



*Supplement of*

## **Drivers and vertical CO<sub>2</sub> flux balances in a Sahelian agroforestry system: Insights from high frequency measurements**

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**Supplementary materials:**

Table S1: data description

Parameters	Symbol	Unit	Method	Sensor	Data processing	Measurement height (m)
Volumetric water Content	VWC	%	TOMST	TMS-4	native	-0.06
Air temperature	T <sub>air</sub>	°C	TOMST	TMS-4	native	0.15
Soil temperature	T <sub>soil</sub>	°C	TOMST	TMS-4	native	-0.06
Crop + Weed LAI	LAI.field	m <sup>-2</sup> leaf m <sup>-2</sup> soil	NDVI	Pontailleur et al. (2003)	-	18
Chamber Leaf Area Index	LAIch	m <sup>-2</sup> leaf m <sup>-2</sup> soil	Manual, from leaflet count and SLA	-	-	crop level
Soil + crop net CO <sub>2</sub> fluxes in chambers, gap-filled	FCO <sub>2</sub> ch	g C-CO <sub>2</sub> m <sup>-2</sup> d <sup>-1</sup>	Chambers	Picarro G2508	native time series, then gap-filled	0.5
Soil + crop respiration in chambers, gap-filled	Rch	g C-CO <sub>2</sub> m <sup>-2</sup> d <sup>-1</sup>	Chambers	Picarro G2508	Computed, Lloyd and Taylor (1994)	0.5

Parameters	Symbol	Unit	Method	Sensor	Data processing	Measurement height (m)
Crop Gross Primary Productivity in chambers, standardised with LAI, gap-filled	GPPch	g C-CO <sub>2</sub> m <sup>-2</sup> d <sup>-1</sup>	Chambers	Picarro G2508	Computed, Lasslop et al. (2010)	0.5
Global Radiation	Rg	W m <sup>-2</sup>	Skye Instruments		Computed from PAR	20
Ecosystem respiration, gap-filled	Reco.EC	g C-CO <sub>2</sub> m <sup>2</sup> d <sup>-1</sup>	EC	Smartflux	Computed ReddyProc, Lasslop et al. (2010)	20
Gross Primary Productivity, gap-filled	GPP.EC	g C-CO <sub>2</sub> m <sup>2</sup> d <sup>-1</sup>	EC	Smartflux	Computed ReddyProc, Lasslop et al. (2010)	20
Net Ecosystem Exchange, gap-filled	NEE.EC	g C-CO <sub>2</sub> m <sup>2</sup> d <sup>-1</sup>	EC	Smartflux	Computed ReddyProc, Lasslop et al. (2010)	20

Table S2: Measurement sequences for 15min time closure

<b>Steps</b>	<b>Description</b>	<b>Time (s)</b>
<i>Full cycle</i>	<i>Time needed for one full cycle</i>	<i>1800</i>
Step 1: start	Initialisation: one port of Matrix opens at the beginning of time start	20
Step 2: Purge	Time needed for measurement of ambient air before closing	420
Step 3: Closure	Time needed for closing chamber lids	10
Step 4: Measurements delay	Time needed to start measurements when chamber is closed	60
Step 5: Measurements	Time required for measurements (data acquisition)	900
Step 6: Open	Opening chamber & next port of Matrix opening and previous port of Matrix closing	10
Step 7: Standby time between measurements	Full time cycle (1800 s) minus the sum of step 1 to step 6.	380

Click twice on the plot → 2 red lines appear

Clear Lines

Analyze Segment

Export CSV Copy Results

Results:

**Analysis 1 — 7**  
 2021-06-28 22:07:16 → 2021-06-28 22:22:28  
 Min=440.720 | Max=643.530 | Mean=541.239 | Slope=0.22292068 | R<sup>2</sup>=0.99977 Delete

**Analysis 2 — 8**  
 2021-06-28 22:38:15 → 2021-06-28 22:53:24  
 Min=464.910 | Max=870.430 | Mean=662.999 | Slope=0.45633550 | R<sup>2</sup>=0.99965 Delete

**Analysis 3 — 1**  
 2021-06-28 23:05:26 → 2021-06-28 23:22:31  
 Min=430.200 | Max=477.260 | Mean=452.981 | Slope=0.04419954 | R<sup>2</sup>=0.96873 Delete

**Analysis 4 — 3**  
 2021-06-29 00:07:25 → 2021-06-29 00:22:33  
 Min=439.360 | Max=603.030 | Mean=520.122 | Slope=0.18101808 | R<sup>2</sup>=0.99967 Delete

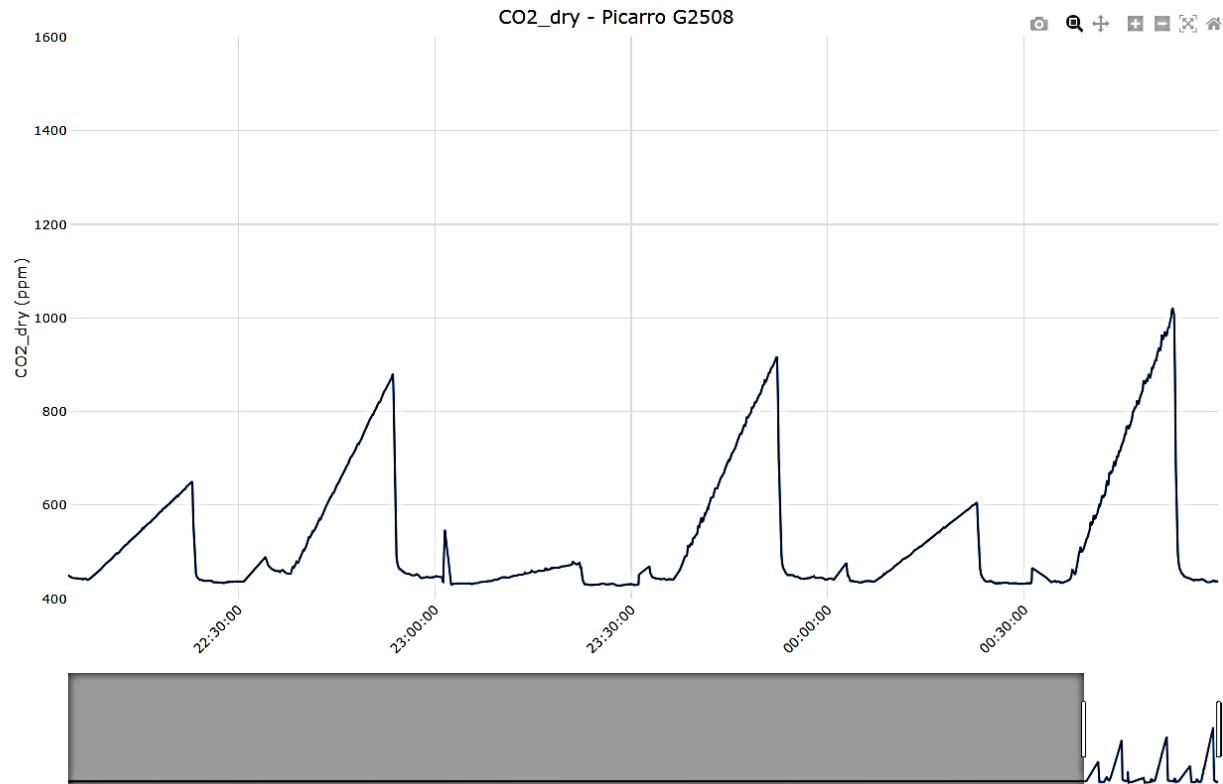


Fig. S1: CO<sub>2</sub> raw recordings and time series with 15 minutes of time closure

Click twice on the plot → 2 red lines appear

Clear Lines

Analyze Segment

Clear colored segments

Export CSV Copy Results

Results:

**Analysis 1 — 8**  
 2021-08-09 11:53:37 → 2021-08-09 11:58:37  
 Min=358.00 | Max=406.00 | Mean=382.51 | Slope (ppm/s)=-0.165026 | R<sup>2</sup>=0.99809

**Analysis 2 — 1**  
 2021-08-09 12:07:10 → 2021-08-09 12:12:10  
 Min=312.00 | Max=392.00 | Mean=351.58 | Slope (ppm/s)=-0.278440 | R<sup>2</sup>=0.99919

**Analysis 3 — 2**  
 2021-08-09 12:22:00 → 2021-08-09 12:27:00  
 Min=355.00 | Max=402.00 | Mean=378.69 | Slope (ppm/s)=-0.174855 | R<sup>2</sup>=0.98530

**Analysis 4 — 3**  
 2021-08-09 12:37:20 → 2021-08-09 12:42:20  
 Min=390.00 | Max=408.00 | Mean=397.91 | Slope (ppm/s)=-0.061347 | R<sup>2</sup>=0.98292

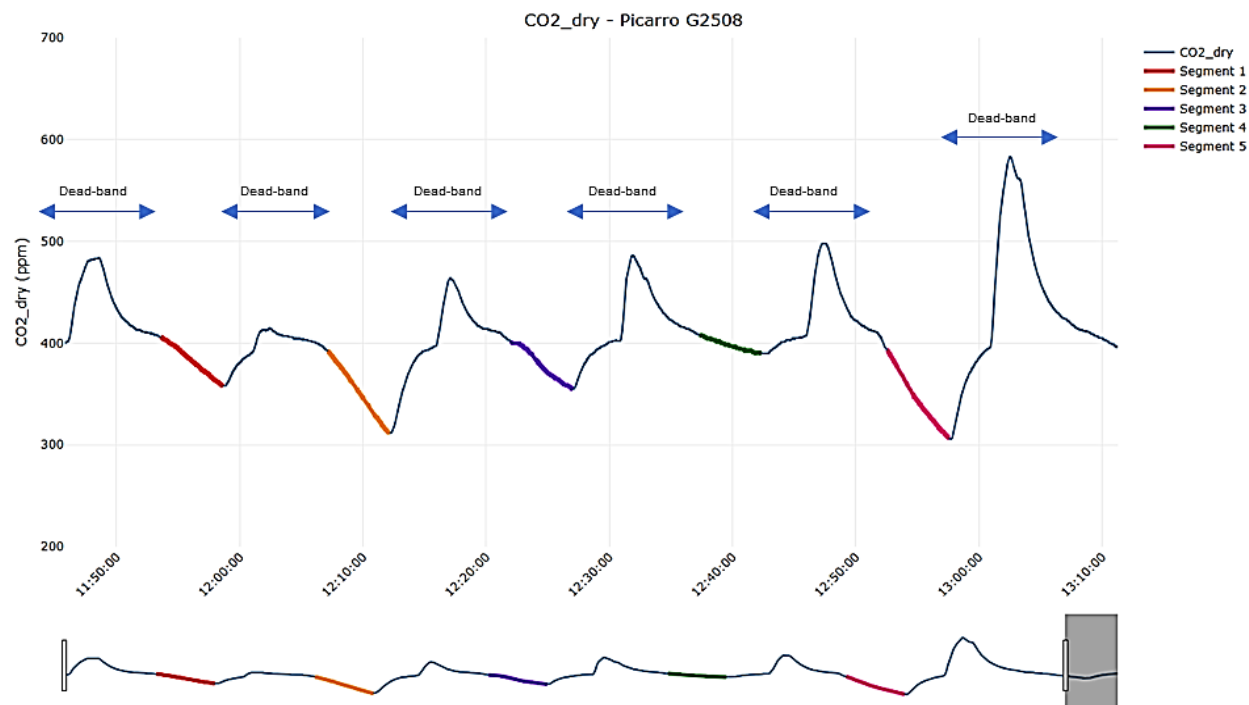


Fig. S2: CO<sub>2</sub> raw recordings and time series with 5 minutes of time closure

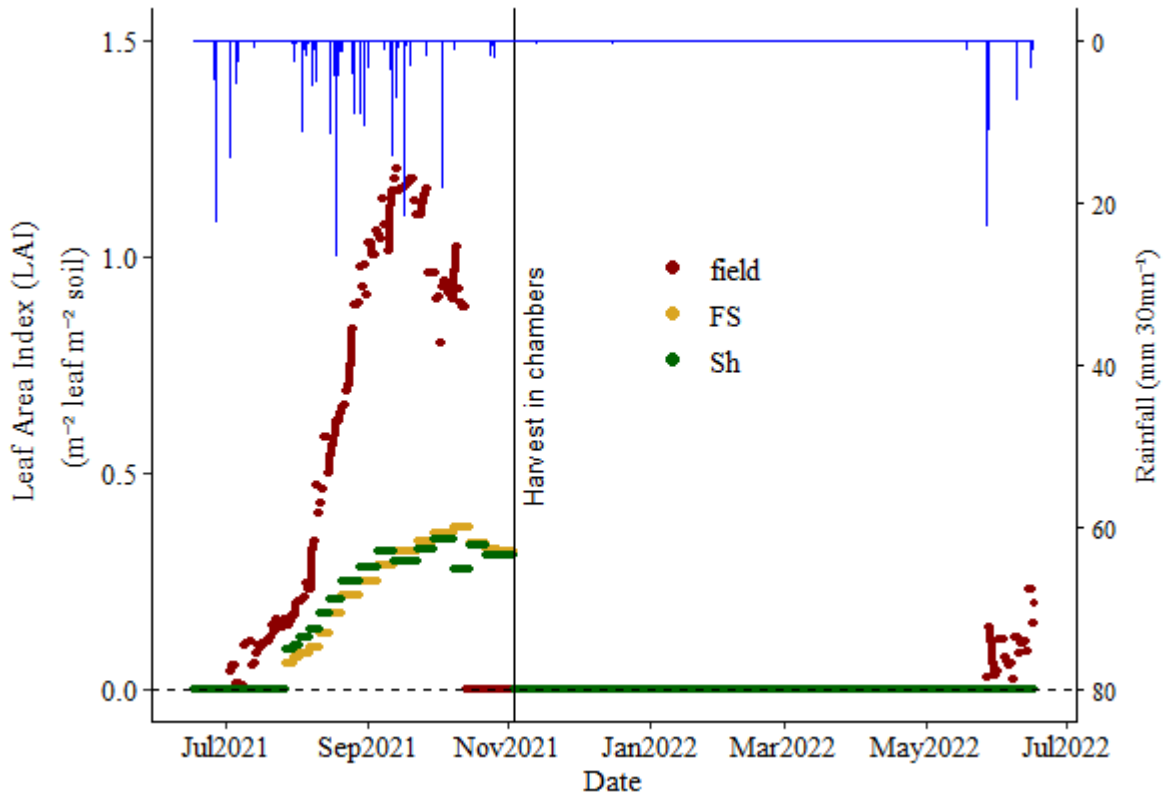


Fig. S3: Dynamics of Leaf Area Index (LAI).

The red points represent the crop LAI for the entire field ( $LAI_{field} = LAI_{Groundnut} + LAI_{Weed} + LAI_{Cowpea}$ ). Yellow and green points indicate the average of LAI within full-sun and shaded chambers, respectively ( $LAI_{ch} = LAI_{of\ groundnut\ only}$ ). The blue line shows half-hourly rainfall, while the vertical solid black line marks the groundnut harvest within the chambers.

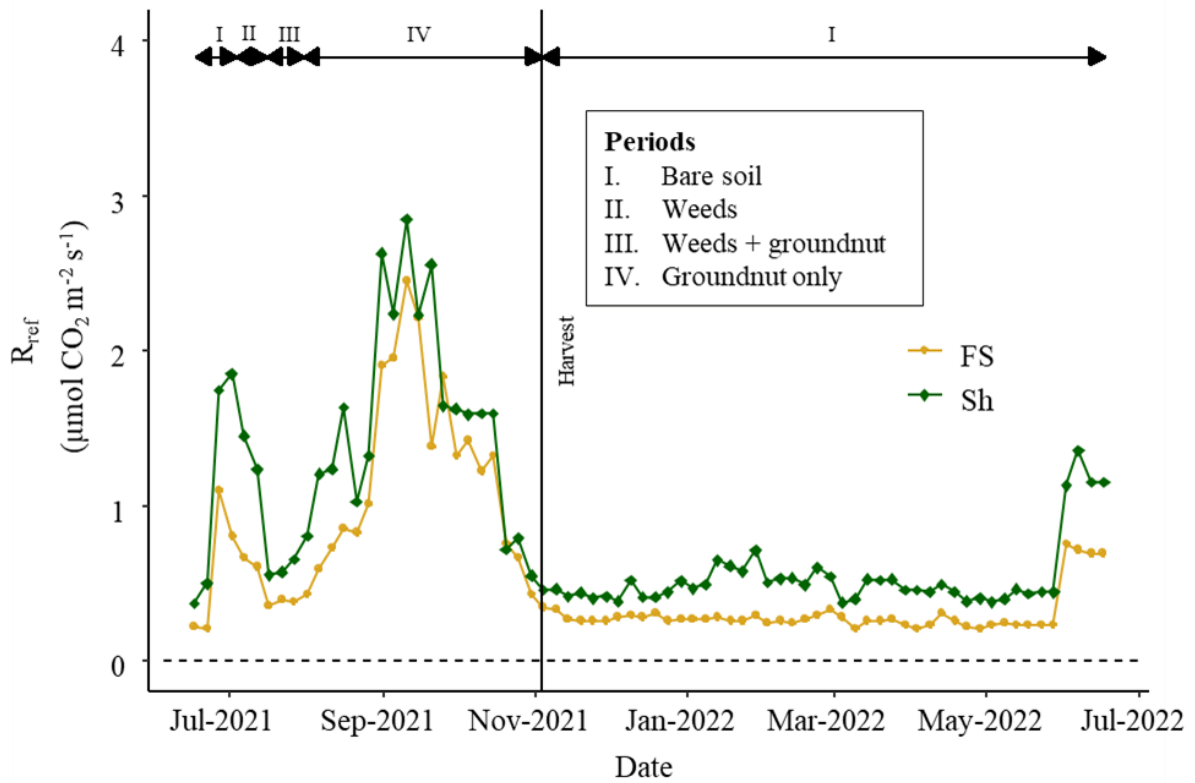


Fig. S4: Seasonal dynamics of the adjusted reference respiration ( $R_{ref}$ , Eq.4), a model parameter for respiration

Yellow and green lines indicate the adjusted reference respiration in full-sun and shaded chambers, respectively, while the vertical solid black line shows the groundnut harvest period within the chambers. Roman numerals (above the black arrows) refer to vegetation conditions prevailing inside the chambers: (I) bare soil, (II) weeds, (III) weeds + groundnuts, and (IV) groundnuts only.

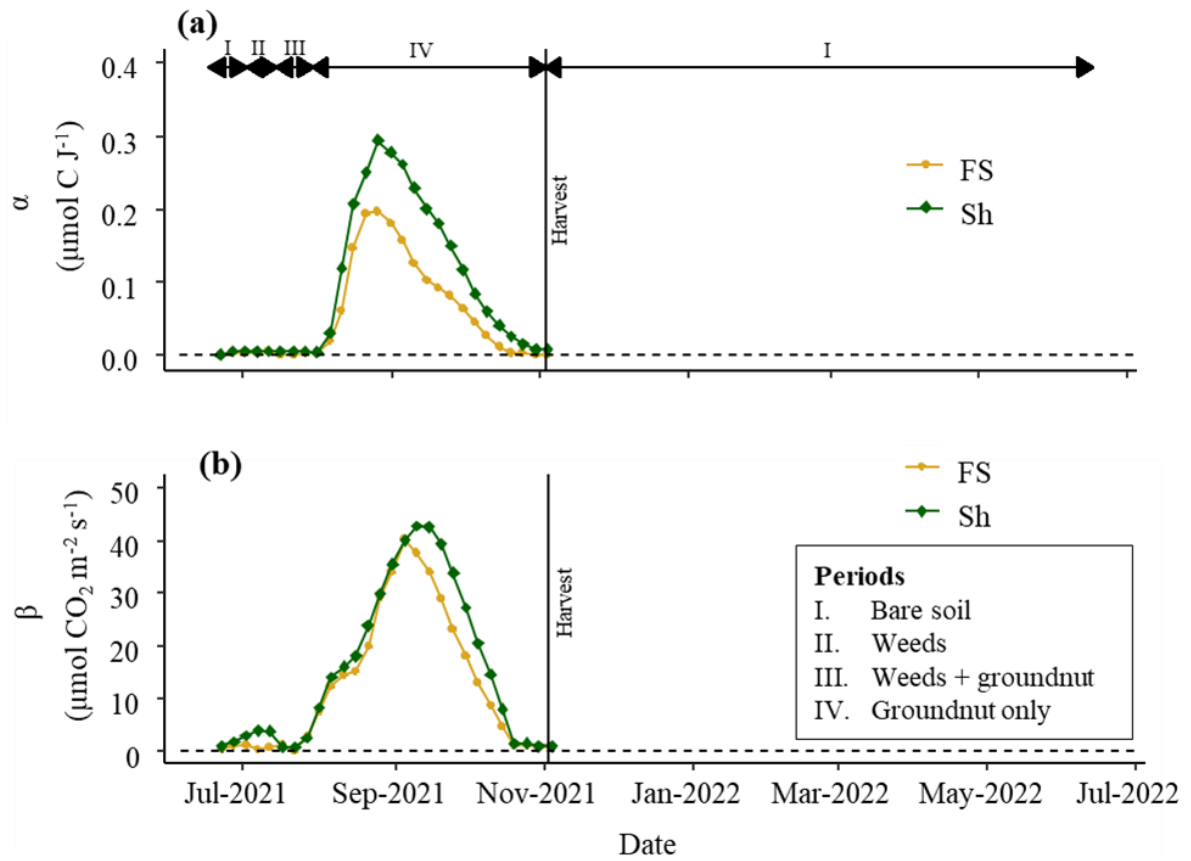


Fig. S5: Seasonal dynamics of GPPch model parameters (Eq.6)

(a) the light use efficiency ( $\alpha$ ) in full-sun (yellow line, FS) and shaded chambers (green line, Sh), and (b) the maximum  $\text{CO}_2$  uptake rate at light saturation  $\beta$  represented by the yellow and green lines for full-sun (FS) and shaded chambers (Sh), respectively; vertical solid black line indicates the harvest period within the chambers. Roman numerals (above the black arrows) refer to vegetation conditions prevailing inside the chambers: (I) bare soil, (II) weeds, (III) weeds + groundnuts, and (IV) groundnuts only.

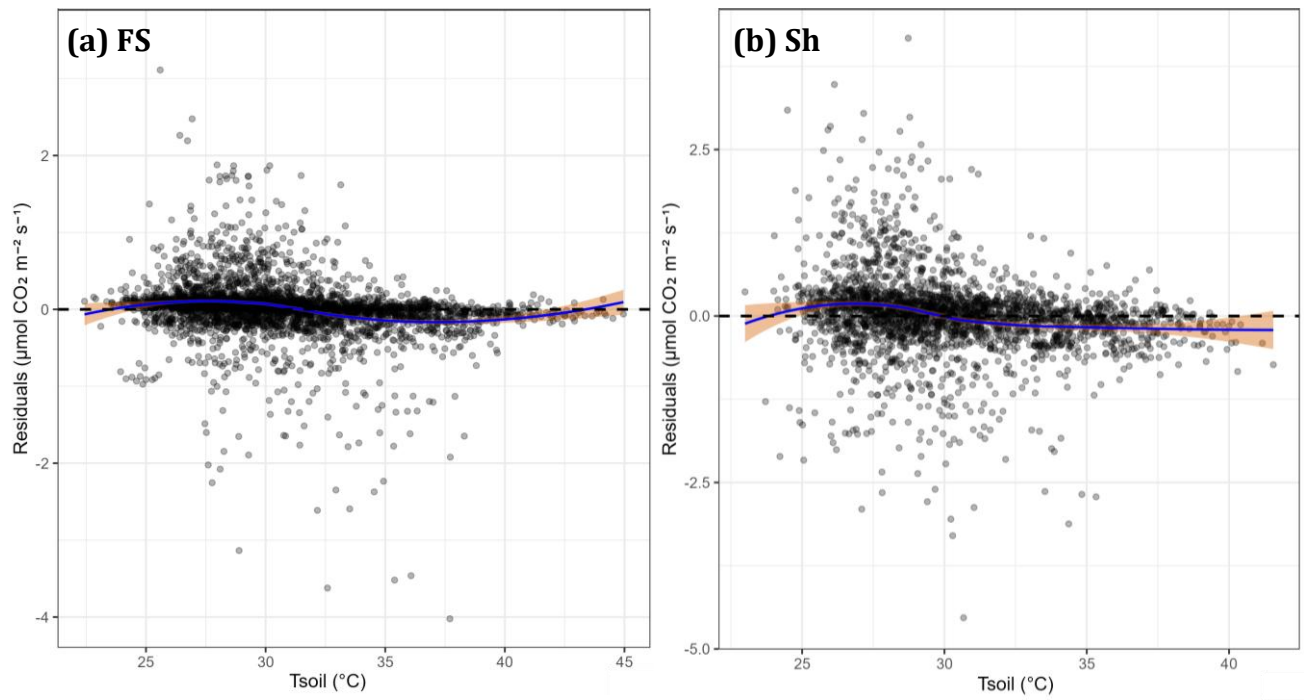


Fig. S6: Residuals of the Lloyd and Taylor (1994) model in (a) full sun and (b) away from trees

The blue curve represents the mean trend of the residuals as a function of soil temperature (Tsoil), and the light orange shading corresponds to the 95% confidence interval.

Table S3: Comparison of the Rch model parameter ( $R_{\text{ref}}$ ) and GPPch model parameters ( $\alpha$  and  $\beta$ ) between the Full sun (FS) and Shaded (Sh) chambers.

	Mean $\pm$ SD	Min	Max	Mann-Whitney test
<b><math>R_{\text{ref}}</math> (<math>\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}</math>)</b>				
FS	0.6 $\pm$ 0.5	0.2	2.5	*
Sh	0.9 $\pm$ 0.6	0.4	2.9	
<b><math>\alpha</math> (<math>\mu\text{mol CO}_2 \text{ J}^{-1}</math>)</b>				
FS	0.06 $\pm$ 0.07	<0.01	0.2	*
Sh	0.1 $\pm$ 0.1	<0.01	0.3	
<b><math>\beta</math> (<math>\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}</math>)</b>				
FS	13.4 $\pm$ 13.2	<0.01	40.2	*
Sh	16.6 $\pm$ 15.0	0.5	42.8	

$R_{\text{ref}}$  ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ),  $\alpha$  ( $\mu\text{mol CO}_2 \text{ J}^{-1}$ ), and  $\beta$  ( $\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ ) represent, respectively, the reference respiration adjusted according to Lloyd and Taylor (1994) (Eq. 4), the light use efficiency of the plant (Groundnut) inside the chambers, and the maximum  $\text{CO}_2$  uptake rate of the plant (groundnut) at light saturation, both adjusted following Lasslop et al. (2010) (Eq. 6). Mean, SD, Min, and Max denote the mean, standard deviation, minimum, and maximum values, respectively. Asterisks indicate the significance levels (\*p value < 0.05) of the Mann-Whitney test, which assesses differences in means between FS and Sh.

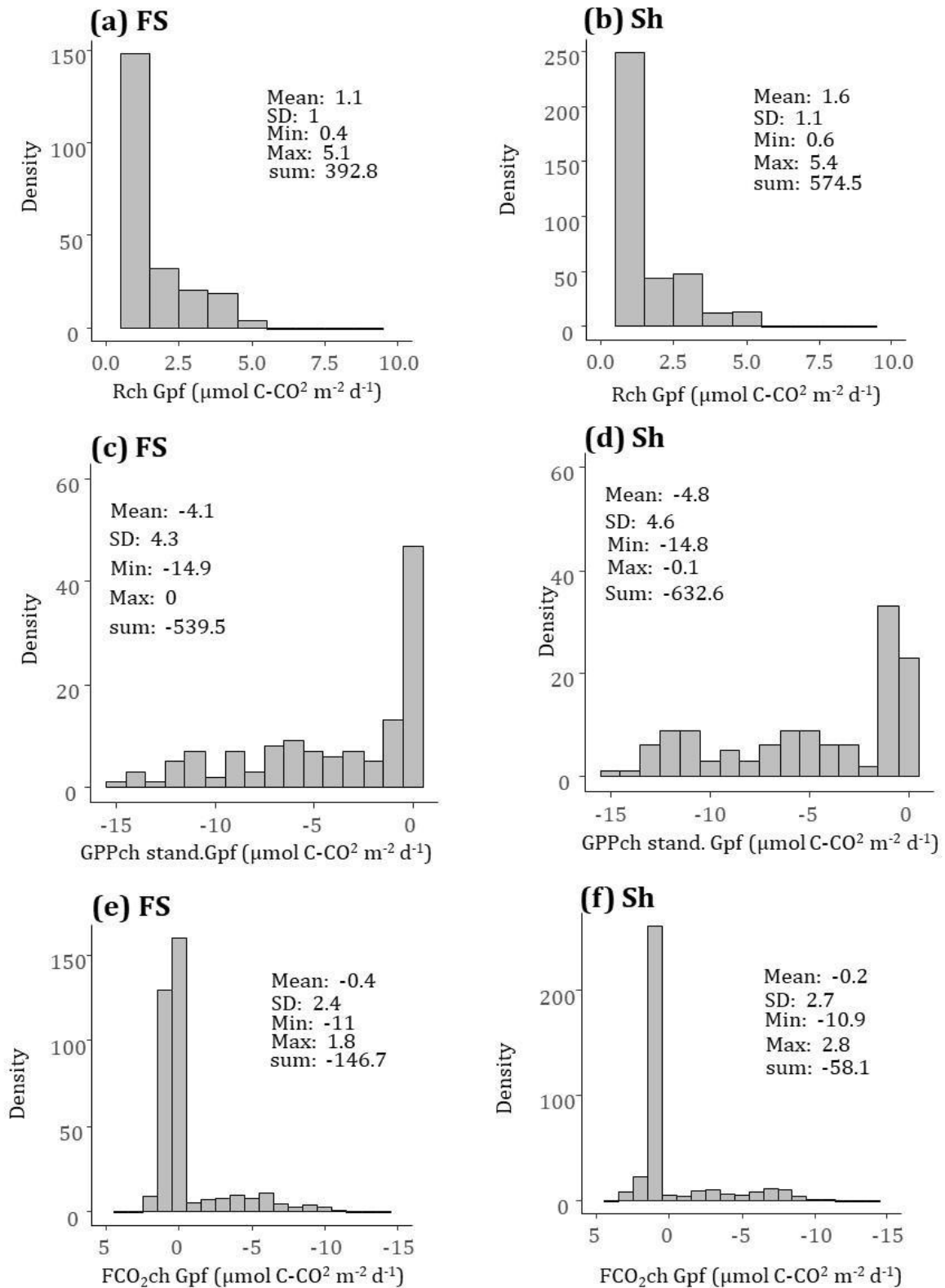
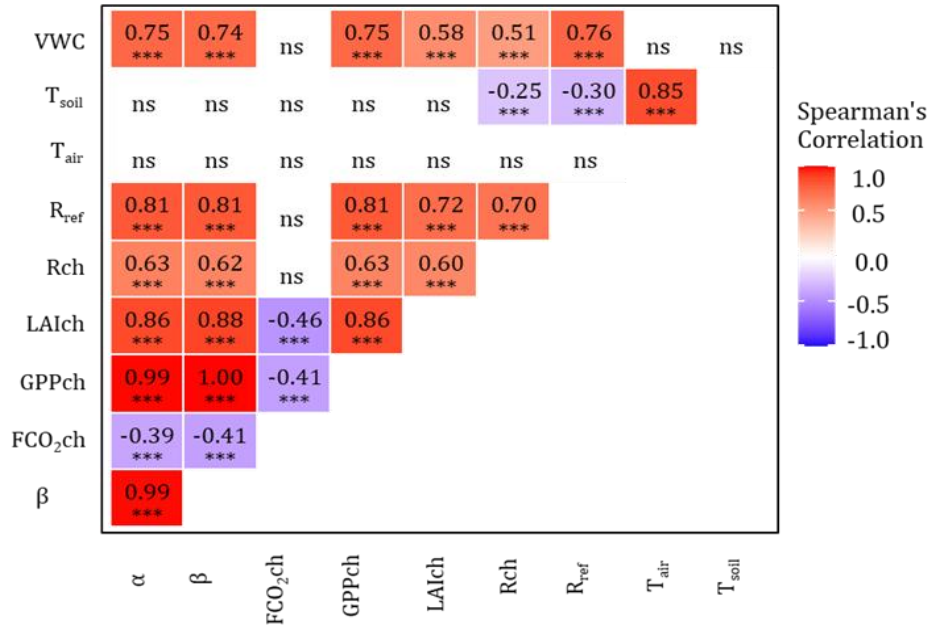


Fig. S7: Density distribution of daily cumulative and gap-filled carbon flux components

Rch in (a) FS and (b) Sh, GPPch standardised for LAI in (c) FS and (d) Sh, and FCO<sub>2</sub>ch in (e) FS and (f) Sh; Summary statistics (Mean, SD, Min, Max) are reported at the daily scale ( $\text{g C-CO}_2 \text{ m}^{-2} \text{ d}^{-1}$ ).

### (a) FS



### (b) Sh

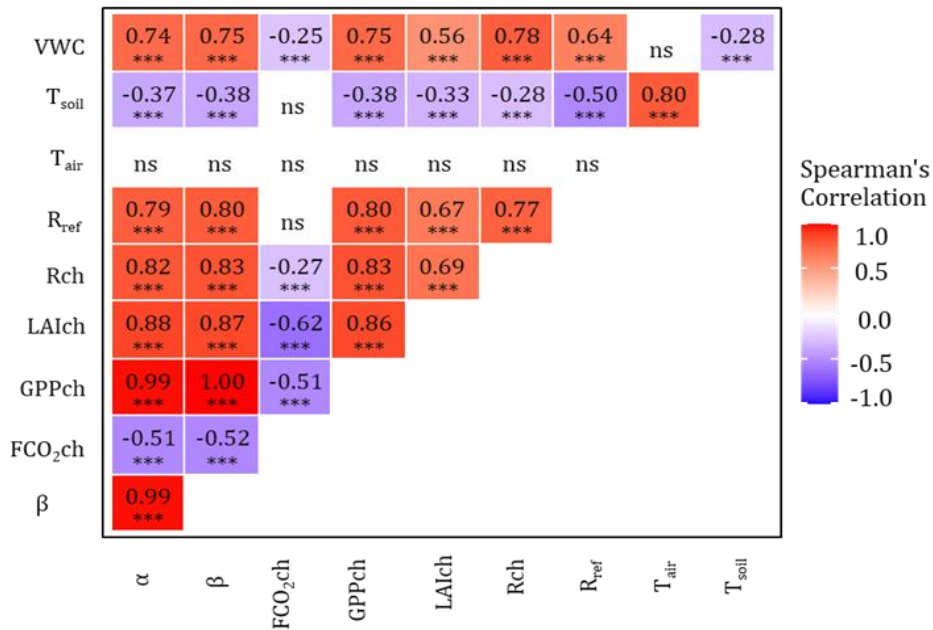


Fig. S8: Correlation matrices between daily cumulative CO<sub>2</sub> flux components for chambers (Rch, GPPch in absolute terms, and FCO<sub>2</sub>ch, in g C-CO<sub>2</sub> m<sup>-2</sup> d<sup>-1</sup>) and daily mean microclimatic parameters, as well as between R<sub>ref</sub> (Eq.4),  $\alpha$  and  $\beta$  (Eq.7).

(a) full-sun chambers (FS) and (b) shaded chambers (Sh). The climatic parameters analyzed include soil temperature at 6 cm depth (T<sub>soil</sub>, °C), air temperature at 15 cm height (T<sub>air</sub>, °C), volumetric water content (VWC, %), and chamber leaf area index (LAIch, m<sup>-2</sup> leaf m<sup>-2</sup> soil). Statistical significance is denoted by (\*\*\*) p<0.001 and ns indicate « non-significant » coefficient.

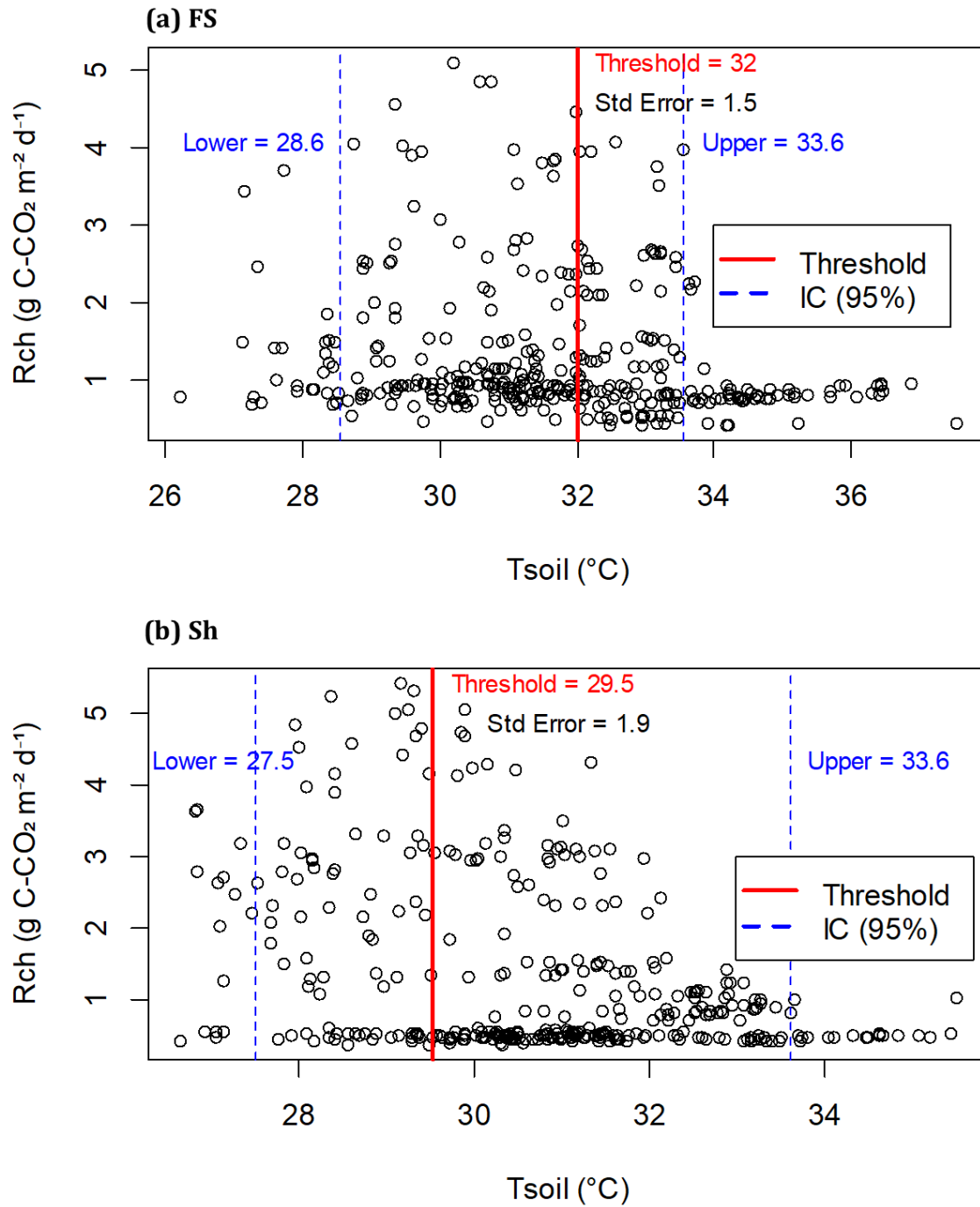


Fig. S9: Relationship between daily mean soil temperature ( $T_{\text{soil}}$ , °C) and daily cumulative chamber respiration (Rch, g C-CO<sub>2</sub> m<sup>-2</sup> d<sup>-1</sup>).

(a) Full-sun chambers (FS) and (b) shaded chambers (Sh). The red line indicates the threshold at which the slope of the relationship between  $T_{\text{soil}}$  and Rch changes significantly. The blue dashed lines represent the 95% confidence interval for the threshold, with lower and upper bounds.

Table S4: Comparison of CO<sub>2</sub> fluxes between Ch.stand and EC measurements according to the season.

Method	Flux	Wet season (July-Sept): Tree + Groundnut + Cowpea + Weeds	Dry Season (October-June): Tree + bare soil	Full Year (g C-CO <sub>2</sub> m <sup>-2</sup> )
EC	GPP.EC	= GPP Groundnut + GPP weeds + GPP cowpea (1)	= GPP tree (5)	-1180
	Reco.EC	= Ra tree AG + Ra tree BG + Ra Groundnut + Ra Weeds + Ra Cowpea + Rh (2)	= Ra tree+Rh = Ra tree AG + Ra tree BG + Rh = Ra tree AG + Rch (6)	1000
	NEE.EC	= (1) + (2)	= (5) + (6)	-180
Ch.stand (upscaled)	Rch.stand	= Ra Groundnut + Ra tree BG + Rh (3)	= Ra tree BG + Rh (7)	410
	GPPch.stand	= GPP Groundnut + GPP Weeds + GPP Cowpea (4)	= 0, no plants in the chambers	-550
	FCO <sub>2</sub> ch.stand	= (3) + (4)	= (7)	-140
Hypothesis to test		GPP.EC = GPPch.stand ?	Reco-EC = Ra tree AG + Rch.stand Ra tree AG = Reco EC - Rch.stand  Ra tree = ± Ra tree AG * 1.3 CUE = NPP tree / GPP tree CUE = (GPP tree- Ra tree) / GPP tree = 0.48 = ca. 0.5 (8)?	

Ra tree AG and Ra tree BG represent the autotrophic respiration from above-ground tree's biomass and below-ground tree's biomass.