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What drives ecosystem nitrous oxide (N_2O) greenhouse gas fluxes in a mature commercial oil palm plantation?

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1 Background

Global atmospheric concentration of nitrous oxide (N_2O), a powerful greenhouse gas with high global warming potential and long atmospheric life span, has been increasing in the past decades. Agriculture and related application of nitrogen-based fertilizers is the main anthropogenic source of N_2O, thus, there is worldwide concern over potential long-term impact of agricultural land-use practices on climate.

During the past decade, oil palm (*Elaeis guineensis* Jacq.) emerged to an important cash crop but despite the growing areal extent and increasing economic importance of oil palm, only little is known about the overall N_2O balance of oil palm plantations at the ecosystem scale.

2 Study aim

- Quantify the seasonal and diurnal pattern of N_2O fluxes and the overall N_2O balance of a mature commercial oil palm plantation.
- Identify atmospheric and environmental drivers of N_2O fluxes.

3 Materials and methods

Study site:

The study site is located in a mature oil palm plantation (*PTPN6*) in the tropical lowlands of the Jambi province on Sumatra, Indonesia. The oil palm plantation covers ~2000 ha and oil palms were planted between the years 1999 and 2004. Average oil palm height is approx. 13 meters. The plantation is fertilized with 144 kg ha^{-1} of Magnesium Nitrate, 575 kg ha^{-1} of NPK granular, and 251 kg ha^{-1} of Dolomite fertilizers in topdress application.

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

Measurement setup and measured parameters:

Parameter	Sensor	Instrument height or depth
N_2O fluxes and water vapor	N_2O/CO Analyzer (Los Gatos Research)	22 m
Wind speed & direction	uSonic-3 Scientific (METEK GmbH)	22 m
Water vapor and CO_2 fluxes	LI7500A (LI-COR Inc.)	22 m
Soil moisture and soil temperature	TRIME-PICO32 (IMKO GmbH)	-5 cm
Radiation	CNR4 (Kipp & Zonen)	22 m
Photosynthetically active radiation	PQS1 (Kipp & Zonen)	22 m
Air temperature & humidity	Thies Clima	22 m
Precipitation	Thies Clima	11.5 m
Throughfall	Mini flowmeter (B.I.O-TECH e.K.)	1.5 m

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

Data collection and processing:

- Continuous measurements of greenhouse gas exchange, surface energy balance components and meteorological parameters were performed since July 2017.
- Concentration of N_2O and water vapor, sonic temperature and wind components *u*, *v* and *w* were sampled at a rate of 10 Hz. Fluxes were calculated for 30-minute intervals using the EddyPro 6.2.0 software package. Standard flux processing and data quality checks have been performed. No gap filling has been applied.
- Climatic variables were measured every 15-s and averaged to 10- and 30-minute intervals.

4 Results and discussion

N_2O fluxes and environmental conditions:

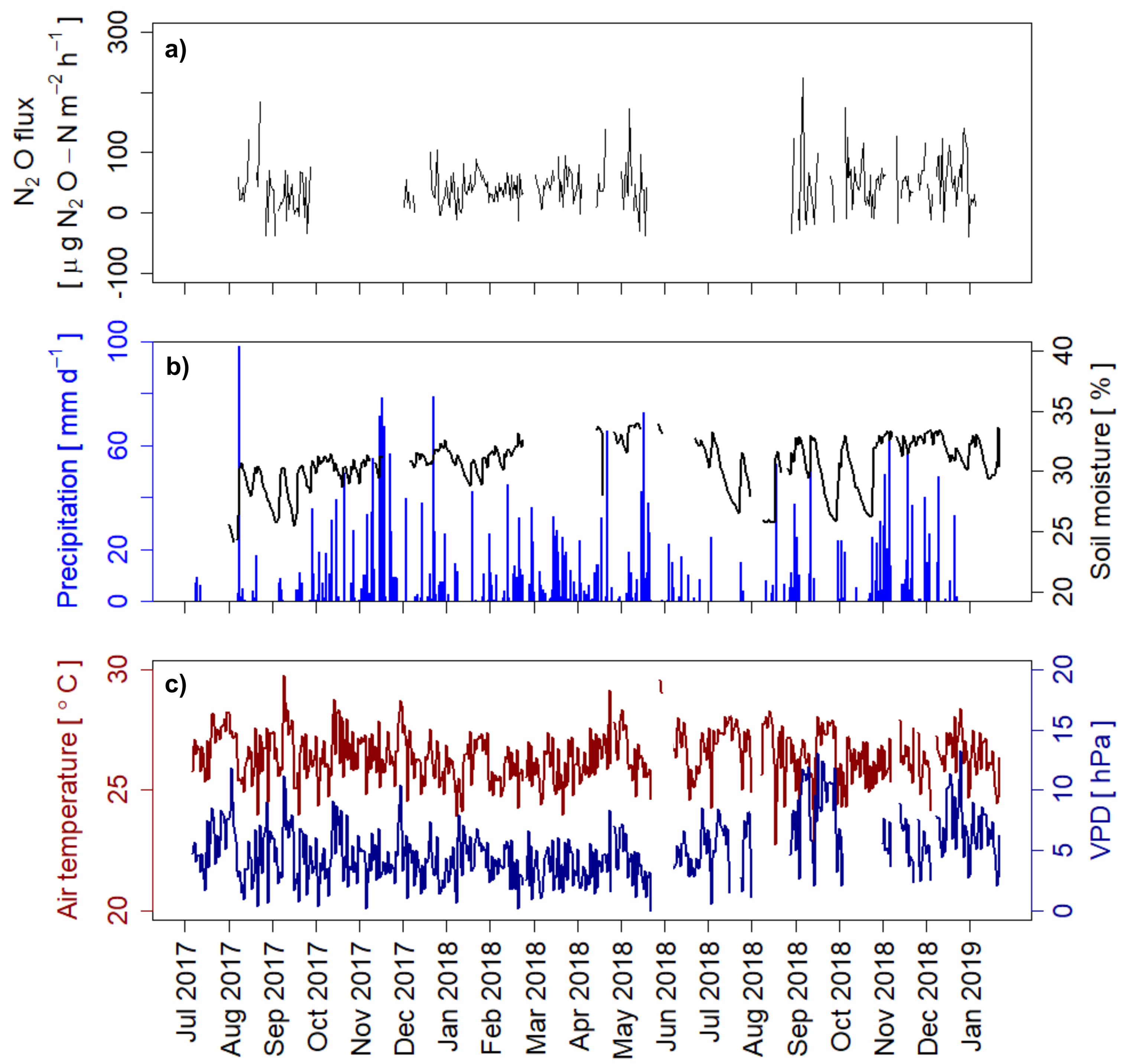

Fig. 2: Daily average N_2O flux (a), daily sum of precipitation (b), daily average soil moisture at 5 cm depth (b), daily average air temperature at 22 m height (c), and daily average vapor pressure deficit (*VPD*) at 22 m height (c).

Diurnal flux behavior

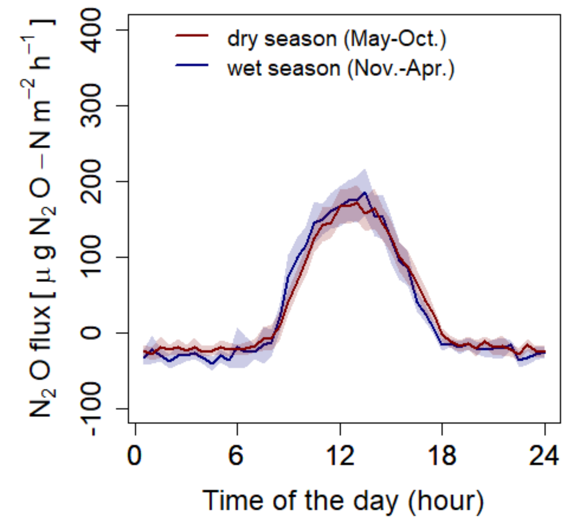

Fig. 3: Diurnal N_2O flux behavior during the dry season (May-Oct.) and during the wet season (Nov.-Apr.). Shaded areas represent 95 % confidence limits.

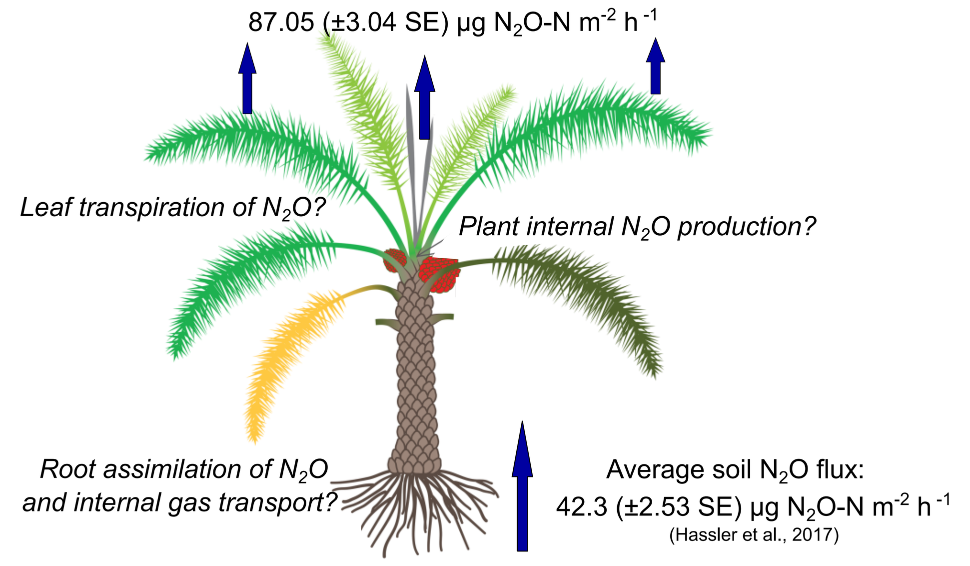

Fig. 4: Soil N_2O fluxes, ecosystem-level N_2O flux and possible other sources of N_2O in the oil palm plantation. Figure adapted from Fan et al., (2015), Geosci. Model Dev., 8.

- Daily mean oil palm ecosystem N_2O fluxes show pronounced day-to-day variation (**Fig. 2 a**) but no fertilization event has been captured.
- Meteorological conditions are influenced by a dry season (May-Oct.) and a wet season (Nov.-Apr.) (**Fig. 2 b, c**) but N_2O fluxes show no distinct difference between dry and wet season (**Fig. 2 a & Fig. 3**).
- Diurnal N_2O fluxes are negative (N_2O uptake) during the night, with average night-time (18:30-06:00 h local time) N_2O flux of -20.16 (±2.53 standard error) µg N_2O-N m^{-2} h^{-1}, and positive (N_2O uptake) during the day, with average day-time (06:30-18:00 h local time) fluxes of 87.05 (±3.04 SE) µg N_2O-N m^{-2} h^{-1} (**Fig. 3 & Fig. 4**). N_2O fluxes reach their peak in the early afternoon (**Fig. 3**).

Which environmental parameters drive N_2O flux in the oil palm plantation?

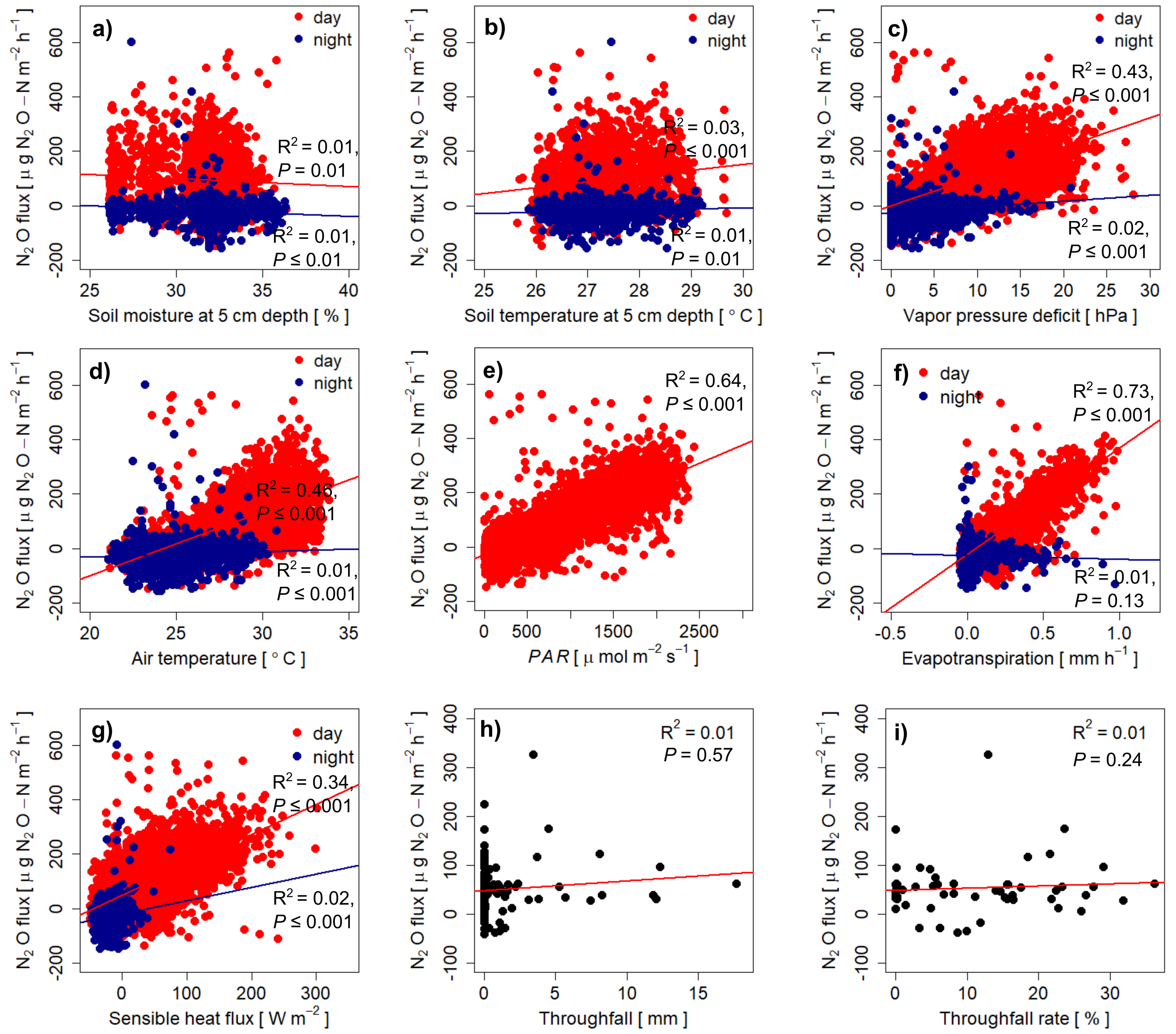

Fig. 5: Scatter plots of day- and night-time N_2O flux (30-minute average) and soil moisture (a), soil temperature (b), atmospheric vapor pressure deficit (c), air temperature (d), photosynthetically active radiation (*PAR*) (e), evapotranspiration (f), sensible heat flux (g), and daily average N_2O flux vs. daily sum of throughfall (h) and throughfall rate (i).

- N_2O fluxes show no correlation with soil moisture (**Fig. 5 a**) and soil temperature (**Fig. 5 b**) but day-time N_2O fluxes generally increase with increasing vapor pressure deficit (*VPD*) (**Fig. 5 c**), increasing air temperature (**Fig. 5 d**), increasing photosynthetically active radiation (*PAR*) (**Fig. 5 e**), increasing evapotranspiration (**Fig. 5 f**) and increasing sensible heat flux (**Fig. 5 g**).
- The total amount of throughfall and throughfall rate has no impact on N_2O fluxes (**Fig. 5 h, i**).

5 Summary and outlook

- The oil palm plantation is a source of N_2O, with average flux of 43.3 (±2.53 standard error) µg N_2O-N m^{-2} h^{-1}. The observed annual N_2O flux, based on 30-minute average values, equals to 3.63 (±0.10 SE) kg ha^{-1} yr^{-1} of N_2O-N emission and a global warming potential of 169.80 (±4.57 SE) g CO_2-equivalent m^{-2} (46.31 g carbon-equivalent m^{-2}).
- Day-time eddy covariance-based N_2O emissions are up to two times higher compared to chamber-based measurements from an earlier study at the same oil palm plantation (Hassler et al. 2017) (**Fig. 4**).
- The relatively strong coupling of day-time N_2O fluxes with air temperature, *VPD*, *PAR*, and evapotranspiration might be related to light- and humidity-dependent plant internal gas transport through N_2O-root assimilation, leaf transpiration and plant internal N_2O production (**Fig. 4**).
- The reason for the observed negative night-time N_2O flux is still unclear. Possibly, it could be *true* N_2O uptake driven by microbial activity or anaerobic denitrification but also terrain-related vertical advection or drainage flow (Cowan et al., 2014).

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