Long-term field study of the influence of the photosynthetic performance of temperate grassland species on ecosystem CO₂ exchange fluxes at the ecosystem-scale

A. Digrado 1, L. Gourlez de la Motte 2, A. Bachy 2, A. Mozaffar 2,3, N. Schoon 3, F. Bussotti 4, C. Amelync 3,5, A-C. Dalcq 6, M-L. Faucconnier 7, M. Aubinet 7, B. Heinesch 7, P. Du Jardin 1, P. Delaplace 1

Under environmental constraints, plants are able to proceed to adjustment in their photosynthetic processes to promote acclimation. However, it is currently unclear how alteration in the functioning of the photosystem II and the photosystem I influences CO₂ gas exchange at the ecosystem-scale.

During two years, frequent measurements of chlorophyll a fluorescence (ChlF) in field condition were performed on the three main species of a temperate grassland ecosystem (Lolium perenne L., Taraxacum sp. and Trifolium repens L.). ChlF data were analyzed with the JIP-test to characterize the photosynthetic performance and its response to combined environmental constraints. Species responses were weighted based on their relative abundance to estimate the photosynthetic performance of the ecosystem. In addition, monitoring of CO₂ fluxes was performed by eddy covariance. ChlF data were analyzed along with CO₂ fluxes to determine the impact of alteration in the ecosystem photosynthetic performance on CO₂ ecosystem exchange.

I. Evolution of photosynthetic processes measured by ChIF and micro-meteorological conditions in the field

II. Relationship between micro-meteorological conditions, photosynthetic performance and CO₂ fluxes

Chlorophyll fluorescence parameters description

Fv/Fm Maximum quantum yield of the PSII

PIAbs Performance Index: representation of the energy conversion from photons absorbed by PSII to the reduction of intersystem electrons

Ψe Efficiency of the electron transport beyond QA

ΔFV/FM Efficiency with which an PSII trapped electron is transferred beyond the PSII acceptor side

Figure 1: Environmental conditions encountered in the 2014 and 2015 study periods. Values at 11, 15, 17 and 17 h for each day of ChIF measurements are represented for (a) PPFD, photosynthetic photon flux density; (b) Tair, air temperature; (c) SM, soil moisture at a depth of 5 cm and (d) VPD, vapour pressure deficit. Grey bars separate the different days of measurements. The arrows indicate the first and third day of the heat wave.

Figure 2: Variation of ChlF parameters (F0 and net CO₂ ecosystem exchange (NEE)) in the 2014 and 2015 study periods. The average value (± SD) is 30 for each of the four measurement time period (11:00, 15:00, 15:00 and 17:00) is represented. The top plot indicates which ChlF cluster agreed, ChlF cluster (a–c) and (d) has been assigned each time using the canonical correlation analysis-clustering. Grey bars separate the different days of measurements. Arrows indicate the first and the third day of a heat wave.

Figure 3: Canonical correlation analysis showing the relationships between (a) micro-meteorological parameters (PPFD, photosynthetic photon flux density; VPD, vapour pressure deficit; Tair, air temperature; SM, soil moisture at a depth of 5 cm; RH, relative air humidity; SM, soil moisture) and ChlF parameters (psii, L. perenne; orange, Tarac dum sp.; orange, light blue; F; orange, black, ecosystem); (b) micro-meteorological parameters and CO₂ fluxes (GPP, gross primary productivity; Rₘ, ecosystem respiration); Correlations between the first canonical axis of the two CCA plots and between the second canonical axis of the two CCA plots were 88.6% (P < 0.001) and 60.5% (P < 0.001), respectively. (b) micro-meteorological parameters and CO₂ fluxes (GPP, gross primary productivity; Rₘ, ecosystem respiration). Correlations between the first canonical axis of the two CCA plots and between the second canonical axis of the two CCA plots were 78.8% (P < 0.001) and 54.7% (P < 0.001), respectively. (c) ChIF parameters and CO₂ fluxes. Correlations between the first canonical axis of the two CCA plots and between the second canonical axis of the two CCA plots were 72.4% (P < 0.001) and 25.0% (P < 0.05), respectively.

Figure 4: Linear regression between (a) GPP, gross primary productivity at light saturation and the daily variation of ecosystem ChIF parameters (F0/Fm, Fv/Fm, Fv/Fm, and ΔFv/Fm) and (b) Rₘ, dark respiration normalized at 10°C and the daily variation of ecosystem ChIF parameters.

Figure 5: Average ± SD NEE net CO₂ exchange ecosystem in six different species. (c) CO₂ fluxes (NEE) are plotted against the photosynthetic performance responses (PIAbs) of the four species (a) − (d). Different letters indicate significant differences among the clusters (Tukey HSD, α = 0.05).