Proofs of non-stomatal limitations of potato photosynthesis during drought by using eddy covariance data

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Objectives

- To infer ecosystem physiological proprieties from eddy covariance data at the canopy level.
- To evaluate wether a reduction in potato photosynthesis during drought originates from a strict stomatal control (SOL) or from non-stomatal limitations (NSOL).
- To use relative extractable water (REW) as an indicator to detect drought effects on agrosystems.

Site : BE-Lon

- Production crop : 4 years roation typical of central Belgium including seed potatoes (2010, 2014 and 2018).
- Temperate climate (mean annual T and P: 10 °C, 800 mm)
- Soil type : loamy soil and a plowed horizon over the 30 first cm.
- Soil water content measured at five depths (5, 15, 25, 55 and 85 cm).

Methodology

Classic post processing treatments for EC data. Two different timescales :

Inter-day timescale :

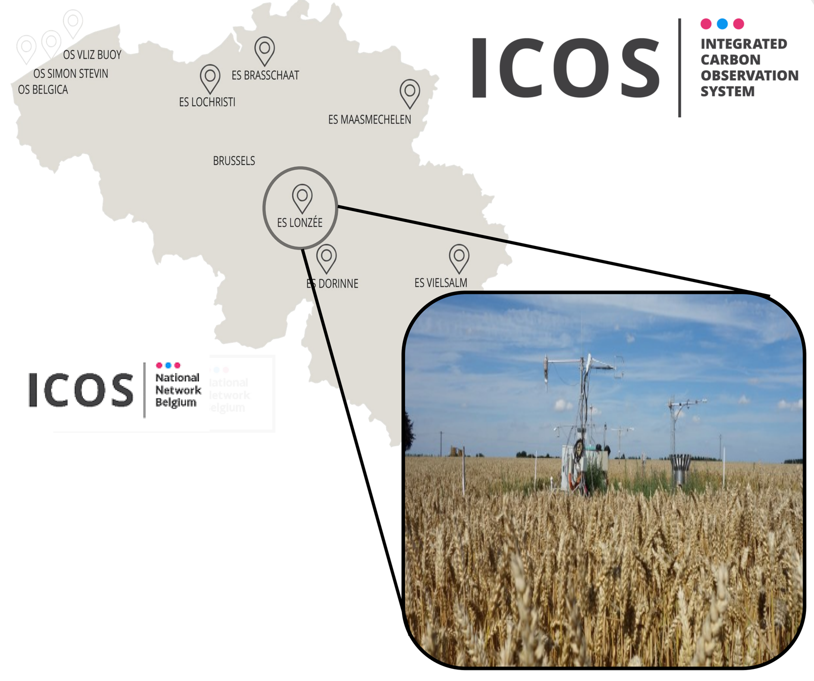
- SOL : canopy sensitivity to photosynthesis G_1 with the Medlyn et al. model (Medlyn et al., 2011) (Eq. 1). Use of the Penman-Monteith equation (Penman, 1948) to determine G_c.
- NSOL : apparent maximum carboxylation rate V_{cmax} (Eq. 2) (Arneth et al., 2002).
- Sensitivity analysis : quantification of the bias induced by the non-inclusion of water stress influence in the parametrization of V_{cmax} and G_1 : calculation of ratios between GPP modelled by using unstressed V_{cmax} and G_1 values, and measured GPP (GPP_{Vcmax}*/GPP and GPP_{G1}*/GPP) (Zhou et al., 2013).

Intra-day timescale :

- Coupling between carbon and water fluxes: rank correlation between transpiration and normalized carbon assimilation (DWCI) (Nelson et al., 2018).

Quality controls for G_1 and V_{cmax} calculations : PPFD, surface wetness, phenology and statistic filters (Knauer et al., 2018).

REW was daily computed by weighting the water availability of each soil layer by its height up to the maximum root depth (Eq. 3), modelled with the Hartmann et al. (2017) model. Breakpoints were determined by using segmented linear regressions.



(1) $$G_C = 1.6\left(1+\frac{G_1}{\sqrt{VPD}}\right)\frac{GPP_{sat}}{C_a}$$

(2) $$V_{cmax} = \frac{GPP_{sat}(C_i+K_m)}{C_i-\Gamma^*}$$

(3) $$REW = \frac{\sum_{surf}^{root\ depth} SWC - SWC_{wp}}{\sum_{surf}^{root\ depth} SWC_{fc} - SWC_{wp}}$$

Results

1 Pedo-climatic conditions and crop dynamics

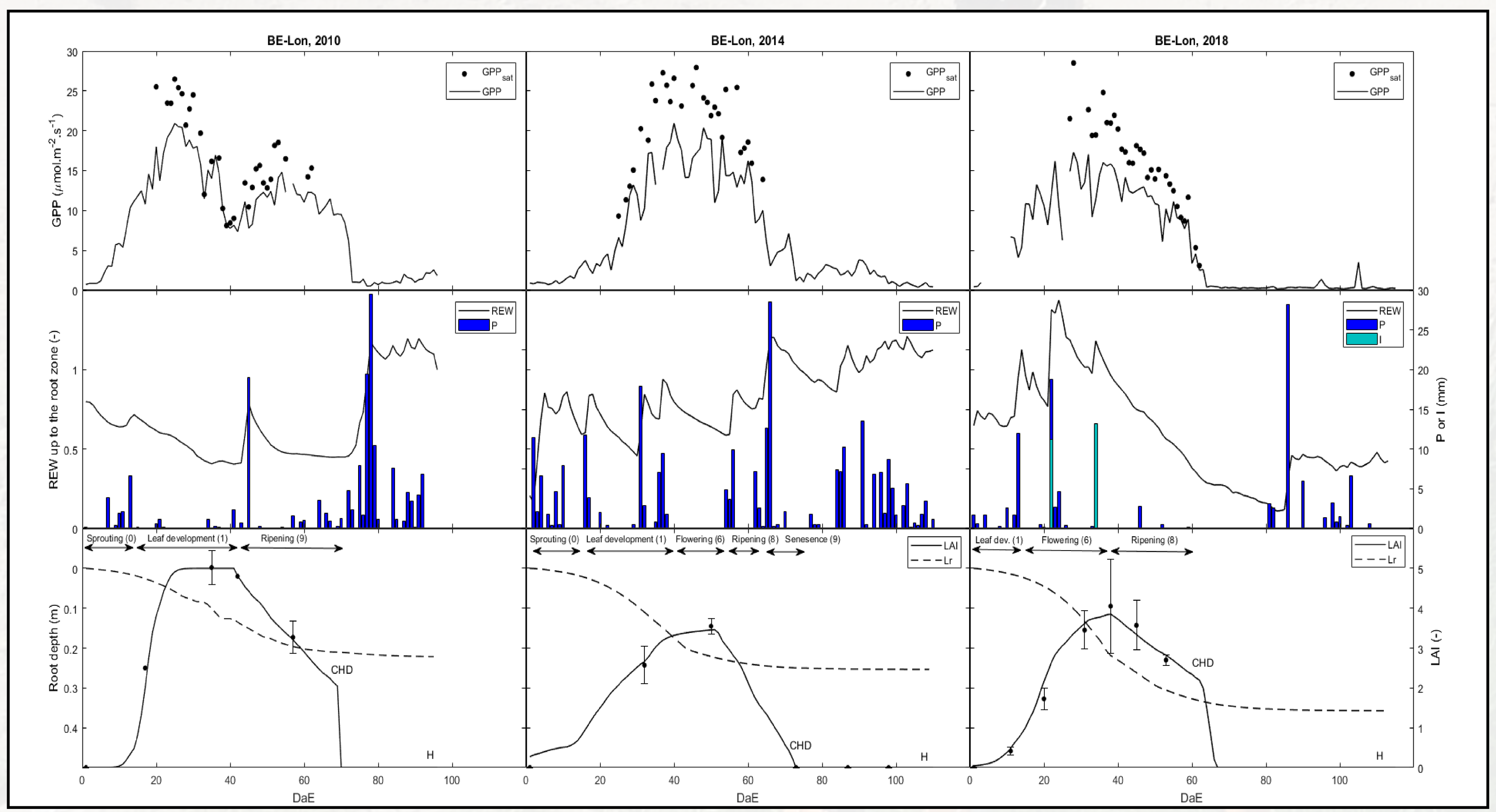


Figure 1: GPP_{sat} (saturated photosynthesis when PPFD exceeded 1200 µmol.m^{-2}.s^{-1}) and GPP daily averaged fluxes during the cultivation periods in 2010, 2014 and 2018 in the first row. In the second row, REW evolution, precipitation and irrigation data are shown. In the third row are presented the evolution of green leaf area index (LAI) measurements and root depth (Lr) modelled values. The development stages are mentionned with their BBCH code in parenthesis. « CHD » means haulm killing, and « H » harvest. DaE » means days after emergence.

2 Impact of drought on SOL and NSOL

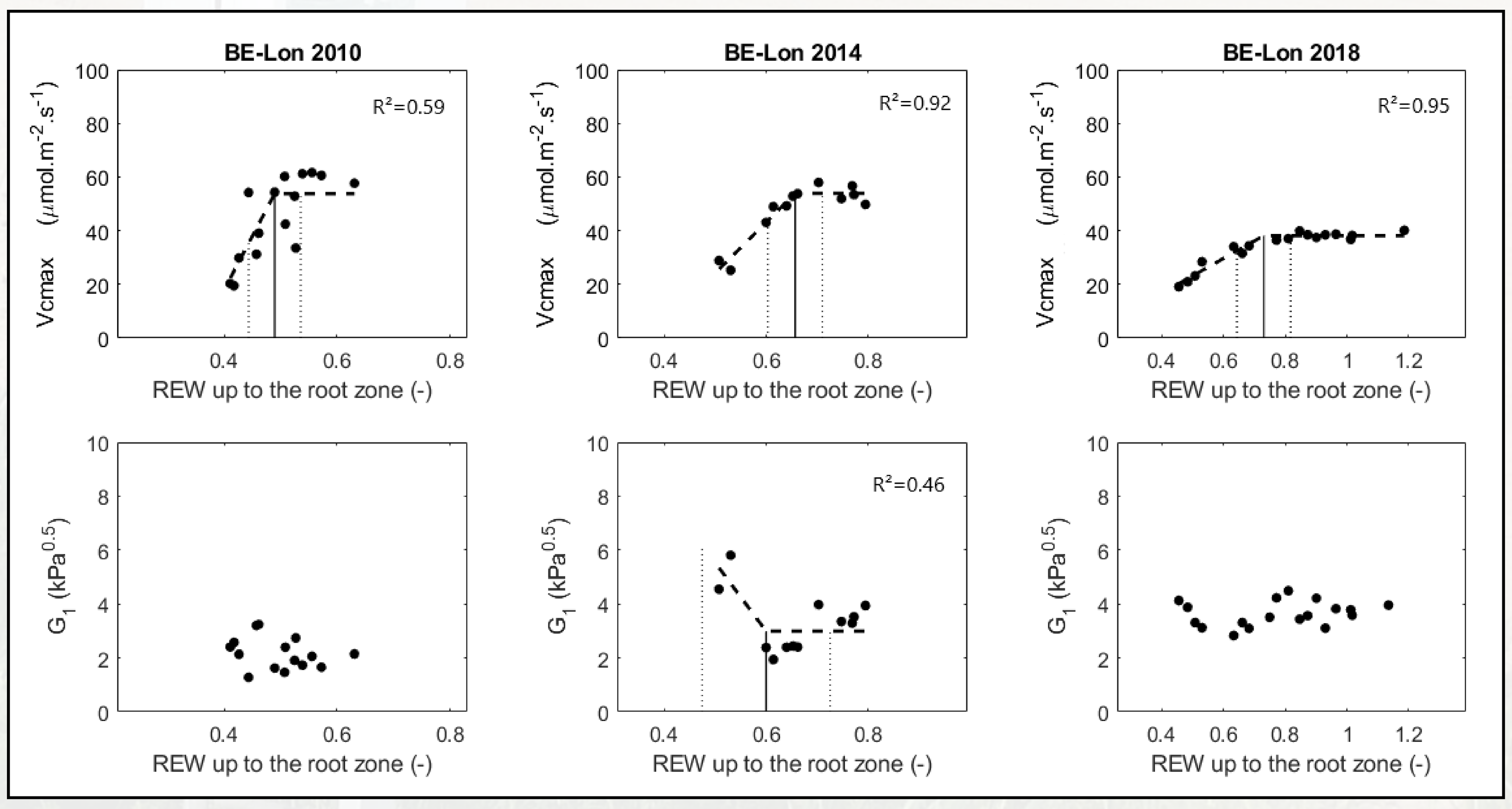


Figure 2 : Relationships between REW and NSOL (V_{cmax} - for the upper part) or between REW and SOL (G_1 - for the down part). The solid line represents the REW breakpoint when V_{cmax} or G_1 started to decrease. The dashed line corresponds to the confidence interval around the breakpoint. The R^2 value gives the determination coefficient of the segmented linear model.

3 Impact of drought on GPP modelling and coupling between carbon and water fluxes

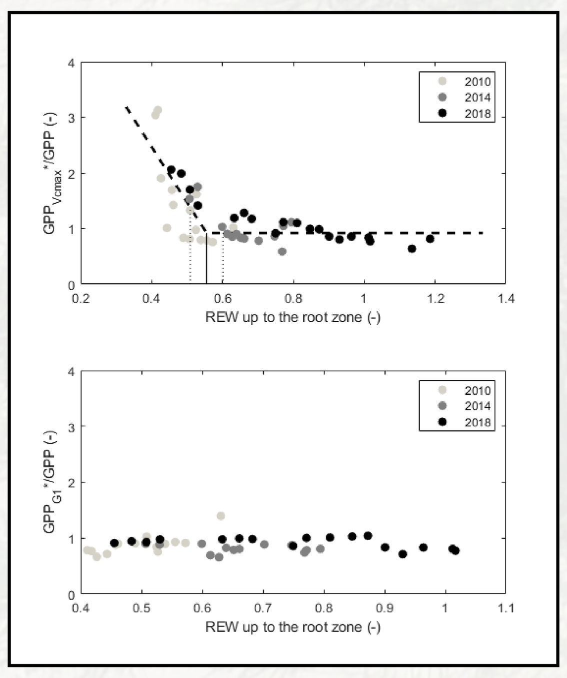


Figure 3 : Relationship between the ratios GPP_{Vcmax}*/GPP , GPP_{G1}*/GPP and REW in 2010, 2014 and 2018. These ratios represent the impact of NSOL (GPP_{Vcmax}*/GPP) and SOL (GPP_{G1}*/GPP) on GPP modelling during drought.

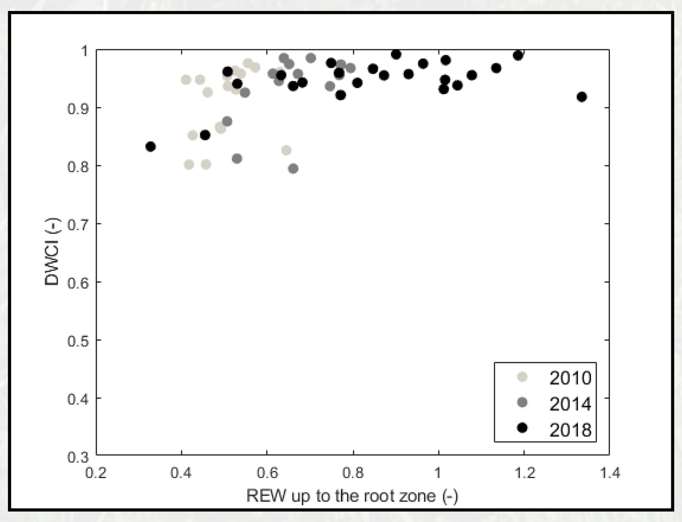


Figure 4 : Relationship between diurnal carbon water index (DWCI) with REW in 2010, 2014 and 2018.

Discussion

- GPP anomalies recorded in 2010 (leaf development stage), 2014 and 2018 (ripening stage). Synchronized dynamics with REW and lack of precipitation (fig. 1).
- **G_1 remained constant** while **V_{cmax} decreased** from a REW breakpoint (fig. 2). The slight increase in G_1 in 2014 might be attributed to low GPP and transpiration values.
- **NSOL were the dominant mechanism** of photosynthesis control when soil **water availability decreased by 45 % (REW = 0.55 ± 0.05)** (fig. 3).
- No decoupling between carbon and water fluxes at the intra-day timescale (fig. 4) : we hypothesize that **NSOL** had a **cojoint effect on G_c and GPP**.
- Discrepancy between « optimal » stomatal behaviour (decrease of G_1) and our results: need of a revision of the cost associated with the opening of stomata.

Take home message

- NSOL were the dominant mechanism limiting photosynthesis during drought.
- REW = 0.55 ± 0.05 could be used as a relevant threshold for crop modelling.

What's next ?

- Use of fluorometry and gas exchange measurements to infer g_m dynamics.
- Complete overview of photosynthetic flux limitations during drought.