Measuring and modelling soil GHG Fluxes

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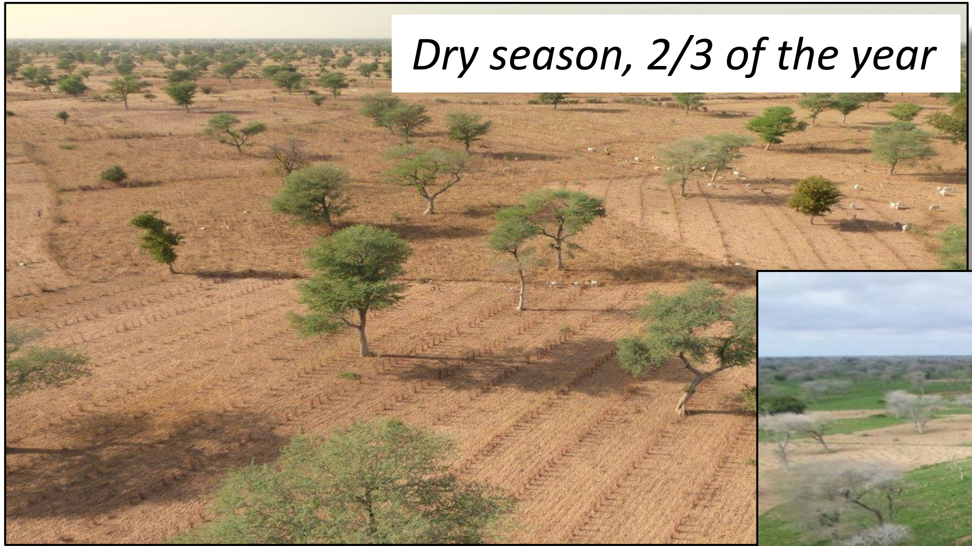
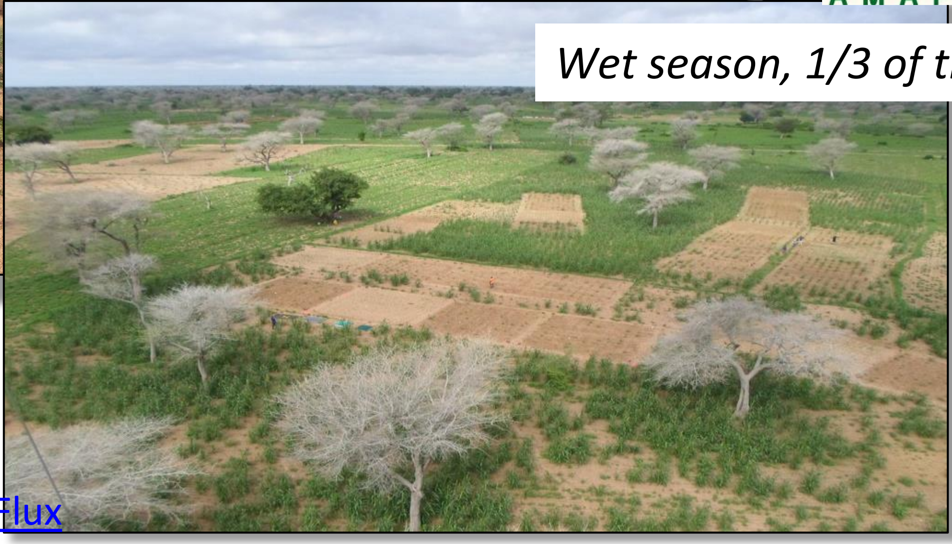
"*Faidherbia-Flux*": A long-term Collaborative Observatory on food security, GHG fluxes, ecosystem services, mitigation and adaptation in a semi-arid agro-silvo-pastoral ecosystem (groundnut basin in Niakhar/Sob, Senegal)





"*Faidherbia-Flux*" Web site :
https://lped.info/wikiObsSN/?Faidherbia-Flux

Contact: olivier.roupsard@cirad.fr

Study sites

Two distinct landscapes with contrasting soil and climatic conditions

NIAKHAR (Sob) – Groundnut Bassin (SENEGAL)


Agrosilvopastoral area dominated by the *Faidherbia albida*
Cropped area (millet, groundnut in an annual rotation)
Instrumented site (*Faidherbia* flux)

Dahra Dijolof – « Ferlo » (SENEGAL)


Silvopastoral area (with transhumant livestock)
Instrumented site (EC Tower, Meteo antenna)

***"Faidherbia-Flux"* Web site :** https://lped.info/wikiObsSN/?Faidherbia-Flux

T Tagesson et al (2015) in Agriculture, Ecosystems & Environment, 2015

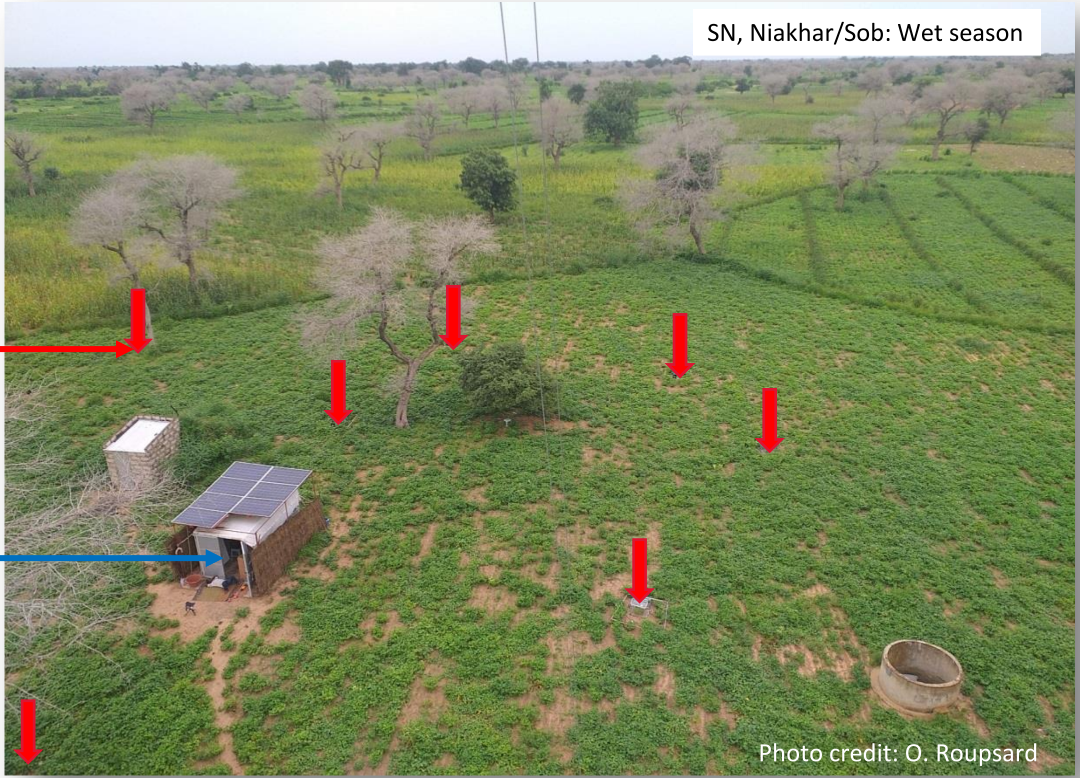
Monitoring of soil gas exchange (sob)

8 automatic chambers used (04 under trees -*Faidherbia albida*- and 04 farm from trees)
With a groundnut plant during the rainy season and without a groundnut plant during the dry season
The whole is coupled to a **Picarro 5 gas analyser**

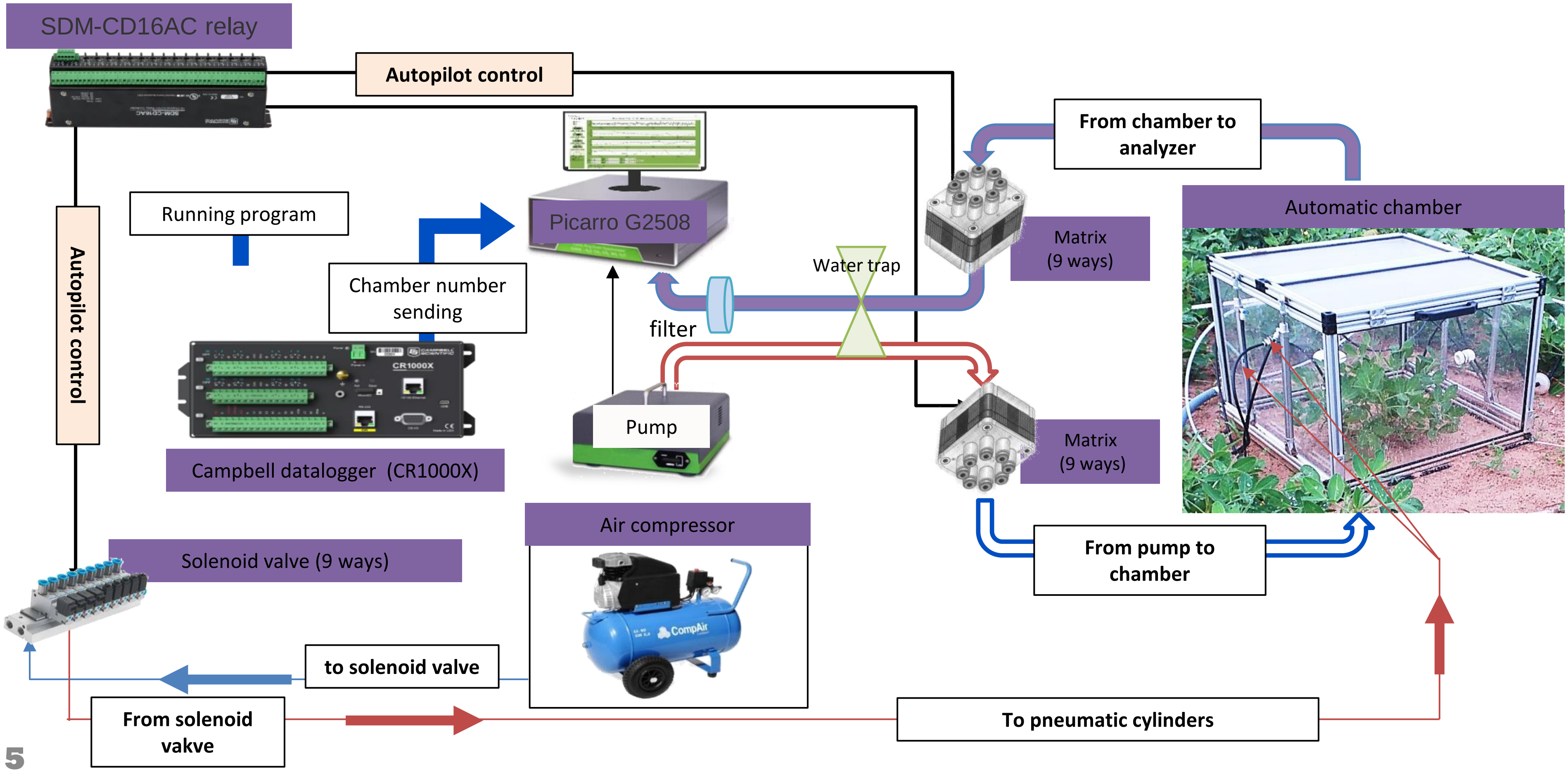
© Design: F. Bouvéry

Picarro G2508 5 gaz analyser+ recirculation pump

Simultaneous and continuous
in situ gas monitoring
(CO_2, CH_4, N_2O, H_2O and NH_3),
https://www.picarro.com



Monitoring of soil gas exchange (Sob)



Soil moisture and temperature monitoring (Sob)

Some technical specifications of the TOMTS ® sensors

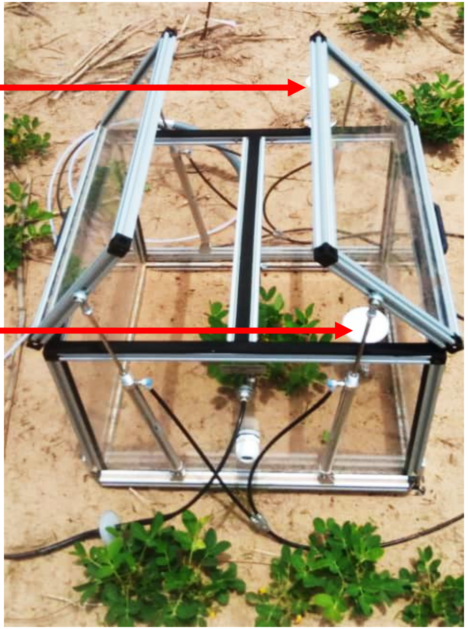
Internal memory : 524.288 events ~ 14 years, Weight: 108 g,

Battery: lithium (3.6 V; 2600 mAh) ~ 10 years,

Size: 29 cm

TOMTS sensor
(25 cm from the outside of the chamber)

TOMTS sensor
(inside the chamber)

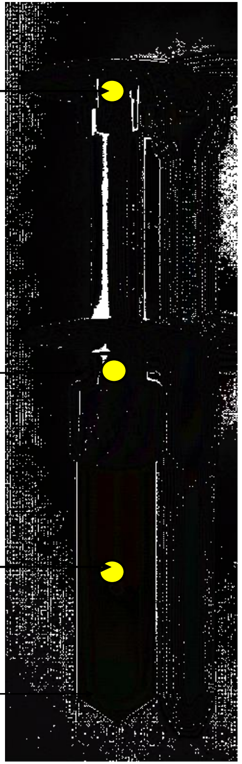


Air Temperature
(15 cm height)

Soil surface Temperature

Soil Temperature
(6cm depth)

Soil moisture (14cm depth)



- Data records every 15 minutes.
- Comparison of the measured parameters between inside and outside the chambers

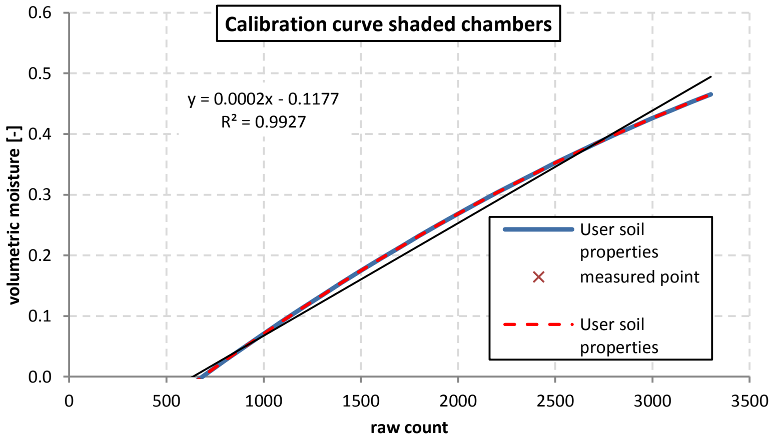
http://www.tomst.com/tms

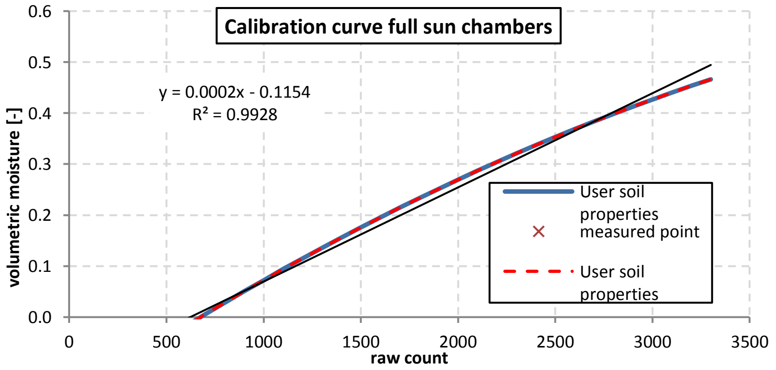
Soil moisture and temperature monitoring (Sob)

- For soil moisture (at 14cm depth), the raw soil moisture signal (~500-3600) was converted to volumetric moisture (0-100% vol.) using a dedicated utility called TMS3calibr.

- The calibration was carried out using soil properties (data from Sidy Sow's thesis).

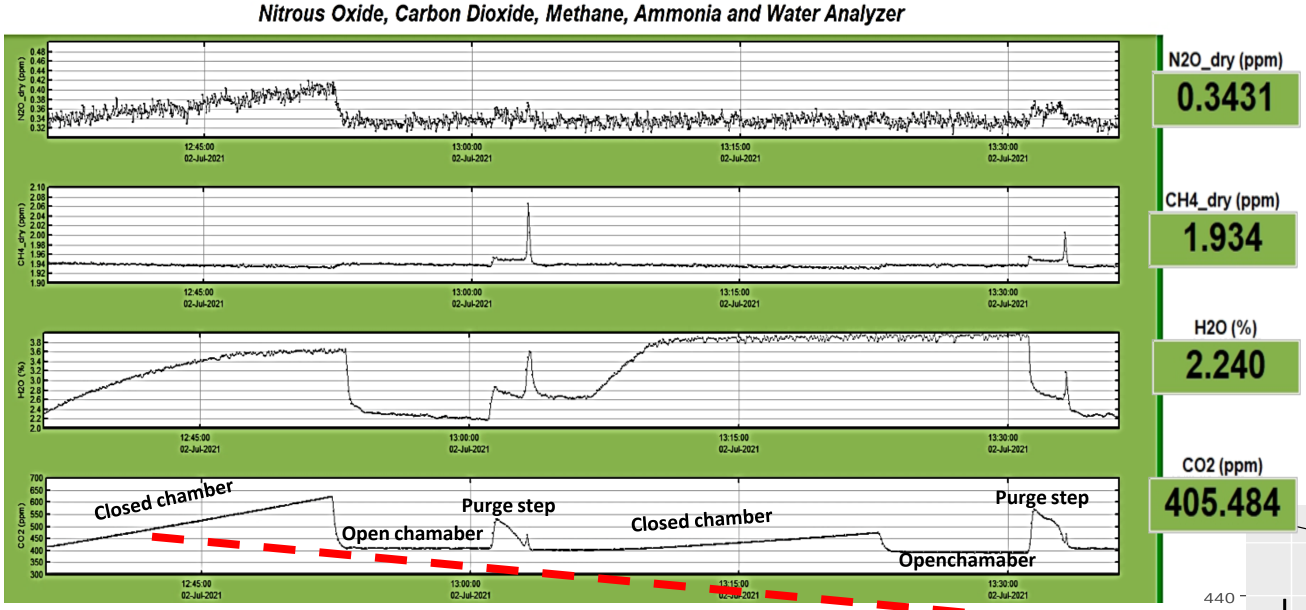
- The calibration equation is based on the bulk density and the clay, silt and sand fractions of the soil, according to the location of the chambers (far from trees and under trees).

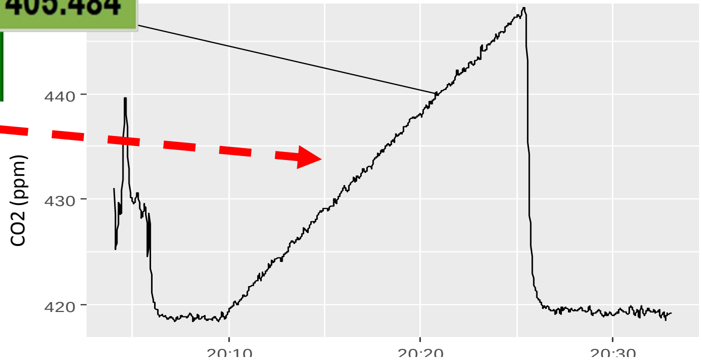




- **Experimental set up: assessing GHG emissions using automatic chambers with gas analyzer**

Graphic interface displays gas concentration in closed chamber or in the ambient air (open chamber)





Cycle length 30 min with 3 steps (purge-opening-closing) including 15 or 05 mins closed time

CO_2 accumulation is linear

A positive slope curve expresses a net CO_2 release (plant + soil respiration > photosynthesis) and a negative slope curve refers to net CO_2 uptake (photosynthesis > respiration)

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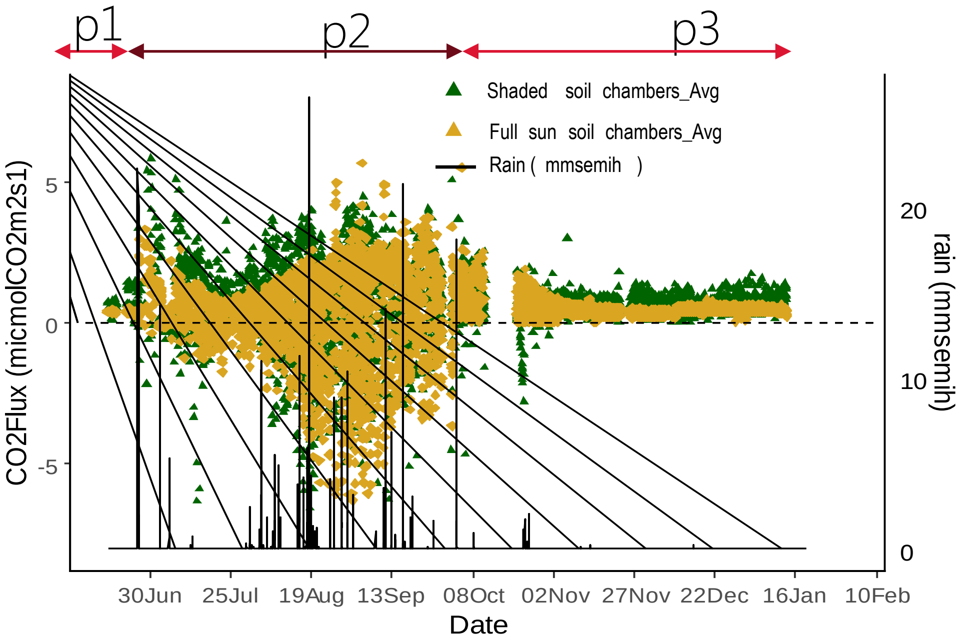
GHG fluxes exchange trends (soil, plant and atmosphere)

❑ CO2 flux (measured from June 21 to January 22)

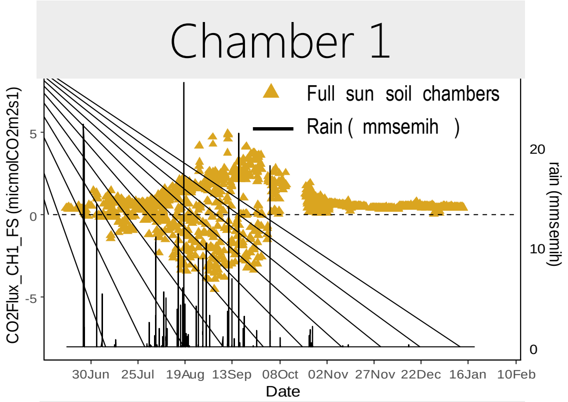


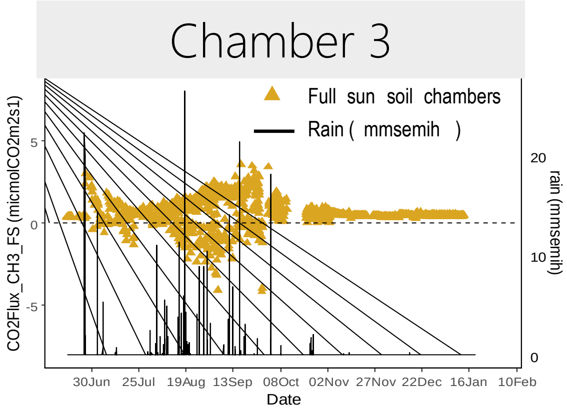
- p1: bare soil, dry season
- p2: cropped soil (groundnut), rainy season
- p3: bare soil, dry season

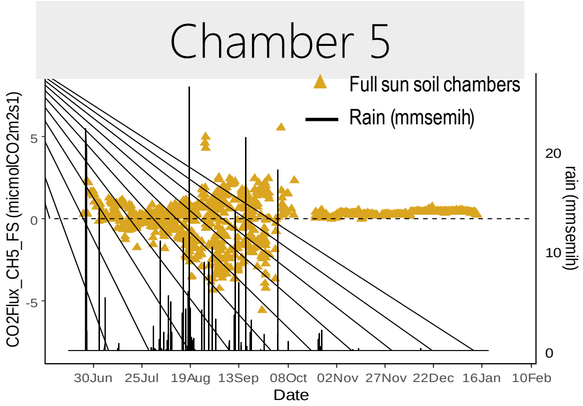
- Soil respiration was highest after the first rainfall (high release of CO2 trapped in the soil pore spaces) and throughout the wet season.
- During the wet season, the maximum soil respiration at night was about 5 µmolCO2m2s-1 and the maximum net CO2 uptake during the day was about -6µmolCO2m2s-1
- Soil CO2 respiration was very low at the end of the dry season, with an average of about 0.6 µmolCO2m2s1.

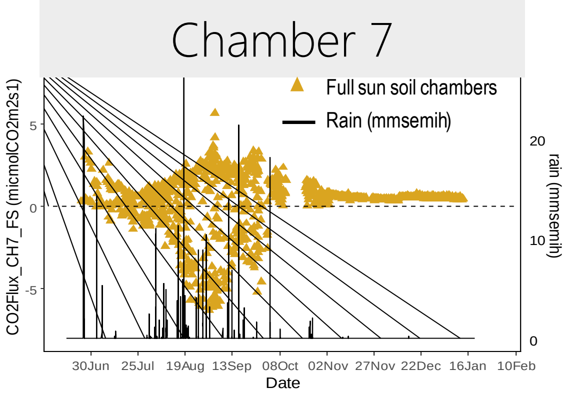
GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Change in CO_2 fluxes between full sun chambers





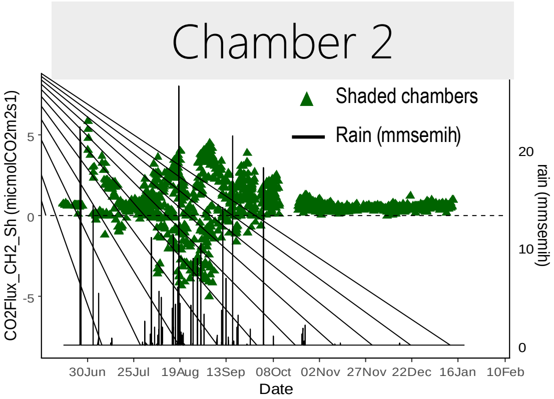


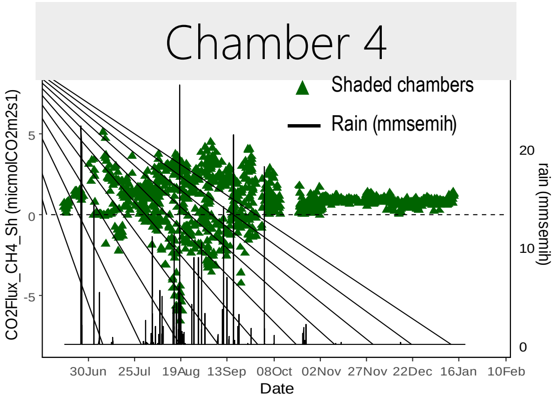


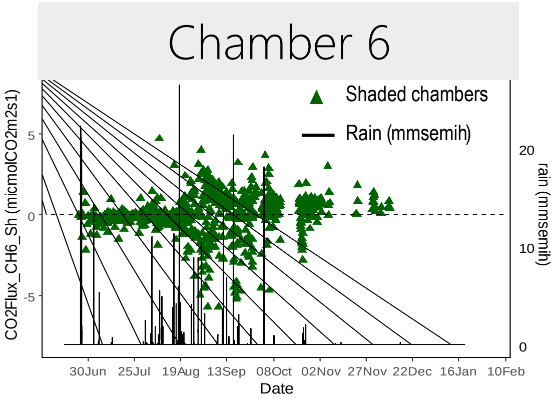
❑ Globally, Full Sun chambers show a similar pattern, but in different intensities

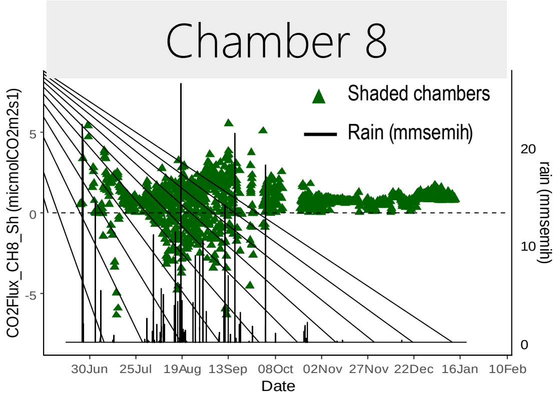
GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Change in CO_2 fluxes between shaded chambers









- Likewise, the shaded chambers show the same patterns but with varying intensities.

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Daily (24h) trends in soil respiration under trees and away from trees

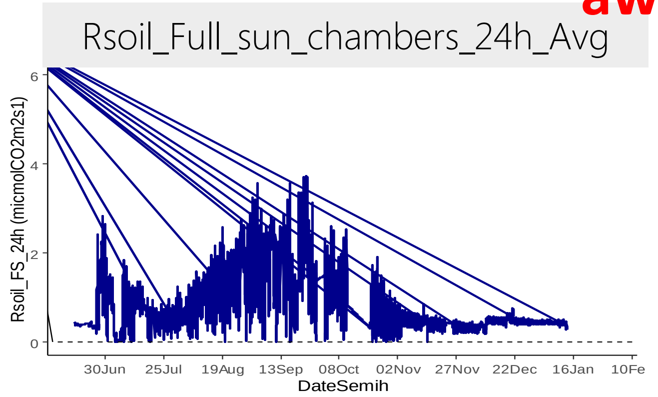


Figure a: 24 hour soil respiration with full sun chambers

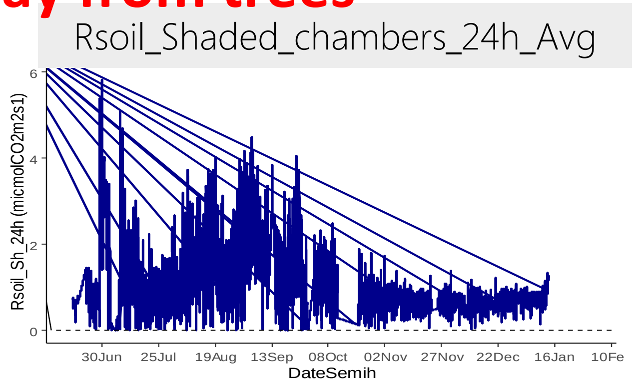


Figure b: 24 hour soil respiration with shaded chambers

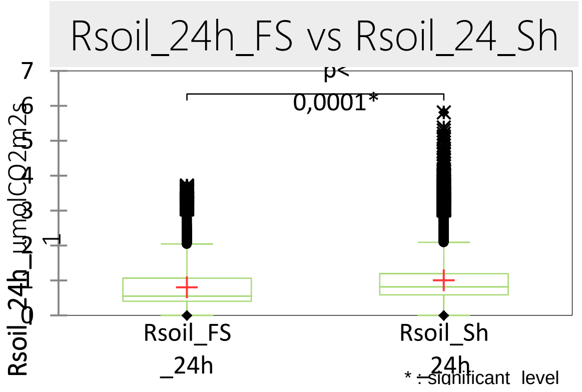


Figure c: Comparing Rsoil_FS_24h and Rsoil_Sh_24h

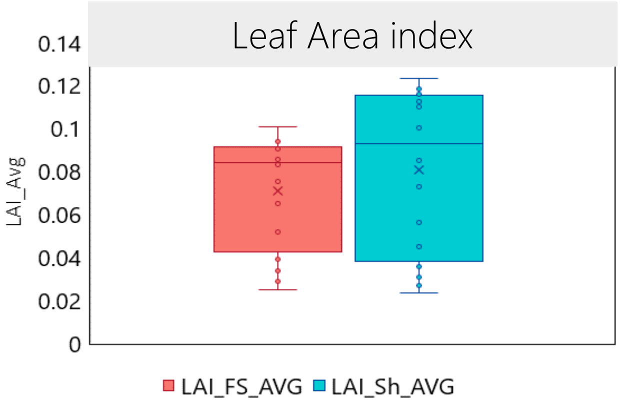
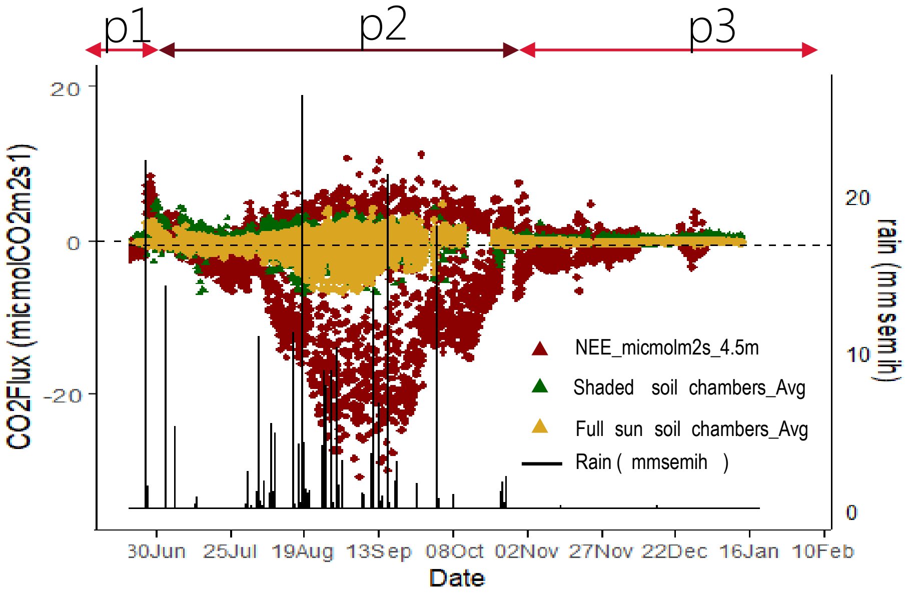


Figure d: Leaf Index area regarding traitement

- Looking at figures a and b, it can be seen that daily soil respiration is highest under trees (Figure c), but the patterns are close.
- This can be attributed to higher biomass production and therefore the LAI (Figure d) under *Faidherbia albida* crowns (Agbohessou et al. in prepare)

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Comparing soil fluxes to EC (Low antenna)



Dry season

rainy season

- p1 : sol nu, saison sèche
- p2 : sol cultivé (arachide), saison des pluies
- p3: sol nu, saison sèche

▲ NEE_micmolm2s_4.5m
▲ Shaded soil chambers_Avg
▲ Full sun soil chambers_Avg
— Rain (mmsemih)

- The CO2 fluxes from the automatic chambers show similar patterns to those from the EC tower.
- During the dry season, the CO2 fluxes obtained by automatic gas chambers were close to the EC fluxes. However, during the rainy season, with crop growth, a large difference was observed (i.e. a factor of 3.74 and 7 respectively for soil respiration and photosynthesis)
- This gap could be due to higher leaf cover as seen by the EC tower.
- We then calculate the CO2 fluxes per unit of leaf area and apply the average leaf area over the plot to correct them.

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Checking for additional CO_2 flux gaps between EC and automatic chambers

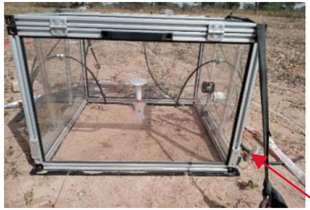
Testing the venting effect on CO_2 fluxes:

Three series of tests were carried out (after harvest)

1. Sampling measurements (from 08 to 10 December 2021)

2 full sun chambers

2 shaded chambers



The device remained connected to the Picarro G2508 gas analyzer with 15-minute measurements.

Dimensions 40 x 40 x 20mm, Voltage 12Volt s DC, Speed 6200rpmn
Operating in Full speed day and night (at closure time)
Vertical position in the chamber

At the same time, four other chambers were selected as control chambers, without fan (2 under trees and 2 far from trees).

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Checking for additional CO_2 flux gaps between EC and automatic chambers

Testing the venting effect on CO_2 fluxes:

1. Sampling measurements (from 08 to 10 December 2021)

Table: Effect of venting on gas fluxes

	CO2Flux µmolm^{-2}s^{-1}_Avg	CH4Flux µmolm^{-2}s^{-1}_Avg	N2OFlux µmolm^{-2}s^{-1}_Avg	H2OFlux mmolm^{-2}s^{-1}_Avg	NH3Flux nanomolm^{-2}s^{-1}_Avg
With fan	0.452790	-0.000372	-0.001262	0.0148743	-0.014996
No fan	0.345943	-0.000421	-3.71E-05	0.0152881	-0.00065
anova (p-value)	**0.03241 ***	0.5972	0.3896	0.931	0.3258
kruskal.test *(p-value)*	0.02478	0.5517	0.6074	0.8701	0.2723

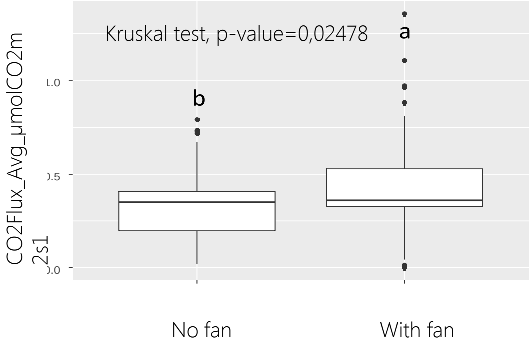


Figure: Comparing no fan to with fan test

- The general pattern showed a significant effect of venting on the CO_2 fluxes.
- However, the venting had no significant effect on the other gases (CH_4, N_2O, H_2O and NH_3)
- Considering that we only worked with 4 replicates, and to avoid any sampling biases it was necessary to reverse the ventilated and non-ventilated chambers and to repeat the test, this to validate the trend.

GHG fluxes exchange trends (soil, plant and atmosphere)

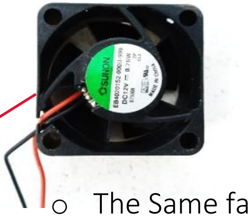
❑ Checking for additional CO_2 flux gaps between EC and automatic chambers

Testing the venting effect on CO_2 fluxes:

2. repeated measurements on a manual chamber (from 08 to 10 December 2021)

https://www.licor.com/env/products/gas_analysis/LI-830_LI-850/

- Chamber connected to the licor 850 2 gas analyser (CO_2, H_2O) 12 volt power supply
- 15-minute measurements cycles.
- by alternating measurement with and without fan



2kohm potentionmeter

- The Same fan used, but this time, with various fan speeds (high, medium and low) modulated by a 2kOhm potentiometer
- We also tested different positions of the fan inside the chamber (vertical and horizontal) by doubling or not.

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Checking for CO_2 flux gaps between EC and automatic chambers

Testing the venting effect on CO_2 fluxes:

2. **repeated measurements on a manual chamber** (from 08 to 10 December 2021)

Table: Effect of venting on gas fluxes

	CO2Flux_Avg (µmolCO2m2s1)	H2OFlux_Avg (mmolH2Om2s1)
	A. Venting	
With fan	0.2944551	0.04348297
No fan	0.2881765	0.04130075
p-value (anova)	0.2071 (N.S)	0.4828 (N.S)
p-value(student test)	0.0606	0.4829
	B. Venting speed	
High	0.2853274	0.03836951
Medium	0.2909863	0.04320044
Low	0.2909863	0.0423323
p-value (anova)	0.8438 (N.S)	0.6781 (N.S)
p-value(student test)	0.3333	0.7558
	C. Fan position	
Vertical	0.2948035	0.03859616
Horizontal	0.2815494	0.04400534
p-value (anova)	0.081 (N.S)	0.2483 (N.S)
p-value(student test)	0.119	0.2492
	D. Number of fan tested	
01 fan	0.2819135	0.04375949
02 fans	0.2944395	0.03884202
p-value (anova)	0.1005 (N.S)	0.2952 (N.S)
p-value(student test)	0.1842	0.2969

- No fan effect was observed whatever the process used,

GHG fluxes exchange trends (soil, plant and atmosphere)

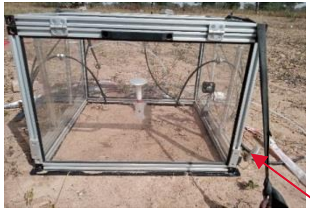
❑ Checking for additional CO_2 flux gaps between EC and automatic chambers

Testing the venting effect on CO_2 fluxes:

3. Reversing Sampling measurements (from 08 to 10 December 2021)

2 full sun chambers

2 shaded chambers



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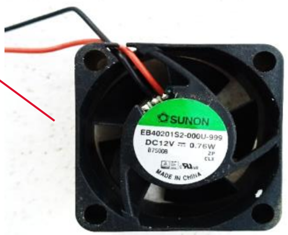


Dimensions 40 x 40 x 20mm, Voltage 12Volt s DC, Speed 6200rpmn
Operating in Full speed day and night (at closure time)
Vertical position in the chamber

At the same time, four other chambers were selected as control chambers, without fan (2 under trees and 2 far from trees).

GHG fluxes exchange trends (soil, plant and atmosphere)

❑ Checking for additional CO_2 flux gaps between EC and automatic chambers

Testing the venting effect on CO_2 fluxes:

3. Reversing Sampling measurements (from 12 to 13 January 2022)

Table: Effect of venting on gas fluxes

	CO2Flux_micmCO2olm2s1_Avg	CH4Flux_micmCH4olm2s1_Avg	N2OFlux_micN2Omolm2s1_Avg	H2OFlux_mmolmH2O2s1_Avg	NH3Flux_nanomolNH3m2s1_Avg
With fan	0.5221	-0.000430	-3.63E-06	0.0066564	0.0048209
No fan	0.4697	-0.000404	-5.97E-05	0.0019933	-0.003127
anova (p-value)	0.4671	0.1466	0.1807	0.6017	0.07994
Test statistique (p-value)	Kruskal.Test, p-value0.5889	student.Test, p-value= 0.16	student.Test, p-value= 0.16	Wilcox.Test, p-value=0.7893	student.Test, p-value=0.08195

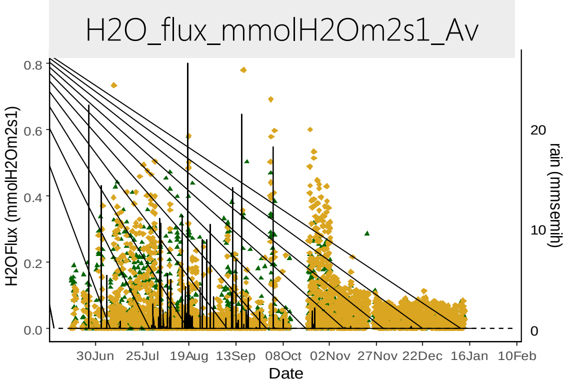
- No fan effect

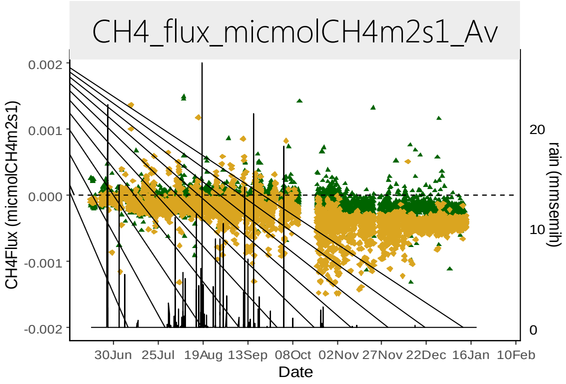
Conclusion:

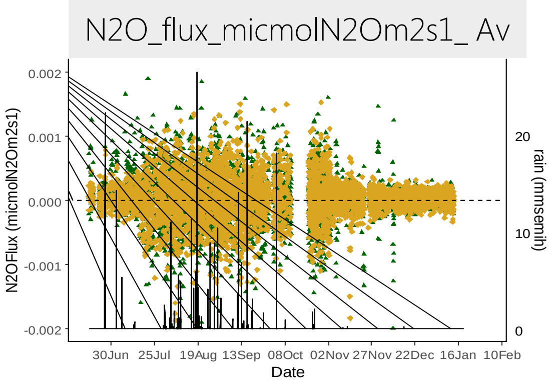
- No significant effect of venting
- Given that the soil respiration is decreasing towards zero in the dry season (on average 0.6 micmolCO2m2s1), the tests could be repeated during the rainy season to confirm or not the tendency

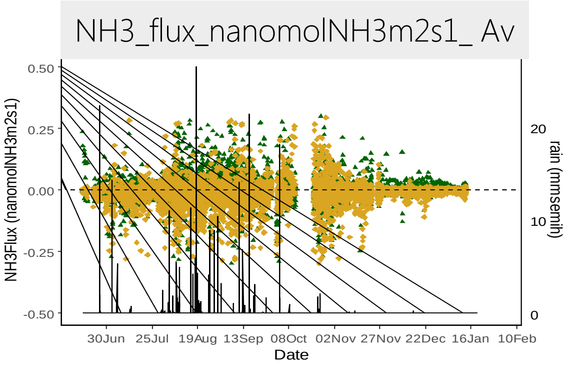
GHG fluxes exchange trends (soil, plant and atmosphere)

❑ H2O, CH4, N2O and NH3 flux trends







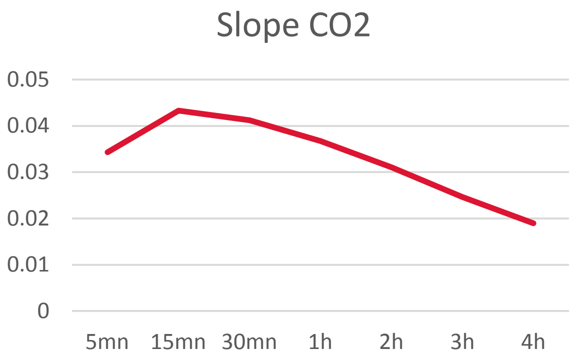


LEGEND
- ▲ Shaded soil chambers_Avg
- ▲ Full sun soil chambers_Avg
- — Rain (mmsemih)

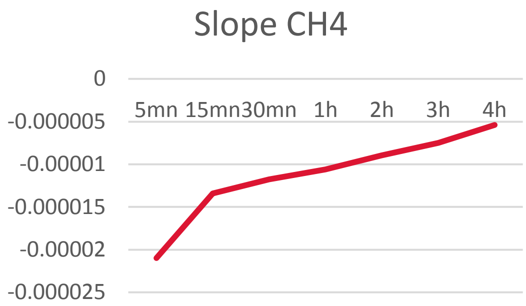
- No clearly trend for the CH4, N2O, and NH3 was found during the rainy season. The fluxes recorded look more like noise which decreases considerably in the dry season.
  Another reason might be the low soil fertility, the lack of nitrogen supply, and the low moisture content in these sandy soils which are not suitable for trace gases production processes like N2O and CH4.
- H2O fluxes seem to be more perceptible during the rainy season, possibly due to soil evaporation and plant transpiration, but with very weak intensity that might be linked to steam vapour condensing in the pipes.

GHG fluxes exchange trends (soil, plant and atmosphere)

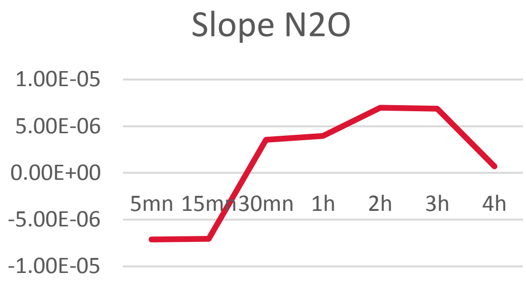
❑ Investigatin time closure on H2O, CH4, N2O and NH3 flux trends



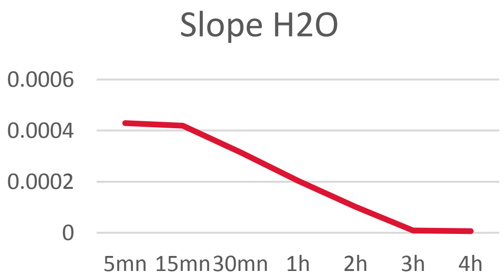
CO2 decreased after 15 minutes of closure



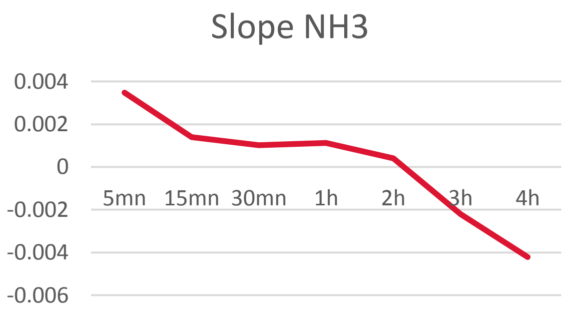
CH2 was still rising



N2O decreased after 2hours of closure



H2O decreased after 5mn of closure



NH3 decreased after 5min of closure

- Tests are ongoing with a closing time of 110 minutes since February 15th

Soil temperature and moisture monitoring)

NB: Mesured parameters were comparing between inside and outside of the chambers and between treatments (under trees and outside of trees) on all the time

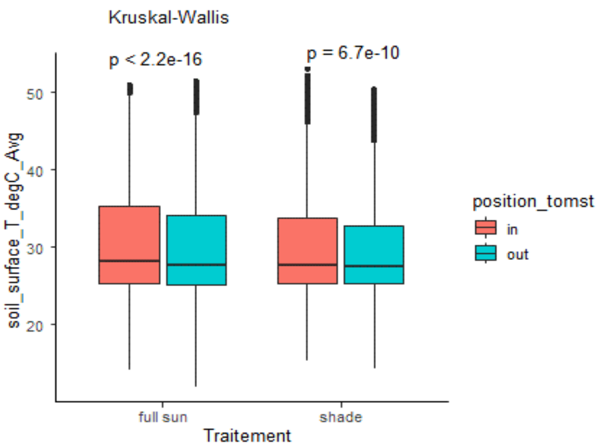


Figure a: Average soil surface temperature according to the treatment and the sensor location

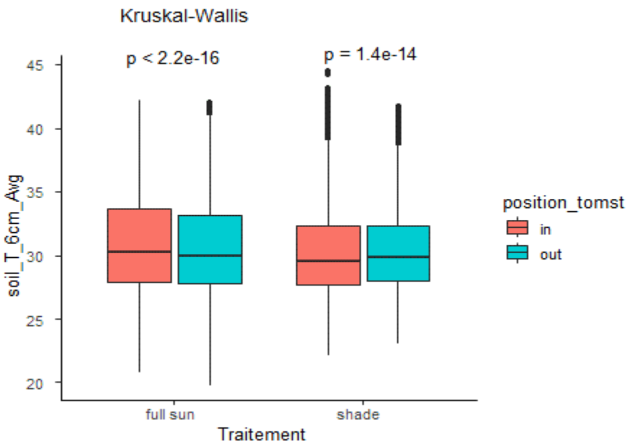


Figure b: Average soil temperature (6cm depth) according to the treatment and the sensor location

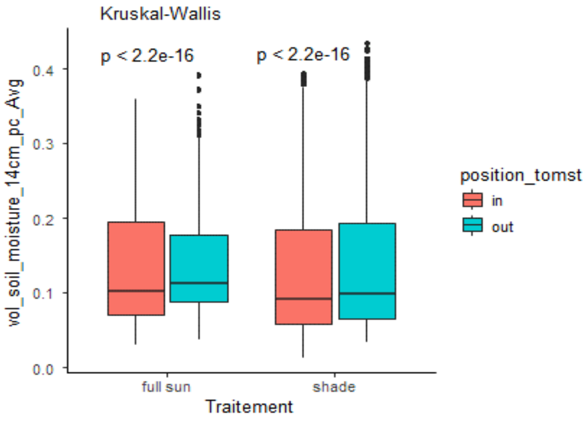
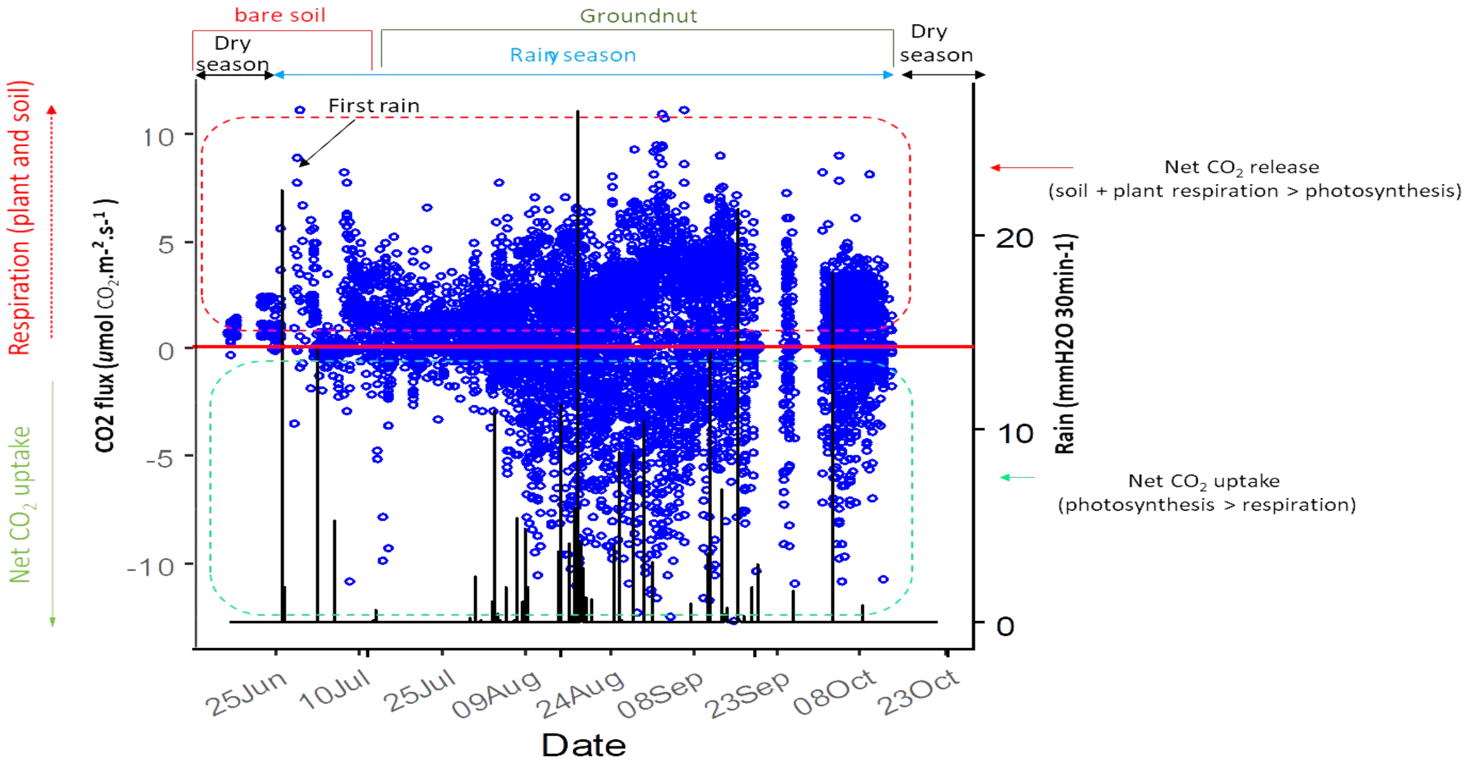


Figure c: Average soil volumetric moisture temperature (14cm depth) according to the treatment and the sensor location

- The Tomsts located in the chambers show a higher soil surface temperature in average during daytime, but the temperatures remain comparable at night whatever their location (in or out chambers) (figure a)
- The same trend is observed for soil temperature at 6cm depth (figure b)
- The soil seems to be slightly wetter outside the chambers whatever Tomst sensors location (under trees and far from trees) (figure c).

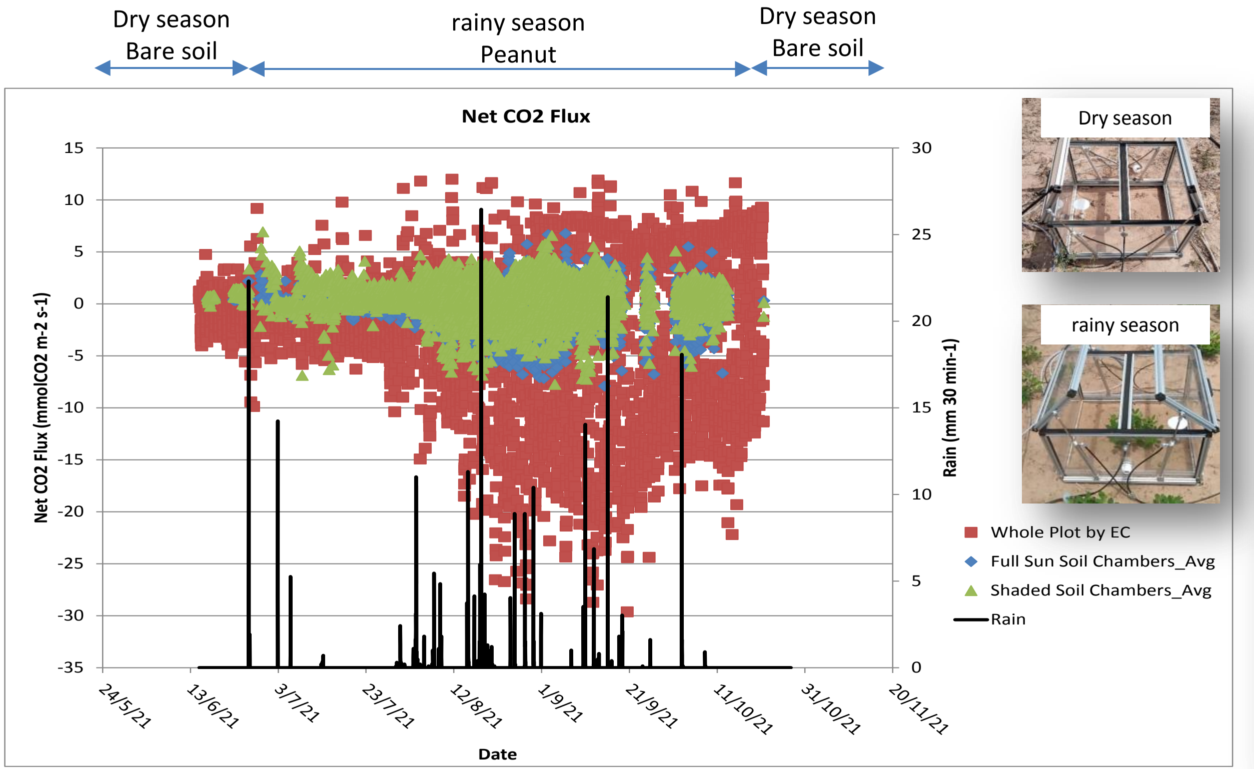
CO_2 exchange between soil + plants and atmosphere

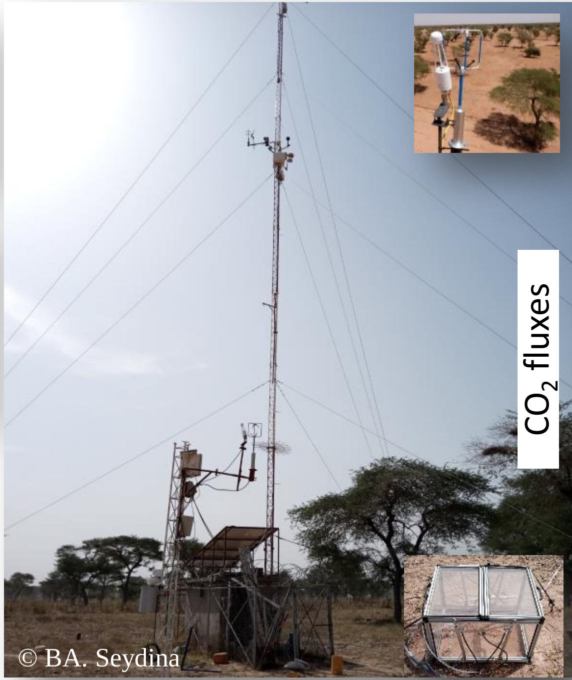


seydina1988@gmail.com (Seydina Ba)

CO_2 fluxes variate between -10 umol.m-2.s-1 to 10 umol.m-2.s-1.
Soil respiration is higher after the first rain comes (high release of CO_2 trapped in the soil porous spaces) and throughout the wet season
CO_2 uptake is nil during the dry season (no crops) very significant in the rainy season (with the development of crops)

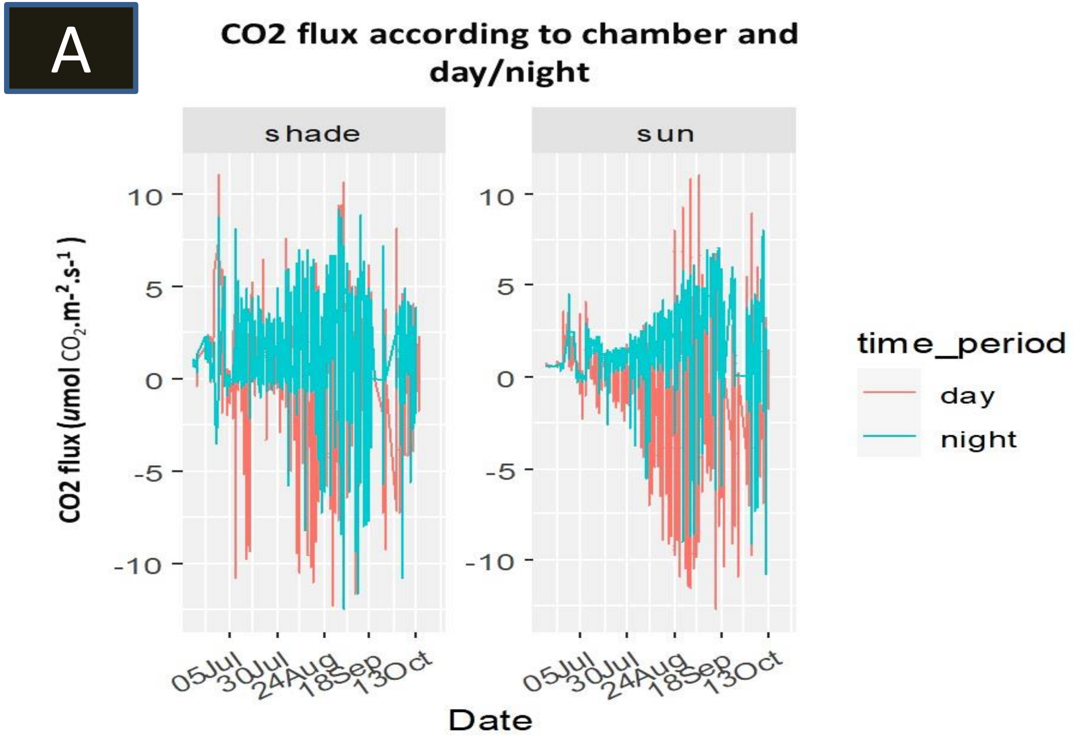
5 months of gas exchanges monitoring (from June to October 2021)

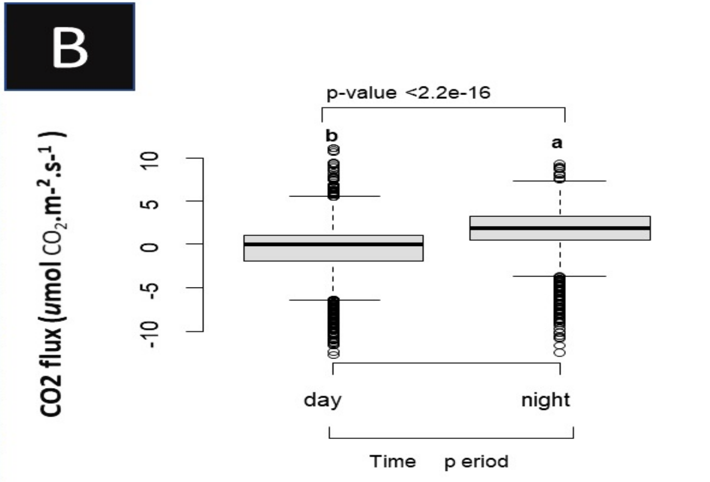


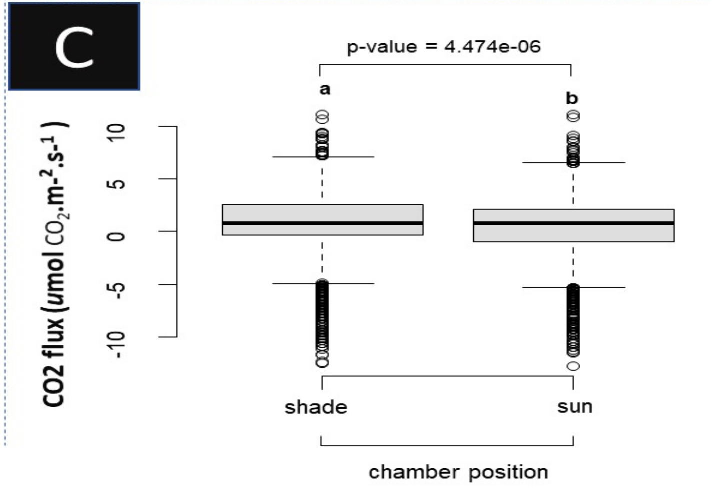


Consistent data for night respiration between EC (whole ecosystem) and soil gas exchanges. However, daily data underestimated by Soil Gas Exchanges

Contacts: seydina1988@gmail.com; olivier.roupsard@cirad.fr





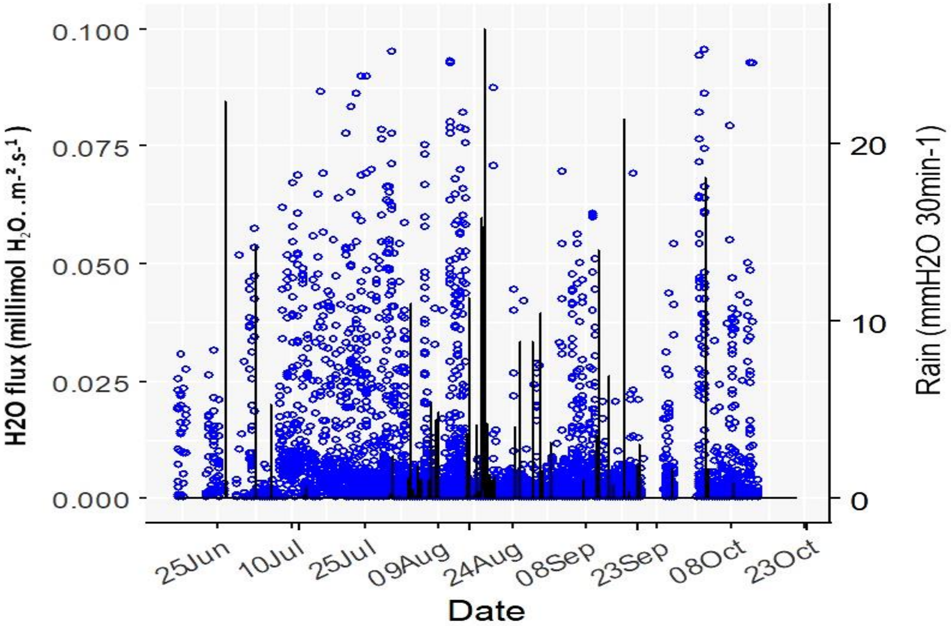


Contacts: seydina1988@gmail.com; olivier.roupsard@cirad.fr

- CO_2 flux is lower during the day, due to photosynthesis possibly exceeding soil+plant respiration (figures A et B)
- CO_2 flux is higher under trees (shade) than outside trees (sun) (figures A et C) due to tree ‘island effect’

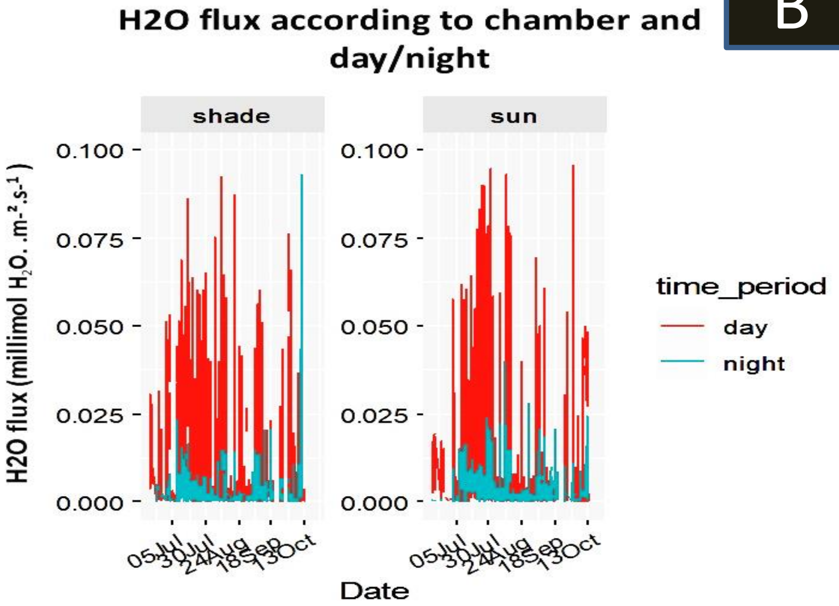
H_2O exchange between soil , plants and atmosphere

A



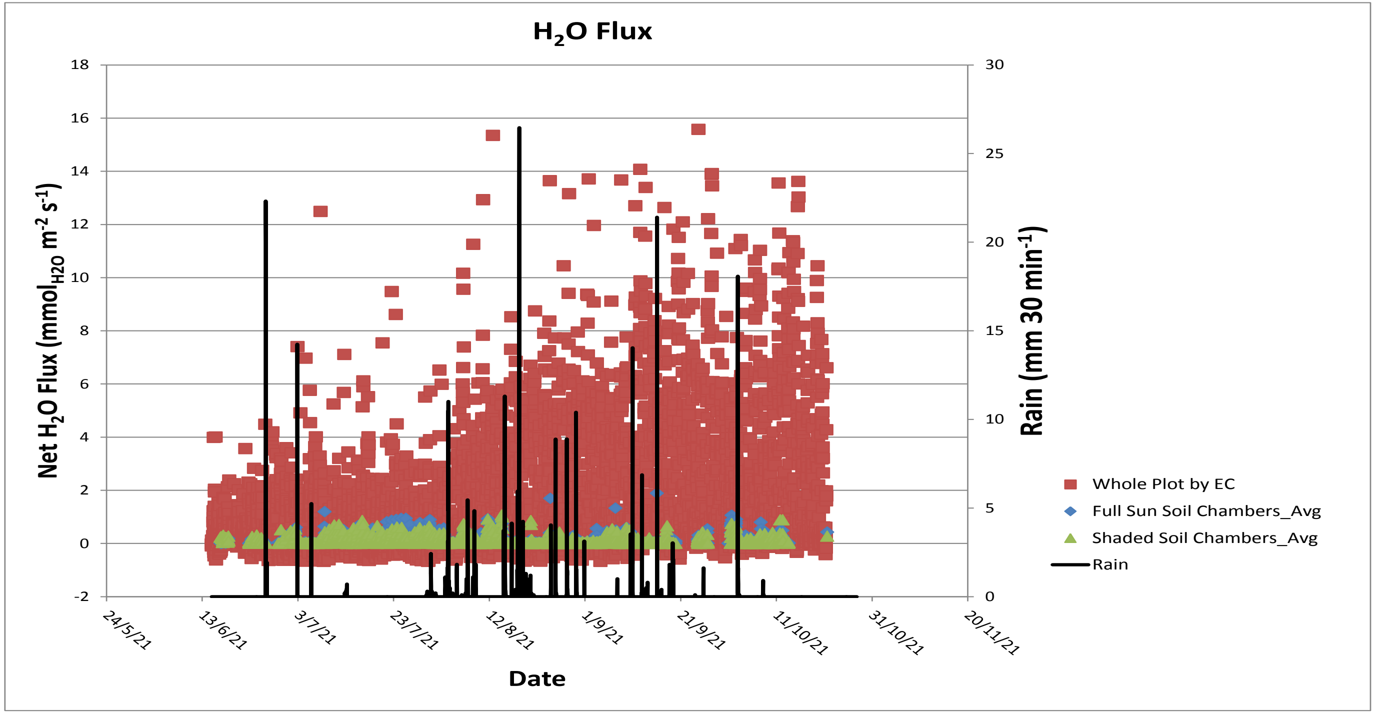
- H2O flux increases dramatically during the wet season,due to soil evaporation and plant transpiration (figure A)

B



- In the daytime, the flux is higher, indicating higher evapo-transpiration (higher energy available). Situation remains comparable under trees (shade) and outside trees (sun) during the day and night. (figure A)

Comparing results: EC *vs* Soil H2O Exchange



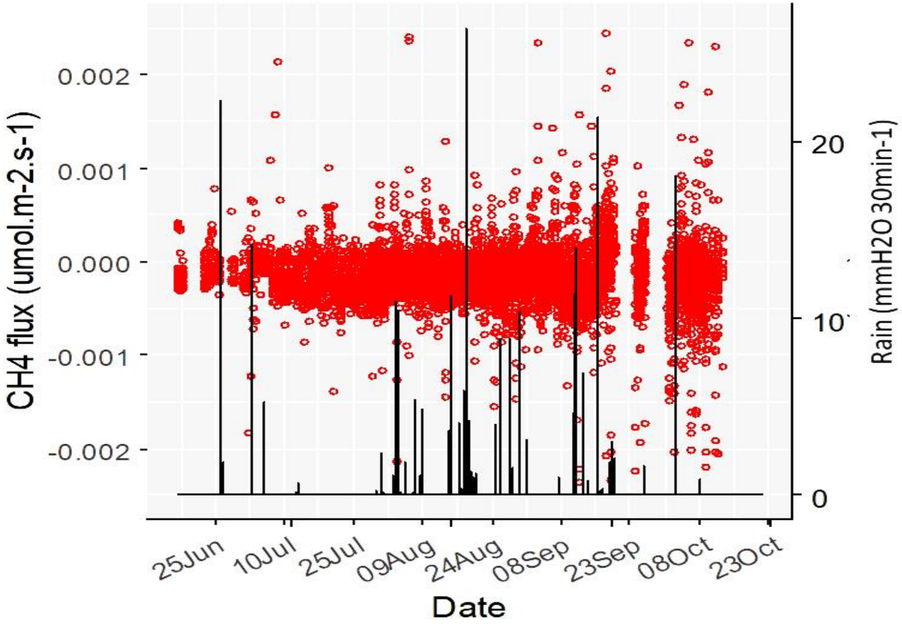
H_2O fluxes

No consistent data for H2O fluxes between EC and soil gas exchanges. Data much underestimated by Soil Gas Exchanges. Could be due to leaf area lower in chamber than average in the field and stomatal closure. We will recompute per unit leaf area. An alternative reason could be a lower aerodynamic conductance in the chamber.

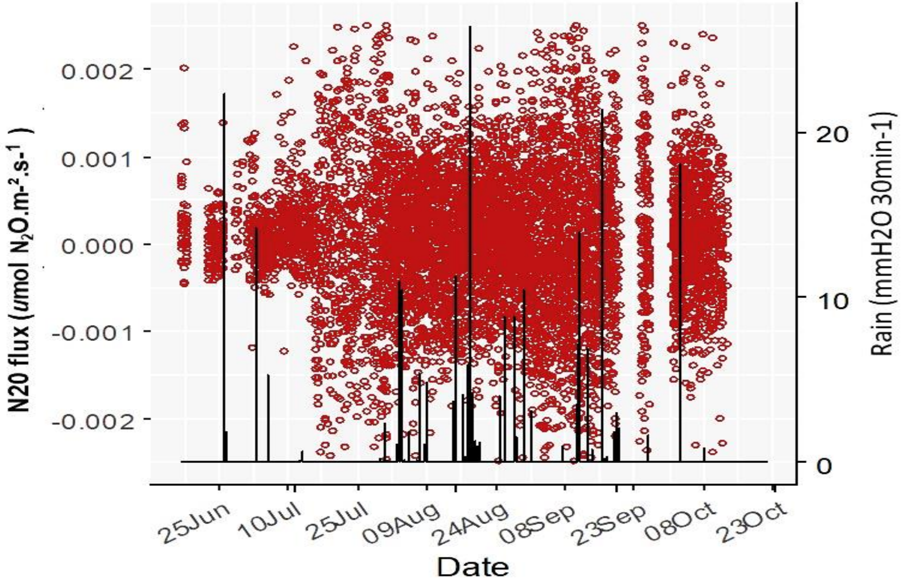
seydina1988@gmail.com (Seydina Ba)

CH_4 and N_2O exchanges between soil, plants and atmosphere

A

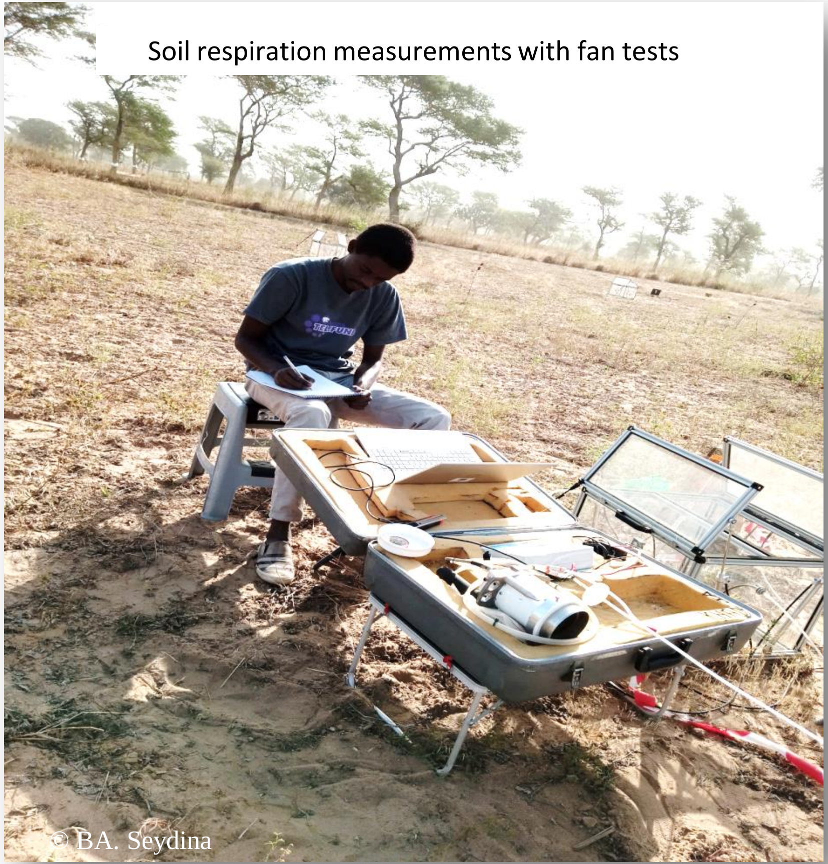


B



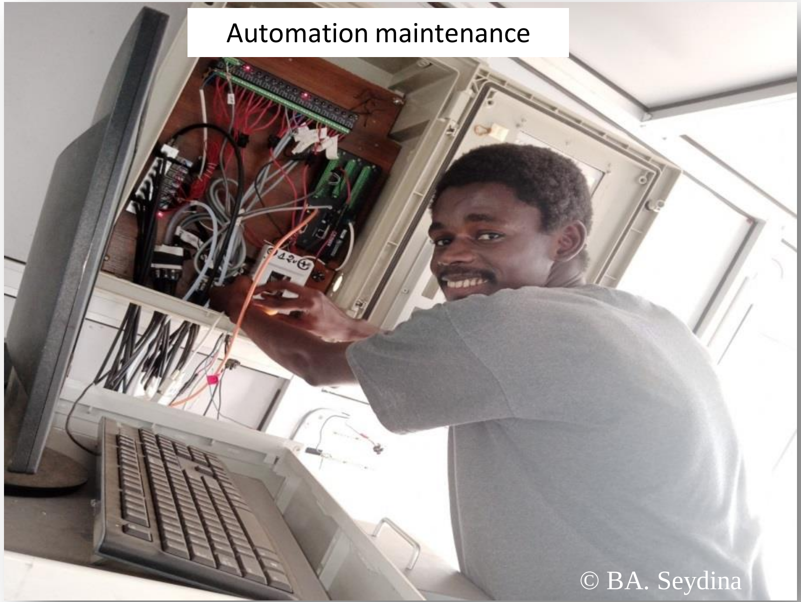
- **Traces for N2O and CH4 gases (**slopes range from and -1.e-4 à 1. e-04**)**

seydina1988@gmail.com (Seydina Ba)



Next steps (2022)

- Deploying automatic gas monitoring systems in a **sylvo-pastoral** system (Dahra)
- Assessment **spatial emissions of gases emissions by mobile chamber with Picarro gaz analyzer (**areas of feces accumulation, **amendments**, & grazing areas to capture N_2O and CH_4)
- Calculate GHG fluxes and intra and inter annual balance. Compare with eddy-covariance for CO_2 and H_2O
- Soil sampling, bulk density measurements, studies of soil carbon stocks and storage drivers.



seydina1988@gmail.com

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Modelling Soil GHG balance in Sahelian systems

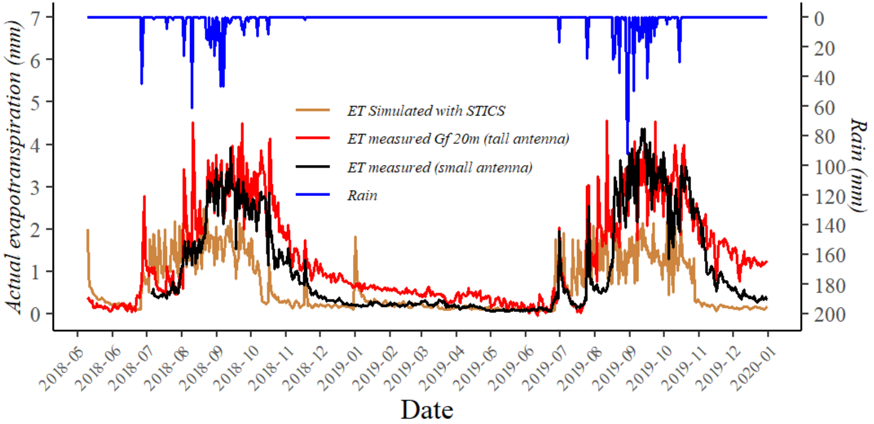
"*Faidherbia-Flux*" **Web site :**
https://lped.info/wikiObsSN/?Faidherbia-Flux

Model STICS :

https://www6.paca.inrae.fr/stics_eng

Agroforestry park, Niakhar, Senegal.
- Millet under Faidherbia albida (2018)
- Groundnut under Faidherbia albida (2019)

Evapotranspiration



- Actual evapotranspiration (ET) simulated with STICS ranges between 0 and 2.6 mm.
- ET measured from flux towers (small and tall antennas) were larger than simulated ET.

ayulrich@yahoo.fr (Yélognissè Agbohessou)

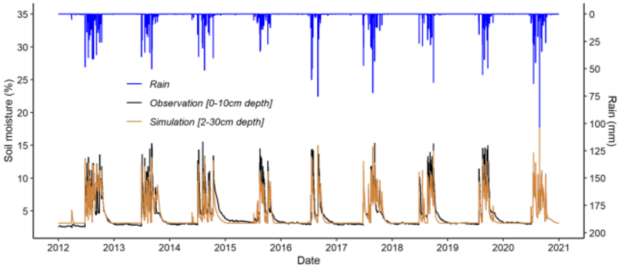
Model STEP :

https://www.sciencedirect.com/science/article/abs/pii/0034425794001268

Sylvopastoral pasture, Dahra, Senegal.

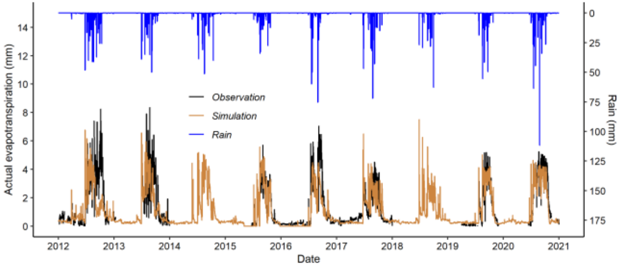
Soil moisture

- The seasonal dynamics of soil moisture were quite well represented by the model.
- The minimum and maximum thresholds correspond to the wilting point and the field capacity, respectively.



Evapotranspiration

- Simulations were consistent with observations
- Lower ET simulated at the end of 2012 and 2013 wet seasons, can be explained by model calibration while simulating water balance. Soil evaporation has been reduced by increasing the



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Modelling Soil GHG balance in Sahelian systems

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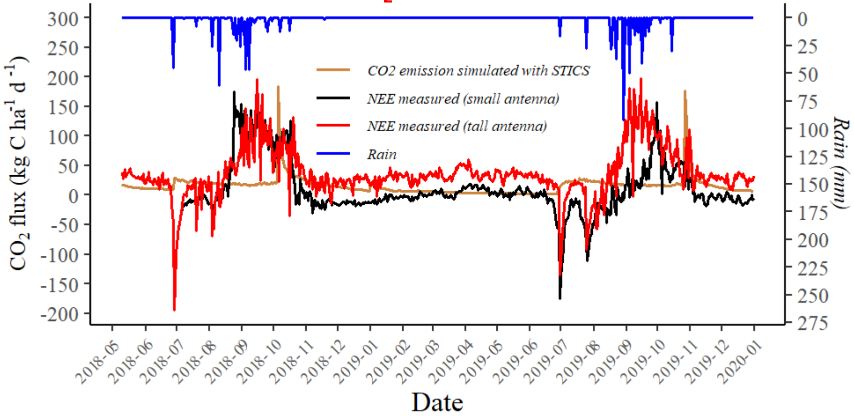
Model :

https://www6.paca.inrae.fr/stics_eng

Agroforestry park, Niakhar, Senegal.
- Millet under Faidherbia albida (2018)
- Groundnut under Faidherbia albida (2019)

CO_2 emissions



- The values of the Net CO_2 Ecosystem Exchange (NEE) have been inverted to obtain positive values for the CO_2 emissions in order to facilitate comparison with the simulated CO_2 emissions.
- Simulated CO_2 emissions and the positive values of the measured NEE from both towers (small and tall) were of the same order of magnitude.
- The model produces the peaks of CO_2 emissions a little later in each wet season when compared to the measured NEE.

ayulrich@yahoo.fr (Yélognissè Agbohessou)

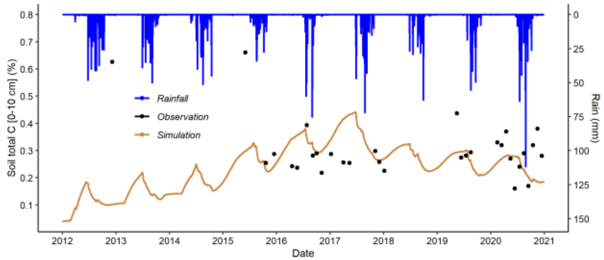
Model STEP :

https://www.sciencedirect.com/science/article/abs/pii/0034425794001268

Sylvopastoral pasture, Dahra, Senegal.

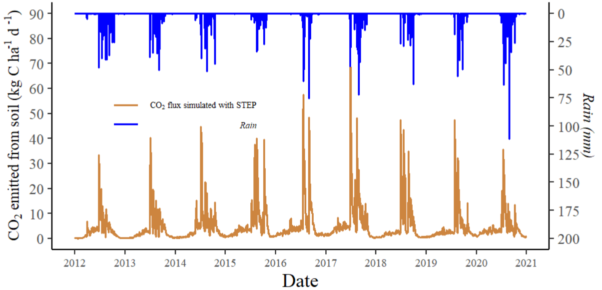
Soil total C

- The values obtained after soil analysis and the simulated values were consistent.



CO_2 emissions

- Largest emissions of CO_2 simulated at the beginning of each wet season are mostly due to : a. the physical effect produced by first rains in semi-arid environment, which releases the CO_2 trapped in the soil pores and, b. the activations of enzymes in the soil which generate the decomposition of organic matter and release CO_2



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Modelling Soil GHG balance in Sahelian systems

"*Faidherbia-Flux*" **Web site :**
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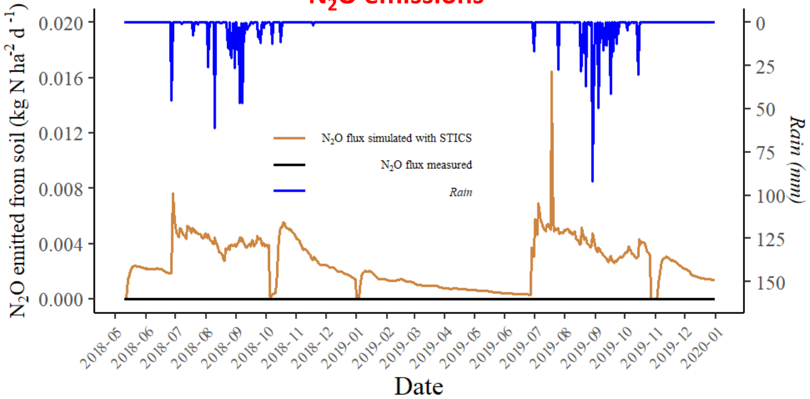
N_2O emissions



- Simulated N_2O emissions from soil by nitrification show a seasonal trend with the largest emissions during the wet season.
- The model was not able to simulate the N_2O emitted from soil by denitrification, even after testing a whole range of values for the parameters profdenit (soil depth on which denitrification is activated) and vpotdenit (potential rate of denitrification for the whole denitrifying layer).
- No N_2O flux deteceted during measurements

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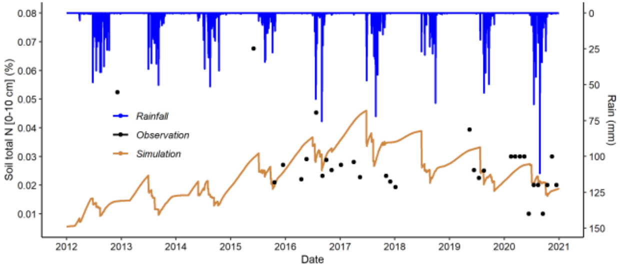
Model STEP : https://www.sciencedirect.com/science/article/abs/pii/0034425794001268

Sylvopastoral pasture, Dahra, Senegal.

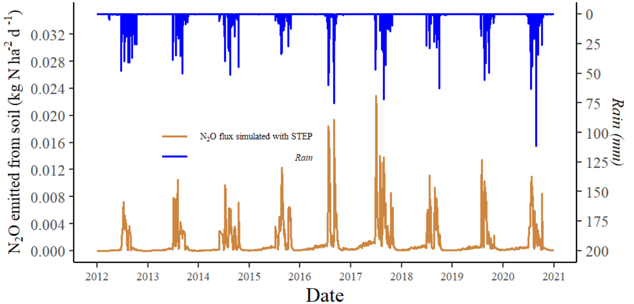
Soil total N

- The values obtained after soil analysis and the simulated values were consistent.



N_2O emissions

- The temporal dynamics of the simulated N_2O fluxes show a clear impact of precipitation on N_2O emissions.
- Simulations showed pulses of N_2O emissions (2019) after the first rains as generally observed in dry ecosystems



Articles

- Duthoit, M., Roupsard, O., Créquy, N., Sauze, J., Van den Meersche, K., 2020. Conception d’un dispositif automatisé de chambres de mesures d’échanges gazeux du sol à fermeture horizontale. **Le Cahier des techniques de l'INRA** (2020, 102). https://www6.inrae.fr/cahier_des_techniques/Les-Cahiers-parus/Les-N-reguliers/2020/Cahier-N-102/Art4-ct102-2020, 19 pp.

Communications

- Agbohessou Y, Delon C, Grippa M, Mougin E, Tagesson T, Roupsard O. 2021. Modeling Greenhouse Gas Emissions from Sahelian Sylvo-pastoral Ecosystems. Poster presentation. AGU, New Orleans, USA 13-17 Dec 2021. Convention Center - Poster Hall, D-F USA.https://agu.confex.com/agu/fm21/meetingapp.cgi/Paper/809234.
- Ba S, Roupsard O, Diongue D, Agbohessou Y, Serça D, Sambou B, Guerin F, Tagesson T, Lardy L. 2021. Monitoring GHG balance in an agro-sylvo-pastoral ecosystem dominated by Faidherbia albida: comparing the soil and ecosystem scales (groundnut basin in Niakhar/Sob, Senegal). Conférence Intensification Durable (CID) 2021. Dakar, 23-26 nov. 2021: Senegal.
- Ba S, Roupsard O, Lardy L, Diongue D, Agbohessou Y, Bouvery F, Guerin F, Tagesson T, Sambou B, Serça D. 2022. Monitoring soil greenhouse gas (GHG) emissions in a Sahelian agro-silvo-pastoral parkland. EGU 2022, 3-8 April 2022, Vienna, Austria. Poster communication.

Shared database in R

Faidherbia-Flux_Collaboratif\Database
https://baobab.sedoo.fr/