Supplement of Biogeosciences, 16, 4463–4484, 2019
https://doi.org/10.5194/bg-16-4463-2019-supplement

Biogeosciences
Open Access

Supplement of

The importance of physiological, structural and trait responses to drought stress in driving spatial and temporal variation in GPP across Amazon forests

Sophie Flack-Prain et al.

Correspondence to: Sophie Flack-Prain (s.flack-prain@ed.ac.uk)

Supplementary Material

Plot Characteristics

Data from the Global Ecosystem Monitoring (GEM) network were used from seven one-hectare permanent sample plots at four locations across the east and west Amazon (Table 1). Differences between soil and species composition at each location were sufficient to avoid significant pseuodoreplication effects (1, 2). The two north eastern plots (CAX04 and CAX06) are located in the Caxiuanã National Forest in Pará State, Brazil. These relatively infertile, slow-growing but high biomass plots (~ 200 MgC ha^{-1}) are typical of the eastern Amazon. Plots typically experience a long but modest intensity dry season from July to December, when rainfall does not exceed 100mm mon^{-1} (3, 4). CAX04 is located on sandy loam, vetic acrisol soil (all soil classifications applied here are World Reference Base Classification (FAO 2014)), whereas CAX06 occupies a clay-rich ferralsol, causing species composition to differ between plots (2, 5). The south western Peruvian plots (TAM05 and TAM06) of the Tambopata Biological Reserve in the Madre de Dios region are subject to a moderate dry season from May to September (6). The region's geomorphology is a result of it being situated on old floodplains of the Tambopata River (7). TAM05 is located on a Pleistocene terrace (7), whilst the palm rich forest of TAM06 is located on a Holocene floodplain (6). Soils at TAM05 are relatively infertile cambisols compared to the more fertile alisols found at TAM06 (8). The Bolivian plots (KEN01 and KEN02) located in the Hacienda Kenia in Guarayos Province, Santa Cruz, experience a strong dry season between April and September and occupy the transition zone between humid Amazonian forests and *chiquitano* dry forests (9). Both plots are situated on relatively fertile sandy loam cambisols (2), though soil depth varies, with KEN01 positioned on deeper soil in a slight topographic depression (Table 3), whilst KEN02 occupies more shallow soil over Precambrian rock (7), leading to a difference in species composition between plots (9). The south eastern plot of the Fazenda Tanguro, Mato Grosso State was subject to an intense dry season between May and September. The old growth forest plot sits close to the dry forest- savannah transition zone (2) and occupies relatively infertile sandy ferralsol soil (7).

SPA Leaf Respiration Model

The Reich, Tjoelker (10) model predicting leaf respiration as a function of leaf N content was integrated into SPA. In align with the approach taken by Atkin, Bloomfield (11), we also adjust the baseline respiration rate as a function of the temperature during the warmest quarter:

$$b = 1.025 - 0.036\ WQ \qquad (1)$$

$$leaf_{resp} = 10^{\,b}\ N_{leaf}^{1.411} \qquad (2)$$

$$leaf_{resp\ t} = 2.0^{\,0.1(Tair-20)}\ leaf_{resp} \qquad (3)$$

$$leaf_{resp\ total} = C_{leaf} \times 2 \times leaf_{resp\ t} \qquad (4)$$

Where;

b is a nitrogen scalar to account for differences in WQ, WQ is the temperature (ºC) during the warmest quarter, $leaf_{resp}$ is the respiration rate of leaves (nmol g^{-1} leaf mass s^{-1}), N_{leaf} is the nitrogen content of the leaf (mmol g^{-1} leaf mass), $leaf_{resp\ t}$ is the temperature adjusted respiration rate (nmol g^{-1} leaf mass s^{-1}), T_{air} is air temperature (ºC), $leaf_{resp\ total}$ is the total leaf respiration (nmol g^{-1} s^{-1}), and C_{leaf} is the foliar C stock (gC m^{-2}).

SPA Non-Structural Carbon Pool

For the purpose of the presented study, LAI was forced in model runs. Where leaf NPP requirements could not be met by daily C assimilated, leaf growth was supplemented by the labile carbon pool as follows:

$$NPP_i = GPP_i - Ra_i \qquad (5)$$

$$NPP_{leaf\ i} = (LAI_i - LAI_{i-1}) \times LCA \qquad (6)$$

$$\text{If } NPP_{leaf\ i} > NPP_i \Rightarrow \qquad (7)$$

$$NSC_i = NSC_{i-1} - (NPP_{leaf\,i} - NPP_i) \quad (8)$$

$$\text{If } NSC_i < NSC_{cap} \text{ AND } NPP_{leaf\,i} < NPP_i \Rightarrow \quad (9)$$

$$NPP_{i+1} = NPP_{i+1} - NSC_{frac} \quad (10)$$

$$NSC_{i+1} = NSC_i + NSC_{frac} \quad (11)$$

Where:

NPP is modelled net primary productivity, GPP is modelled gross primary productivity, Ra is modelled autotrophic respiration, NPP_{leaf} is modelled leaf net primary productivity, LAI is the field estimated leaf area index, LCA is the field estimated leaf C content per unit leaf area, NSC is the non-structural carbon pool, NSC_{frac} is the fraction of NPP redirected towards the NSC pool, NSC_{cap} is the NSC pool capacitance, and i is the daily timestep.

Calculation of Maximum Climatological Water Deficit

We calculate maximum climatological water deficit (MCWD) in line with the equations presented in Aragao et al. (2007):

$$\text{If } WD_{n-1} - E + P_n < 0 \Rightarrow \quad (12)$$

$$WD_n = WD_{n-1} - E + P_n \quad (13)$$

$$\text{Else } WD_n = 0 \quad (14)$$

Where:

WD is the water deficit for each month (n), E is evapotranspiration (assumed to be 100 mm $month^{-1}$), and P is precipitation (mm $month^{-1}$).

Experimental Model Runs

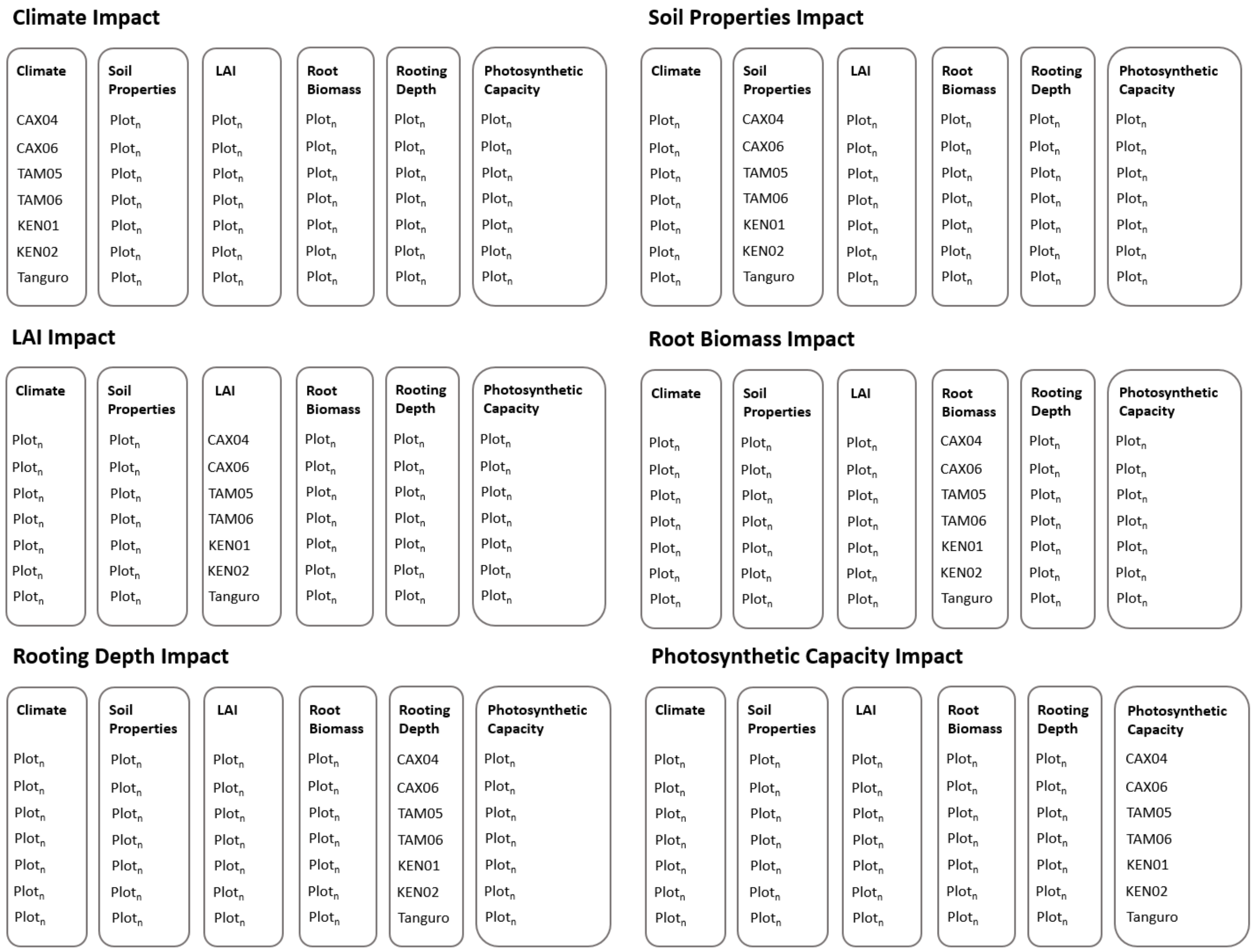

Figure S1. Model experimental design to apportion variation in simulated GPP to that driven by differences in (i) climate, (ii) soil properties, (iii) LAI, (iv) root biomass and (v) rooting depth, and (vi) trait responses driven by photosynthetic capacity (V_{cmax} and J_{max}). For a given plot i.e. Plot$_n$ (CAX04, CAX06, TAM05, TAM06, KEN01, KEN02, Tanguro), model inputs (i-vi) were alternated to that of all other plots, and the simulated GPP retrieved.

References

Atkin, O. K., Bloomfield, K. J., Reich, P. B., Tjoelker, M. G., Asner, G. P., Bonal, D., Bönisch, G., Bradford, M. G., Cernusak, L. A., and Cosio, E. G.: Global variability in leaf respiration in relation to climate, plant functional types and leaf traits, New Phytologist, 206(2), 614-636, 2015.

Aragão, L. E. O. C., Malhi, Y., Metcalfe, D. B., Silva-Espejo, J. E., Jimenez, E., Navarrete, D., Almeida, S., Costa, A. C. L., Salinas, N., Phillips, O. L., Anderson, L. O., Alvarez, E., Baker, T. R., Goncalvez, P. H., Huaman-Ovalle, J., Mamani-Solorzano, M., Meir, P., Monteagudo, A., Patino, S., Penuela, M. C., Prieto, A., Quesada, C. A., Rozas-Davila, A., Rudas, A., Silva, J. A., and Vasquez, R.: Above- and below-ground net primary productivity across ten Amazonian forests on contrasting soils, Biogeosciences, 6(12), 2759-2778, 2009.

Araujo-Murakami, A., Doughty, C. E., Metcalfe, D. B., Silva-Espejo, J. E., Arroyo, L., Heredia, J. P., Flores, M., Sibler, R., Mendizabal, L. M., Pardo-Toledo, E., Vega, M., Moreno, L., Rojas-Landivar, V. D., Halladay, K., Girardin, C. A. J., Killeen, T. J., and Malhi, Y.: The productivity, allocation and cycling of carbon in forests at the dry margin of the Amazon forest in Bolivia, Plant Ecology & Diversity, 7(1-2), 55-69, 2014.

Doughty, C. E., Metcalfe, D. B., Girardin, C. A., Amezquita, F. F., Cabrera, D. G., Huasco, W. H., Silva-Espejo, J. E., Araujo-Murakami, A., da Costa, M. C., Rocha, W., Feldpausch, T. R., Mendoza, A. L., da Costa, A. C., Meir, P., Phillips, O. L., and Malhi, Y.: Drought impact on forest carbon dynamics and fluxes in Amazonia, Nature, 519(7541), 78-82, 2015.

Fisher, R. A., Williams, M., Da Costa, A. L., Malhi, Y., Da Costa, R. F., Almeida, S., and Meir, P.: The response of an Eastern Amazonian rain forest to drought stress: results and modelling analyses from a throughfall exclusion experiment, Global Change Biology, 13(11), 2361-2378, 2007.

Malhi, Y., Amezquita, F. F., Doughty, C. E., Silva-Espejo, J. E., Girardin, C. A. J., Metcalfe, D. B., Aragão, L. E. O. C., Huaraca-Quispe, L. P., Alzamora-Taype, I., Eguiluz-Mora, L., Marthews, T. R., Halladay, K., Quesada, C. A., Robertson, A. L., Fisher, J. B., Zaragoza-Castells, J., Rojas-Villagra, C. M., Pelaez-Tapia, Y., Salinas, N., Meir, P., and Phillips, O. L.: The productivity, metabolism and carbon cycle of two lowland tropical forest plots in south-western Amazonia, Peru, Plant Ecology & Diversity, 7(1-2), 85-105, 2014.

Malhi, Y., Aragão, L. E., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., Sitch, S., McSweeney, C., and Meir, P.: Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest, Proceedings of the National Academy of Sciences, 106(49), 20610-20615, 2009.

Malhi, Y., Doughty, C. E., Goldsmith, G. R., Metcalfe, D. B., Girardin, C. A. J., Marthews, T. R., del Aguila-Pasquel, J., Aragão, L. E. O. C., Araujo-Murakami, A., Brando, P., da Costa, A. C. L., Silva-Espejo, J. E., Amezquita, F. F., Galbraith, D. R., Quesada, C. A., Rocha, W., Salinas-Revilla, N., Silverio, D., Meir, P., and Phillips, O. L.: The linkages between GPP, productivity, growth and biomass in lowland Amazonian forests, Global Change Biology, 21(6), 2283-2295, 2015.

Metcalfe, D. B., Meir, P., Aragão, L. E. O. C., Lobo-do-Vale, R., Galbraith, D., Fisher, R. A., Chaves, M. M., Maroco, J. P., da Costa, A. C. L., and de Almeida, S. S.: Shifts in plant respiration and carbon use efficiency at a large-scale drought experiment in the eastern Amazon, New Phytologist, 187(3), 608-621, 2010.

Quesada, C. A., Phillips, O. L., Schwarz, M., Czimczik, C. I., Baker, T. R., Patino, S., Fyllas, N. M., Hodnett, M. G., Herrera, R., Almeida, S., Davila, E. A., Arneth, A., Arroyo, L., Chao, K. J., Dezzeo, N., Erwin, T., di Fiore, A., Higuchi, N., Coronado, E. H., Jimenez, E. M., Killeen, T., Lezama, A. T., Lloyd, G., Lopez-Gonzalez, G., Luizao, F. J., Malhi, Y., Monteagudo, A., Neill, D. A., Vargas, P. N., Paiva, R., Peacock, J., Penuela, M. C., Cruz, A. P., Pitman, N., Priante, N., Prieto, A., Ramirez, H., Rudas, A., Salomao, R., Santos, A. J. B., Schmerler, J., Silva, N., Silveira, M., Vasquez, R., Vieira, I., Terborgh, J., and Lloyd, J.: Basin-wide variations in Amazon forest structure and function are mediated by both soils and climate, Biogeosciences, 9(6), 2203-2246, 2012.

Reich, P. B., Tjoelker, M. G., Pregitzer, K. S., Wright, I. J., Oleksyn, J., and Machado, J. L.: Scaling of respiration to nitrogen in leaves, stems and roots of higher land plants, Ecology Letters, 11(8), 793-801, 2008.