A specific PFT and sub-canopy structure for simulating oil palm in the Community Land Model (CLM-Palm)

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Background

Deforestation driven by the expansion of oil palm plantations has become a major source of GHG emission in Southeast Asia. To quantify the effects of rainforest to oil palm conversion on carbon, water and energy fluxes, a new plant functional type (PFT) and special multilayer structure are introduced for simulating palm species within the framework of the Community Land Model (CLM4.5). Existing PFTs including those for annual crops in current terrestrial biosphere models are not suitable for oil palm due to its multilayer morphology and sequential phenology and frequent intra-annual yields. A specific sub-canopy structure is required to represent the modular and sequential nature of oil palm growth (around 40 stacked phytomers or big leaves) and yield (fruit bunches axillated on each phytomer), as well as its light absorption and photosynthesis.

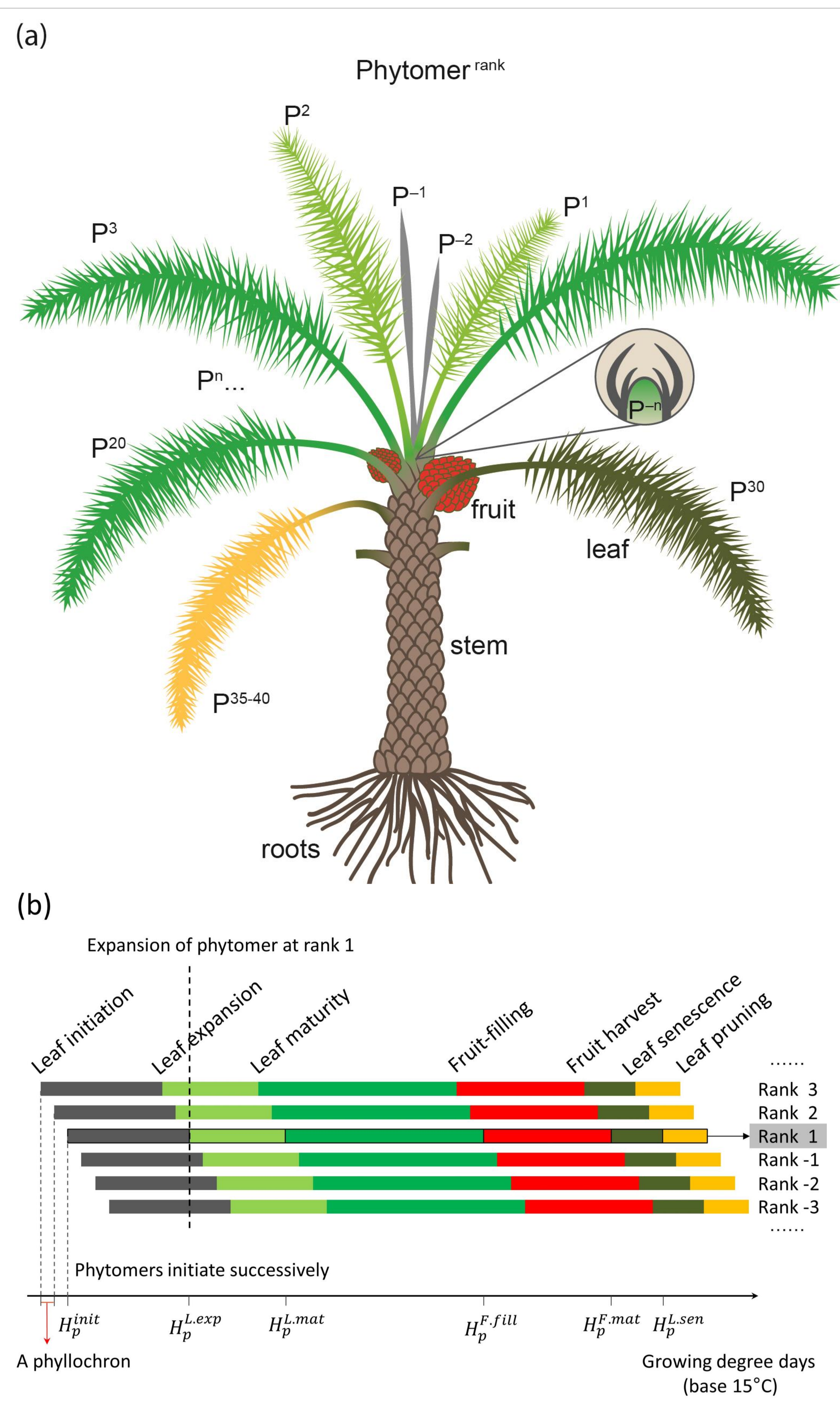


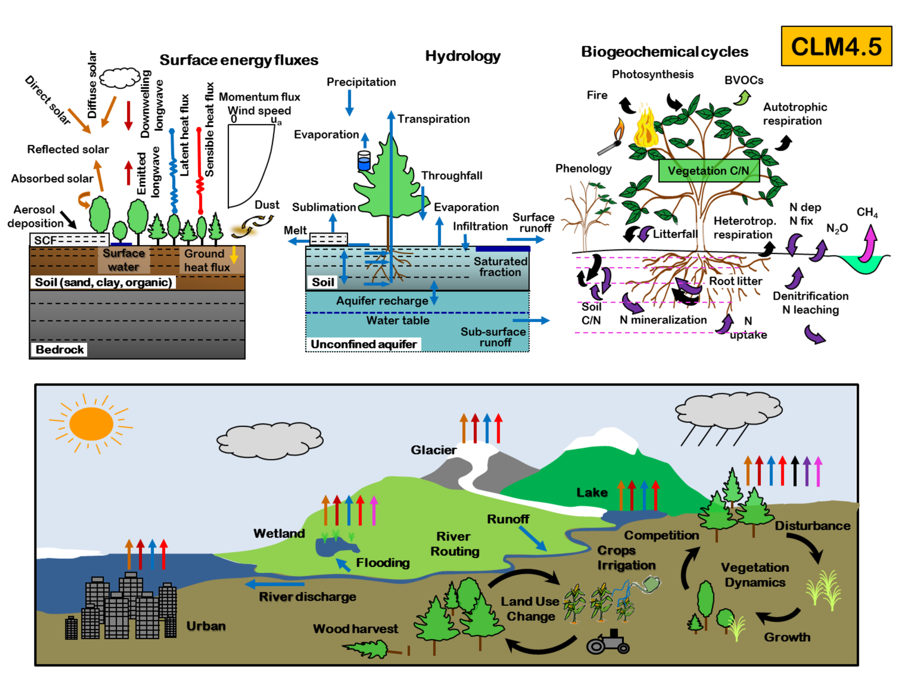
Fig. 1. (a) New sub-canopy phytomer structure of CLM-Palm. P^1 to P^n indicate expanded phytomers and P^{-1} to P^{-n} at the top indicate unexpanded phytomers packed in the bud. Each phytomer has its own phenology, represented by different colors corresponding to: (b) the phytomer phenology: from initiation to leaf expansion, to leaf maturity, to fruit-filling, to harvest, to senescence and to pruning. Phytomers initiate successively according to the phyllochron (the period in heat unit between initiations of two subsequent phytomers).

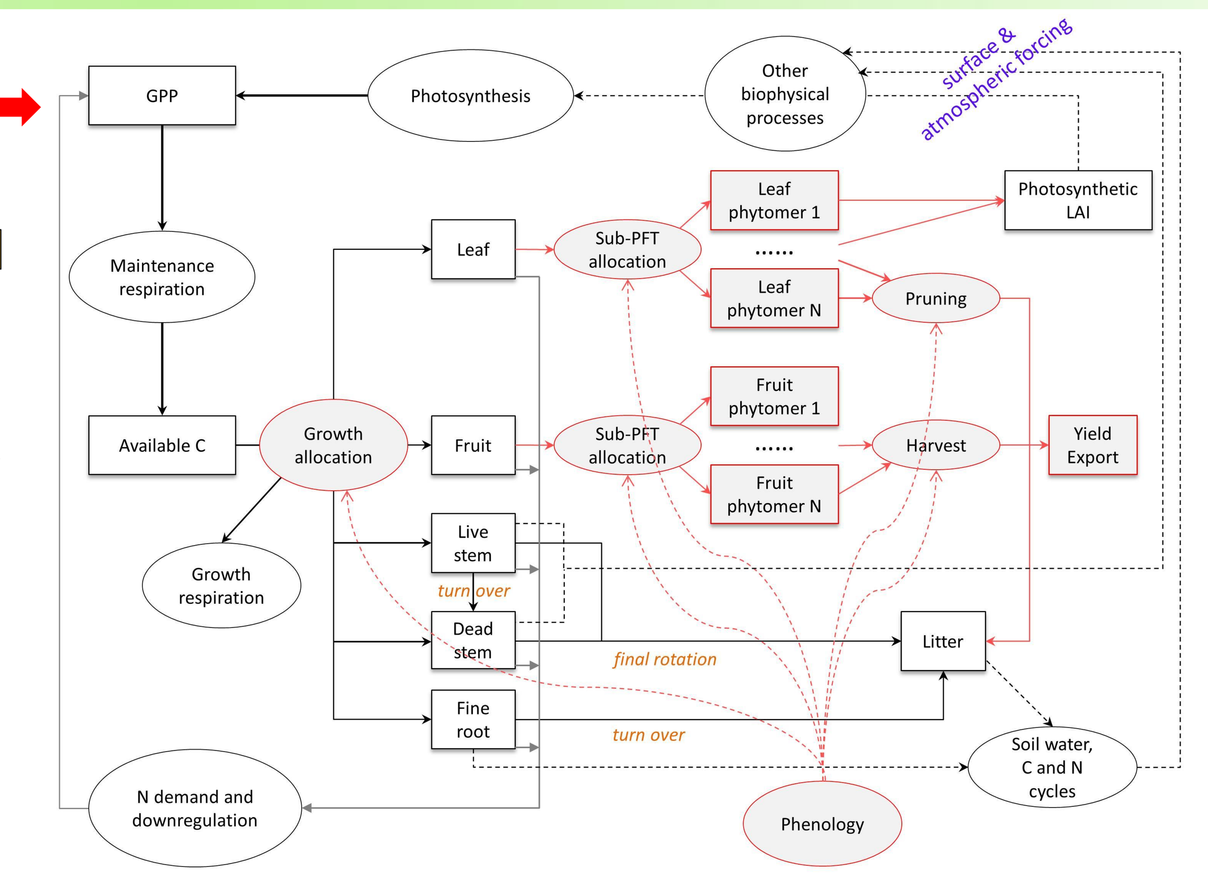
Methodology

The above sub-canopy structure was incorporated into CLM-Palm, in which each phytomer has its own prognostic leaf growth and fruit yield capacity like a PFT but with shared stem and root components. Phenology and carbon and nitrogen allocation operate on the different phytomers in parallel but at unsynchronized steps, so that multiple leaf growth and fruit yields per annum are enabled. Another important phenological phase is identified for the palm PFT - the storage growth period of bud and "spear" leaves which are photosynthetically inactive before expansion. Agricultural practices pertaining to oil palm such as transplanting and leaf pruning are also represented.

CLM-Palm

Fig. 2. CLM-Palm in the framework of CLM4.5. Original functions from CLM4.5 are represented in black or grey. New functions designed for CLM-Palm are represented in red,





Results

CLM-Palm is able to simulate both the PFT-level and sub-canopy-level LAI developments and overall yield from field transplanting to full maturity. The storage growth period of bud and "spear" leaves before expansion is an important phenological phase that helps balance vegetative and reproductive allocation.

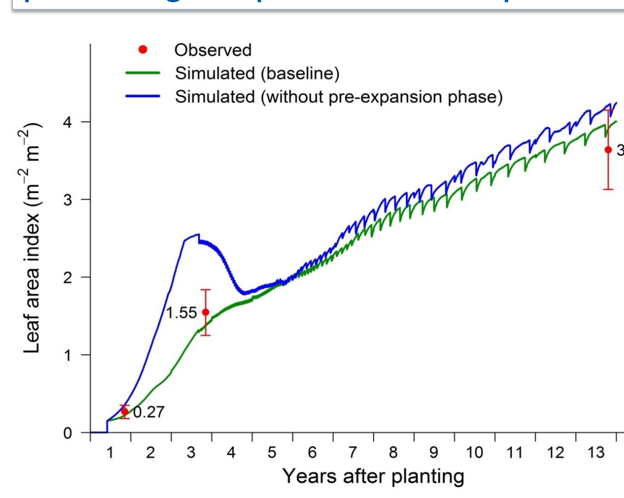


Fig. 3. PFT-level LAI simulated by CLM-Palm. The initial jump at year 1 represents transplanting from nursery. The sharp drops mark pruning events.

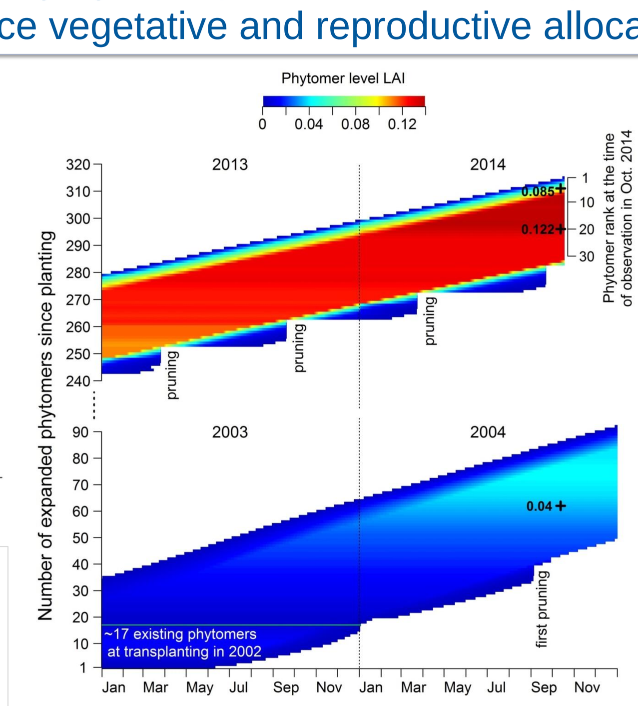


Fig. 4 (left). Simulated Phytomer-level LAI. A phytomer in the model is only meant to represent the average condition of an age-cohort of actual oil palm phytomers across the whole plantation landscape.

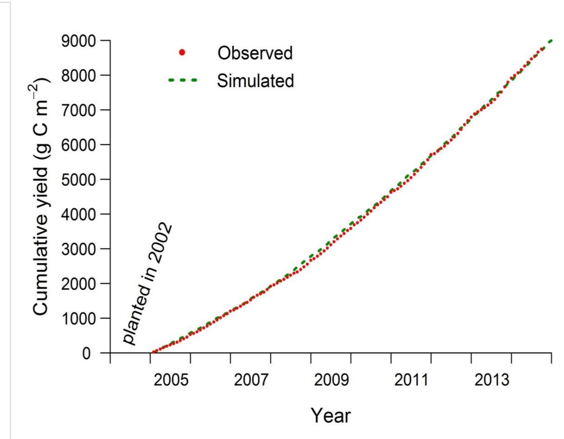


Fig. 5. Simulated PFT-level yield compared with monthly harvest data (2005-2014) from the calibration site PTPN-VI in Jambi, Sumatra.

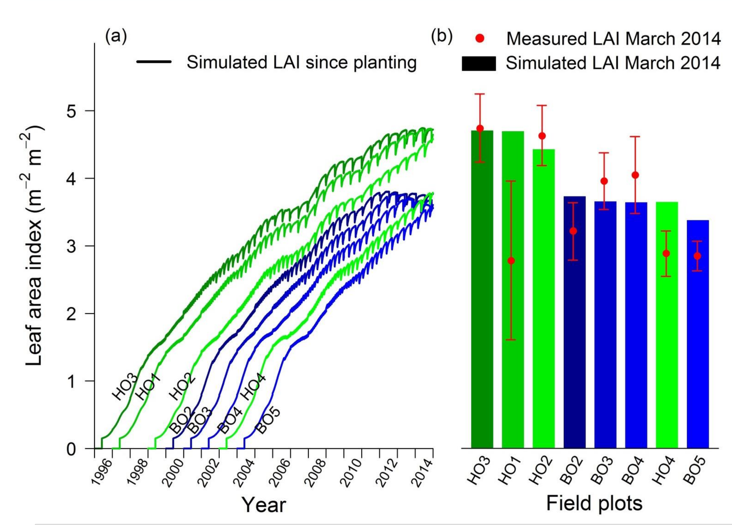


Fig. 6. Validation of LAI with 8 independent oil palm sites (a) since planting; (b) in 2014.

Validation with eight independent oil palm sites from Harapan (H: regular fertilization) and Bukit Duabelas (B: reduced fertilization) regions demonstrate the ability of CLM-Palm to adequately predict the inter-annual dynamics of vegetative growth and fruit yield across sites and sufficiently represent the significant nitrogen- and age-related site-to-site variability in NPP and yield.

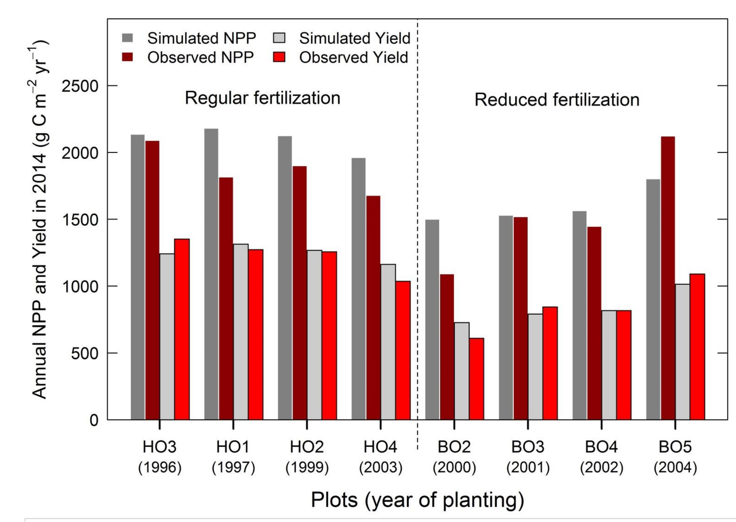


Fig. 7. Validation of yield and NPP with different fertilization treatments.

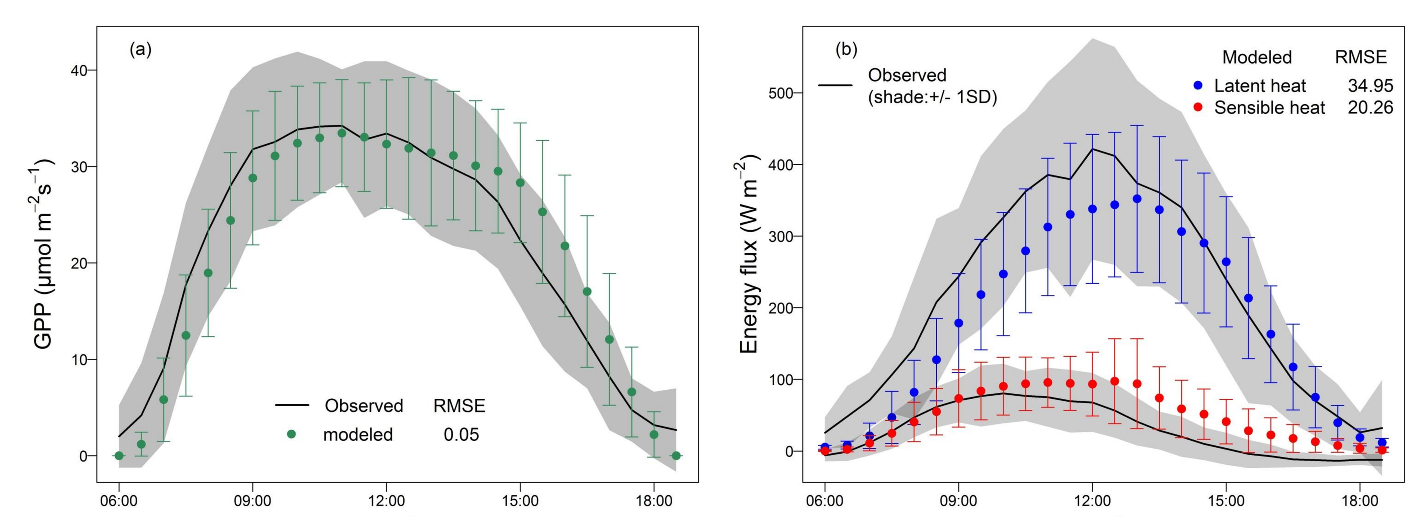


Fig. 8. Observed and simulated GPP (a), latent heat (b) and sensible heat (c) fluxes in a mature oil palm plantation PTPN-VI in Jambi Sumatra.

CLM-Palm simulated CO2 flux matches notably well with GPP derived from eddy covariance measurements. But the model underestimates latent heat flux in the morning and overestimates sensible heat flux in the afternoon, likely due to another special physiological trait of oil palm that is not represented in the model: the water storage in the trunk which is consumed in the early hours of the day, and once is depleted, results in stomatal closure and decreases in photosynthetic rates.

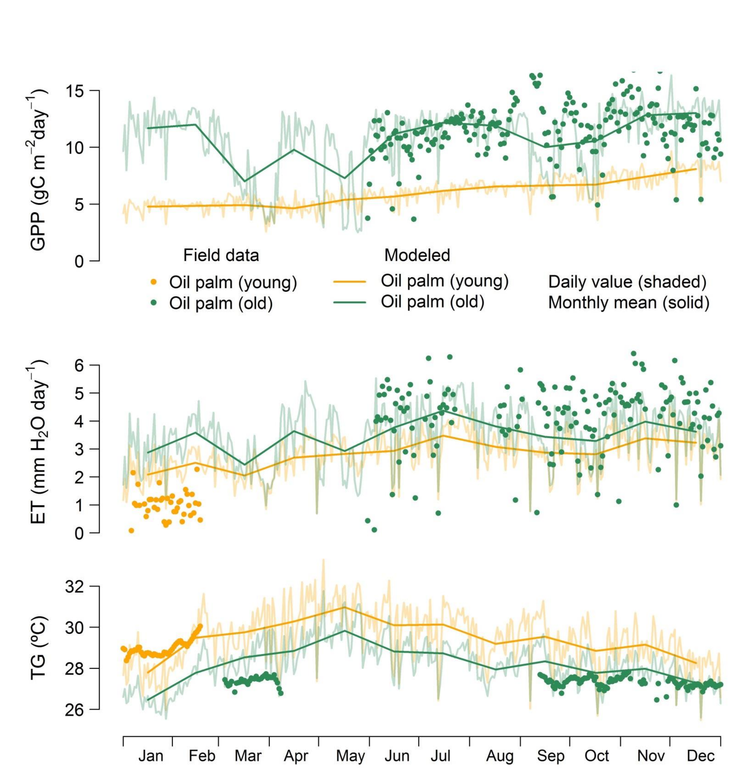


Fig. 9 (left). Observed and simulated GPP, evapotranspiration (ET) and surface temperature (TG).

Young and mature oil palms are inherently different in carbon (GPP), water (ET) and energy (TG) cycles. Therefore, it is important to represent the dynamic phenology and allocation mechanisms during palm development instead of static parameters throughout life for most other PFTs.

Summary

The study supports that species-specific traits, such as palm's monopodial morphology and sequential phenology as well as its unique ecophysiological characters throughout life, should necessarily be represented in terrestrial biosphere models in order to accurately simulate vegetation dynamics and its feedbacks on carbon, water and energy fluxes.

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