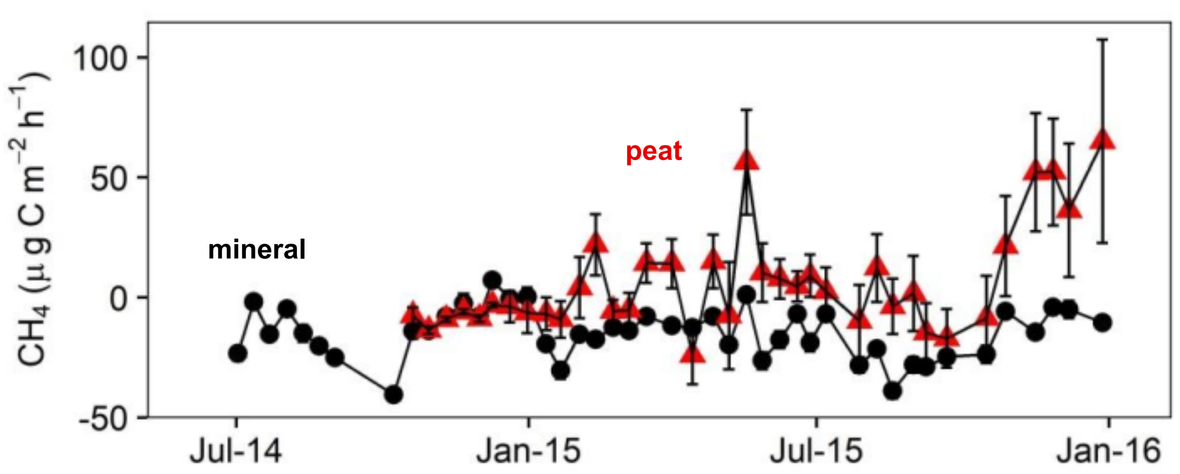

Fig. 3: Mean soil methane (CH_4) fluxes in the oil palm plantation on mineral (black dots) and adjacent peat soils (red triangles). Bars represent standard errors, with n = 4 for mineral soils and n = 3 for peat soils.

Nitrous oxide (N_2O):

The oil palm plantation is a strong source of N_2O, with average flux of 43.3 µg N_2O-N m^2 h^{-1}, and strong day-to-day fluctuations. Average ecosystem emissions of N_2O have a clear diel pattern. N_2O fluxes tend to be lower during the dry season (May-Oct.) and decrease during dry periods.

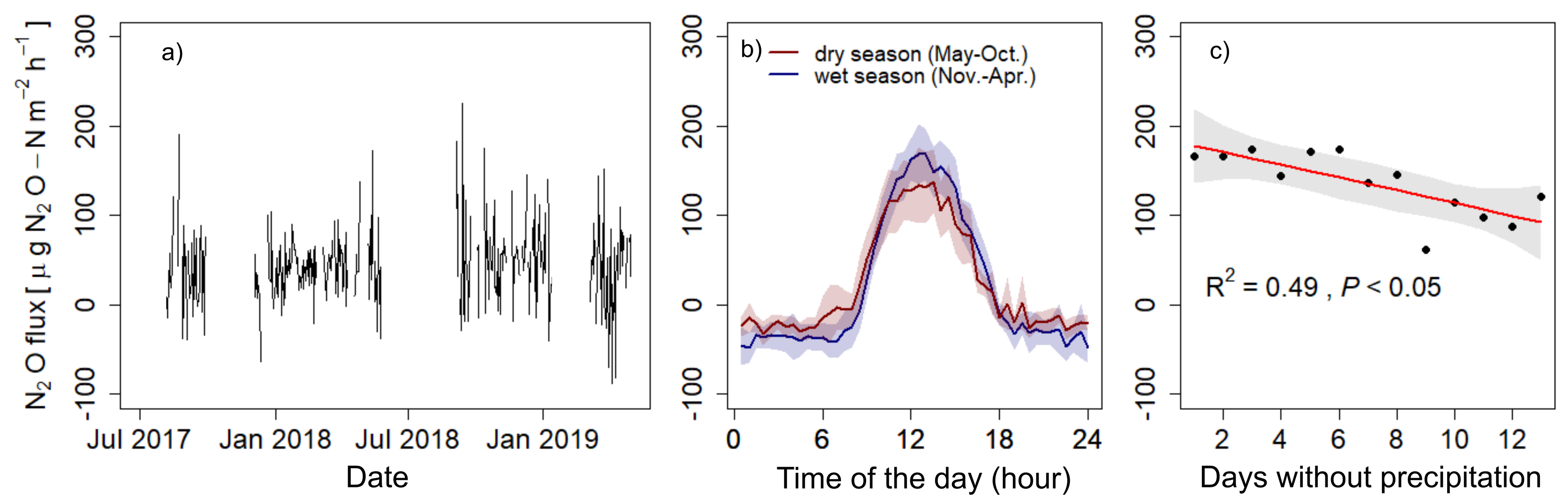

Fig. 4: (a) Daily mean nitrous oxide (N_2O) flux based on 30-minute averages of eddy covariance flux measurements. Data gaps in the time series are due to sensor failure and consequent sensor repair. (b) Mean diel N_2O flux during the wet season (November-April) and during the dry season (May-October). (c) Daily mean of midday (10-14 h local time) N_2O flux in relation to the number of consecutive days without precipitation. Shaded areas represent 95 % confidence limits.

El Niño Southern Oscillation (ENSO):

The ENSO event in 2015-2016 was a major disturbing factor for the oil palm plantation. Drought and smoke haze conditions, with related increase in atmospheric vapor pressure deficit (VPD) and air temperature, as well as changes in light conditions resulted in a complete pause of carbon accumulation for 1.5 months.

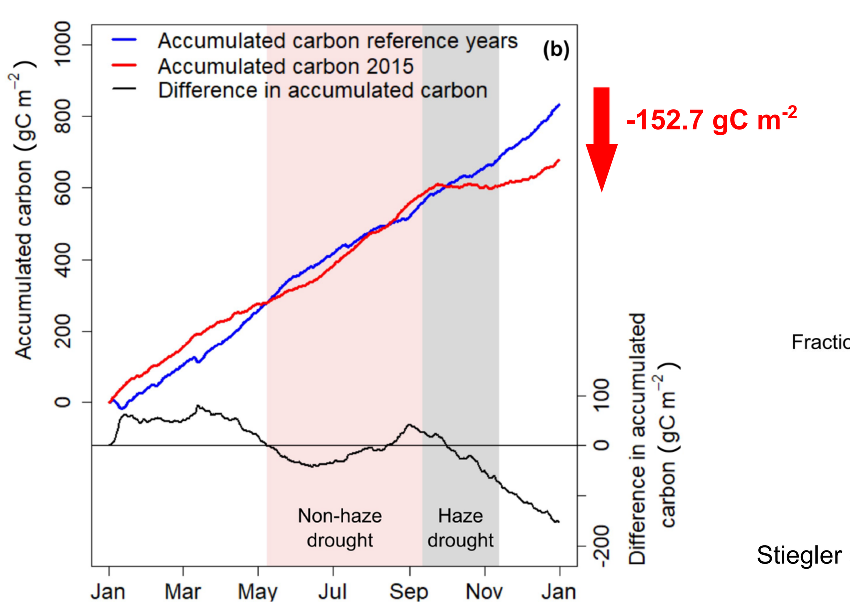

Fig. 5: Accumulated carbon uptake during the period 2015 and the reference time period (2014/2016) and differences in accumulated carbon between the two periods (2015 minus reference time period). Shaded areas in red and grey mark the non-haze drought and the haze drought period in 2015, respectively.

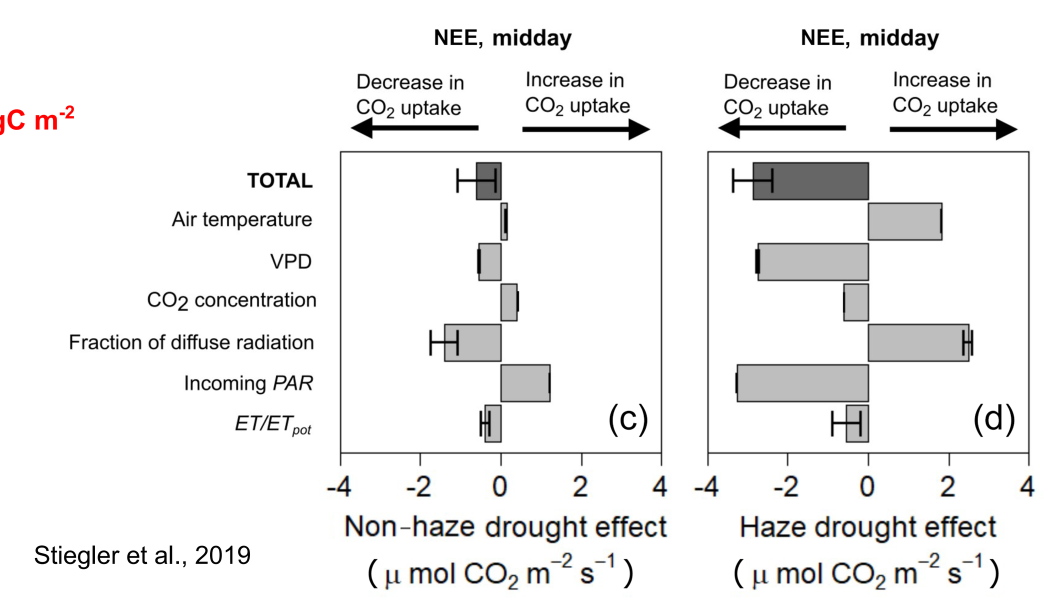

Fig. 6: Contribution and effect of meteorological and environmental parameters during the non-haze drought and haze drought period on the midday net ecosystem CO_2 exchange (NEE) compared to non-drought and non-haze conditions using a multiple linear regression model. Error bars show the standard error.

5 Conclusions

The oil palm plantation is a source of greenhouse gases, mainly due to the high export of yield and due to the high fertilizer application. CO_2 dominates the on-site greenhouse gas budget.

Drought and smoke haze are major disturbing factors for the oil palm plantation.

Adaptation in management practices, e.g. reduced fertilization or alternative management scenarios, may reduce the global warming potential of the oil palm plantation.

Fire-preventing measures, e.g. sustainable land management, may help to mitigate the negative effects of drought.

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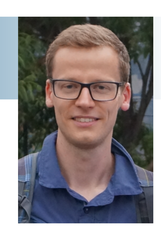

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