Eddy Covariance

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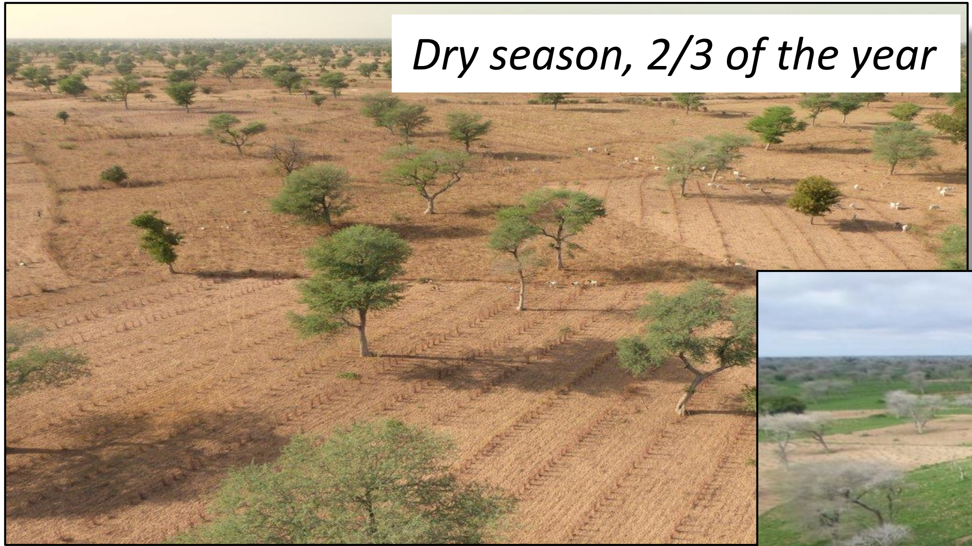
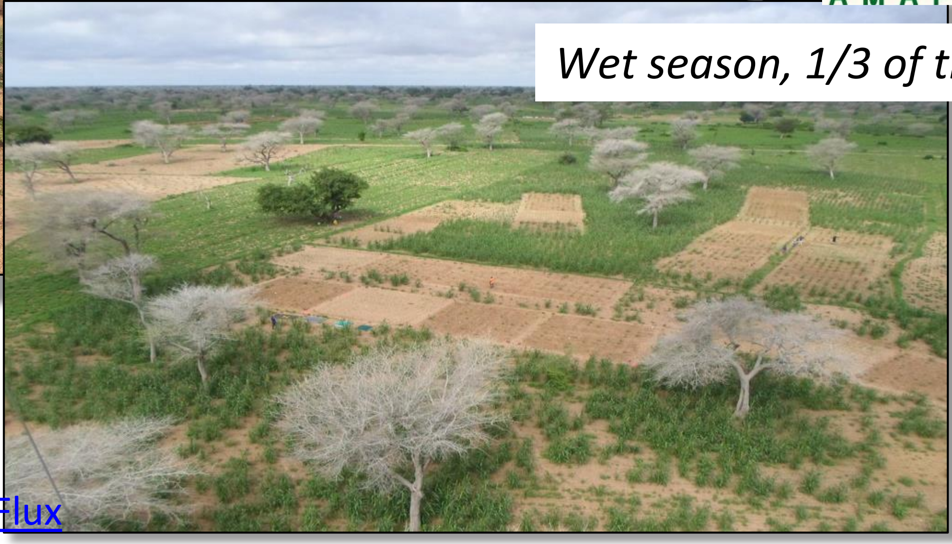
"*Faidherbia-Flux*": A long-term Collaborative Observatory on food security, GHG fluxes, ecosystem services, mitigation and adaptation in a semi-arid agro-silvo-pastoral ecosystem (groundnut basin in Niakhar/Sob, Senegal)



Dry season, 2/3 of the year



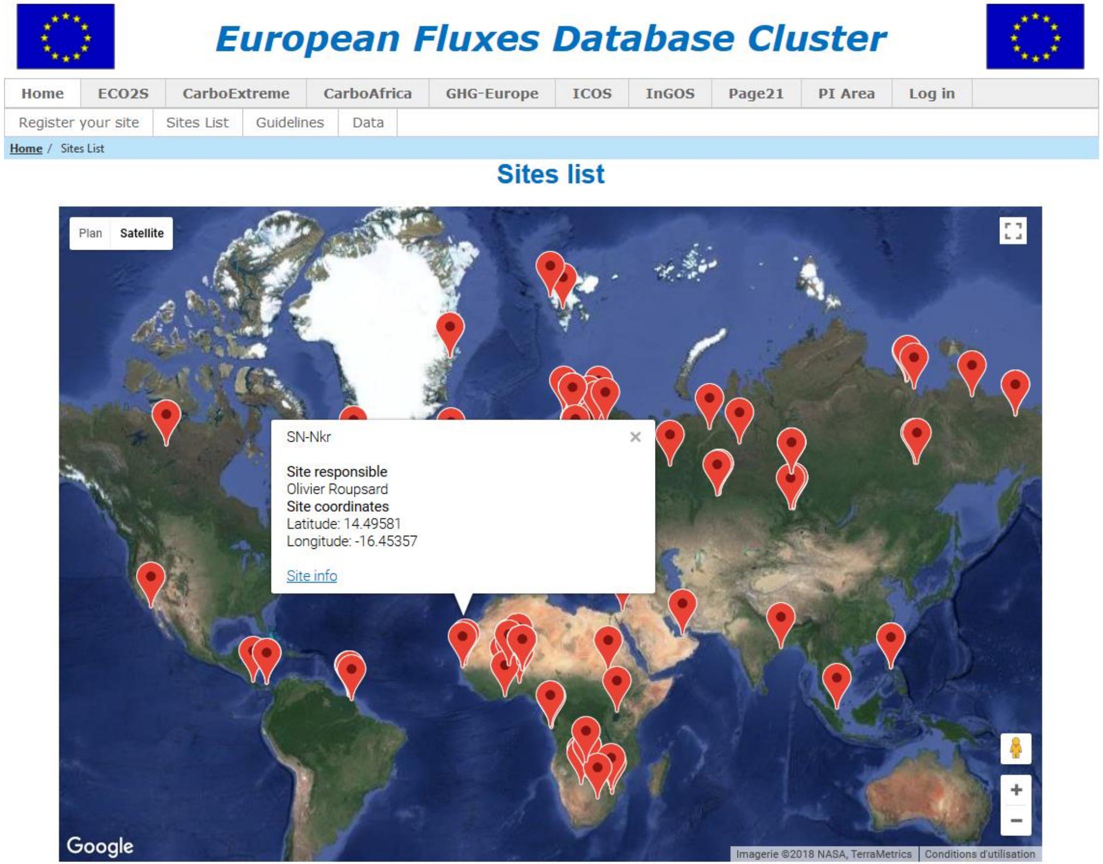
Wet season, 1/3 of the year

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

Contact: olivier.roupsard@cirad.fr

Where is the « Faidherbia-Flux » data available: 1/3 ?

https://fluxnet.org/



GENERAL INFORMATION | STAFF | FLUXES AVAILABLE | DATA POLICY DETAILS

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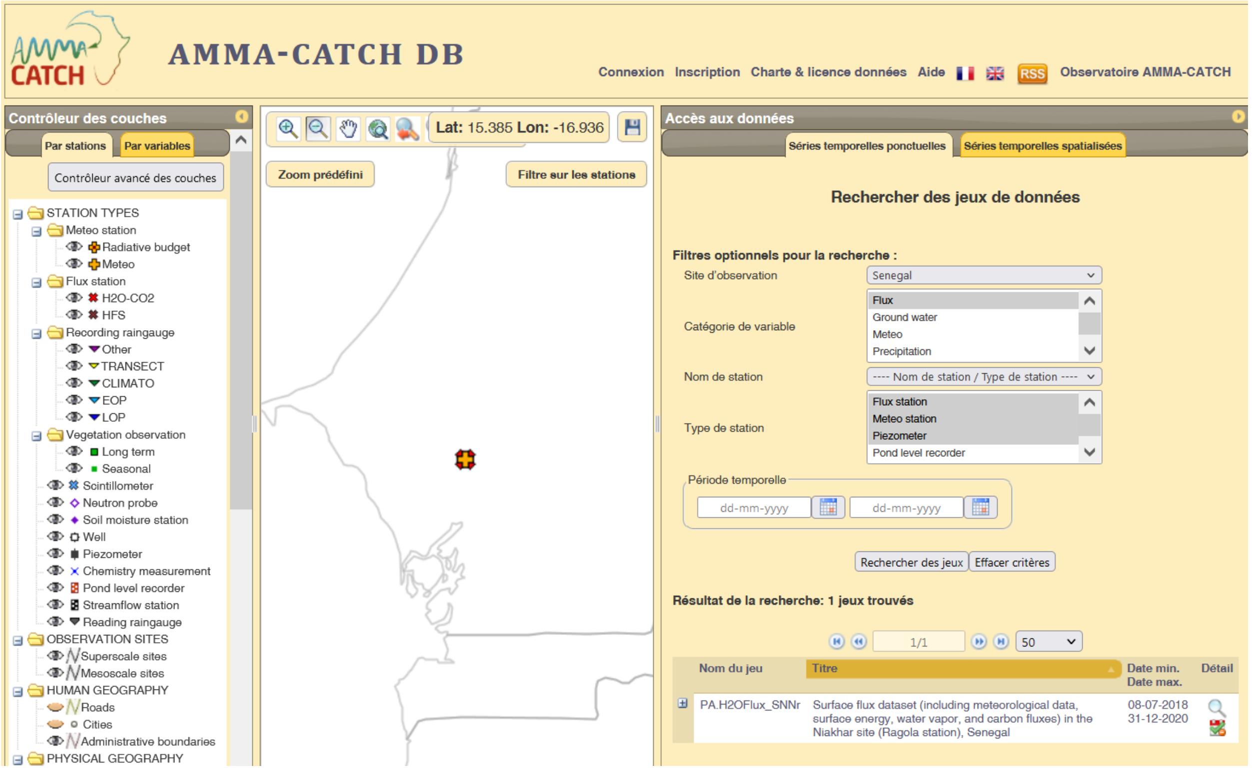
GENERAL INFORMATION | STAFF | FLUXES AVAILABLE | DATA POLICY DETAILS

Site name: Niakhar
Site code: SN-Nkr
Site coordinates: 14.494817 (lat) / -16.452128 (long)
IGBP: CRO
Mean Annual Temperature: 26.95
Mean Annual Precipitation: 578.00
Slope: Flat
Exposure: FLAT
Prevailing Wind Direction: E
Mean Water Table Depth: 10.0000
Days with snow cover: 0

Where is the « Faidherbia-Flux » data available: 2/3 ?

http://bd.amma-catch.org/main.jsf

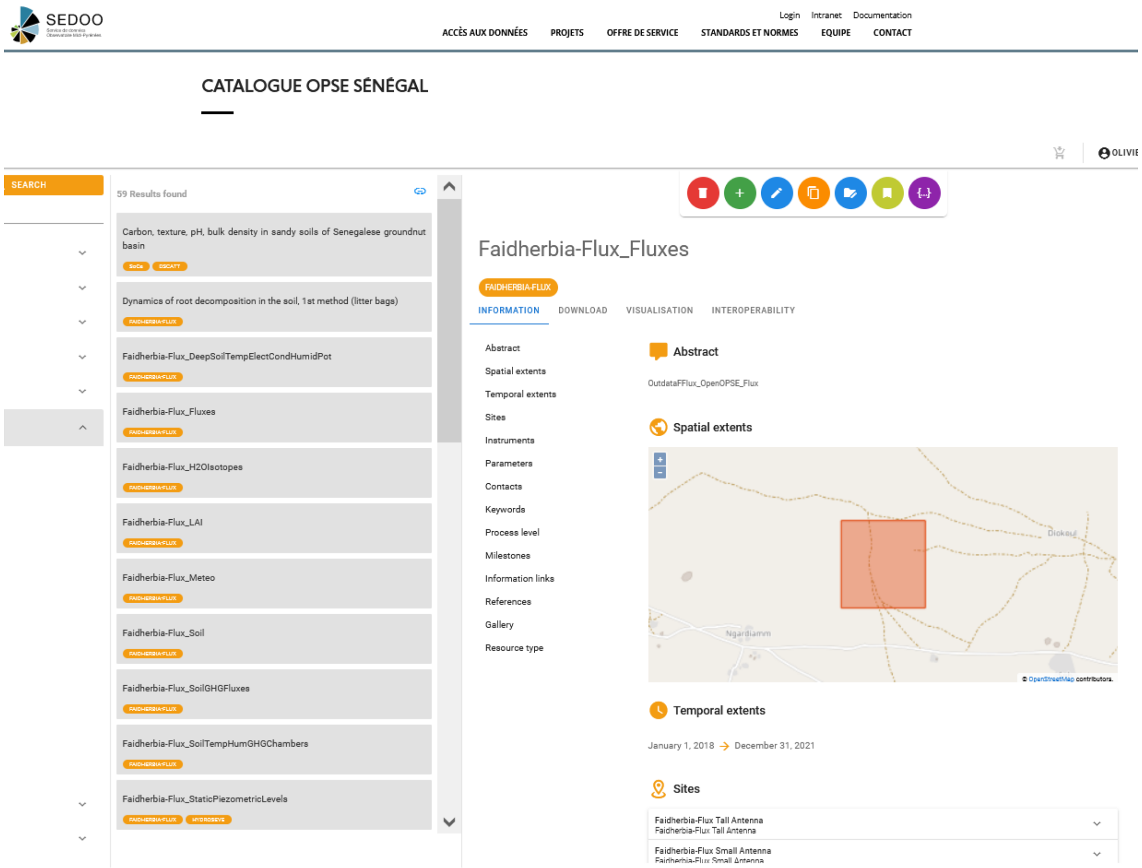


Faidherbia-Flux (SNNs) joined AMMA-CATCH database in 2022 and contributed with data 2018-2021, with DOI:

*PA.Met_SNNs
*PA.Flux_SNNs
*PA.SW_SNNs
*PA.SW2_SNNs
*PA.Sap_SNNs

Where is the « Faidherbia-Flux » data available: 3/3 ?

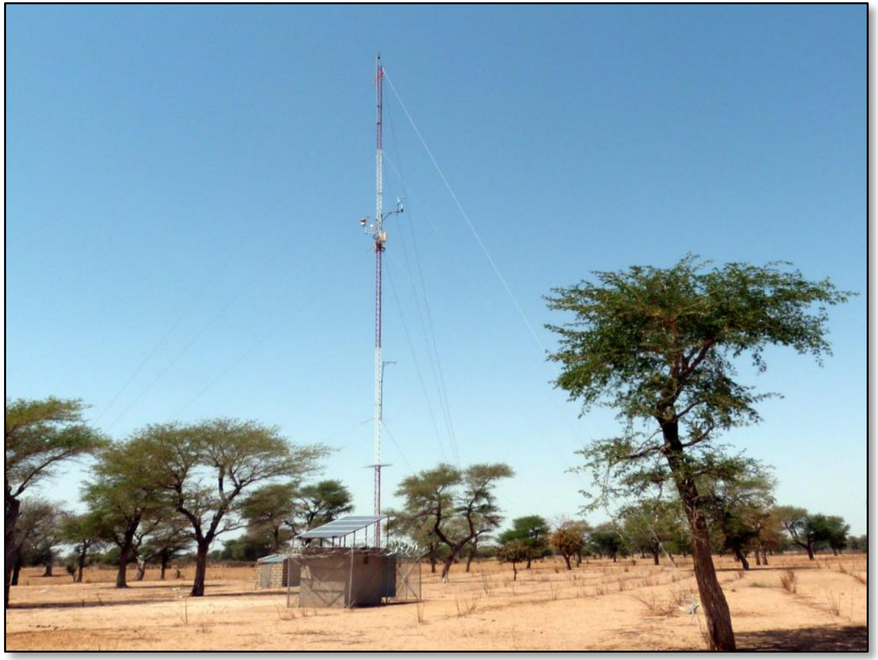
https://www.sedoo.fr/catalogue-openopse/



Faidherbia-Flux (SNNs) joined SEDOO/ OPENOPSE database in 2021 and contributed with data 2018-2021, with DOI:

3 Eddy Covariance antennas

1) Above the whole ecosystem



Eddy-covariance antenna (30m) + shelter (4.5 m^2) + fence + solar panels (4.5 m^2) + Campbell weather station +GNSS.

2) Above Crop (here millet)

Fluxes at ecosystem level, above tree crowns: 20m high

Fluxes above millet, below tree crowns: 4.5 m high

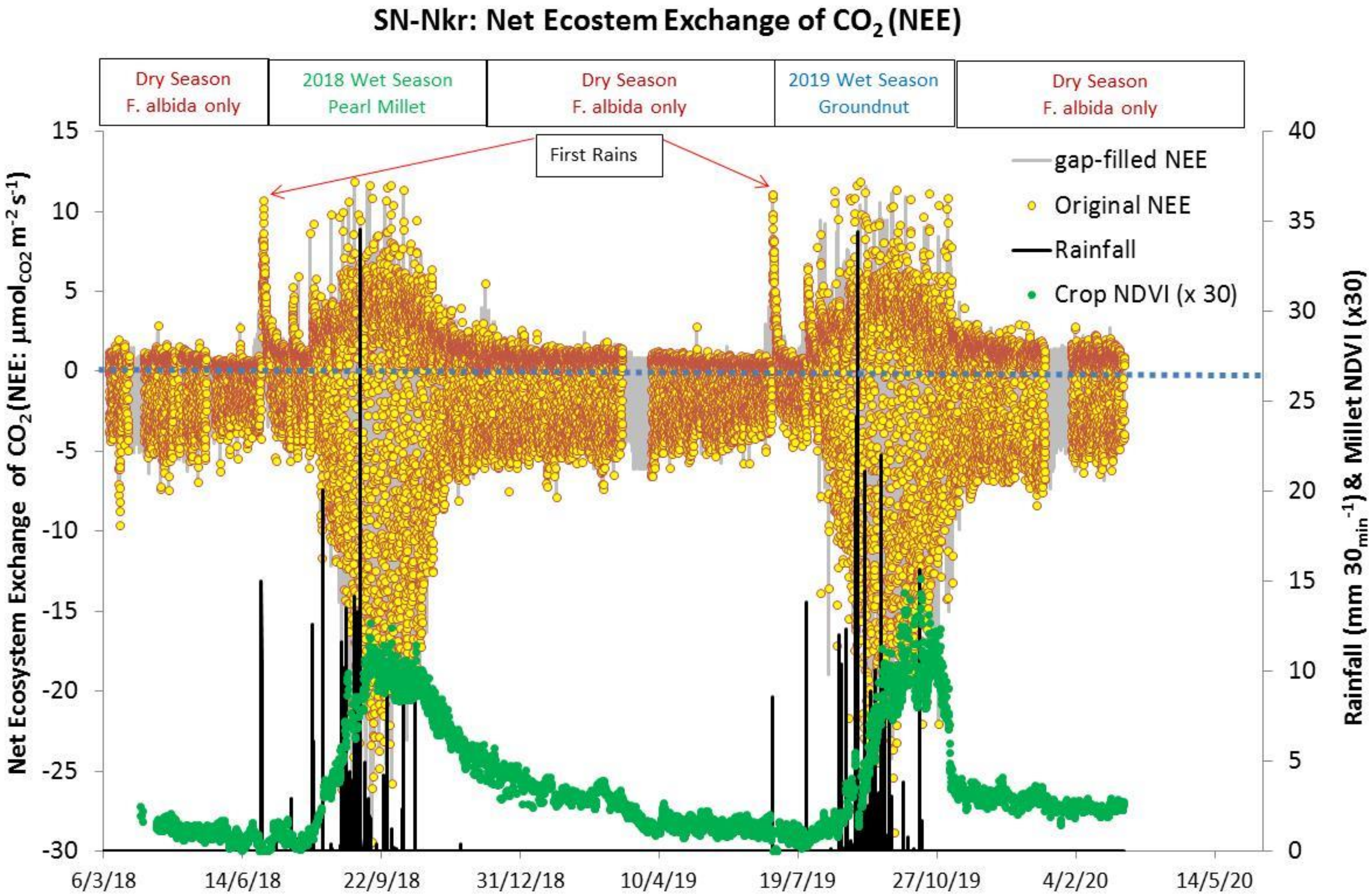
3) Above counter-crop (here peanut)

Results from tall Eddy Covariance antenna, above the trees and the ecosystem mosaic

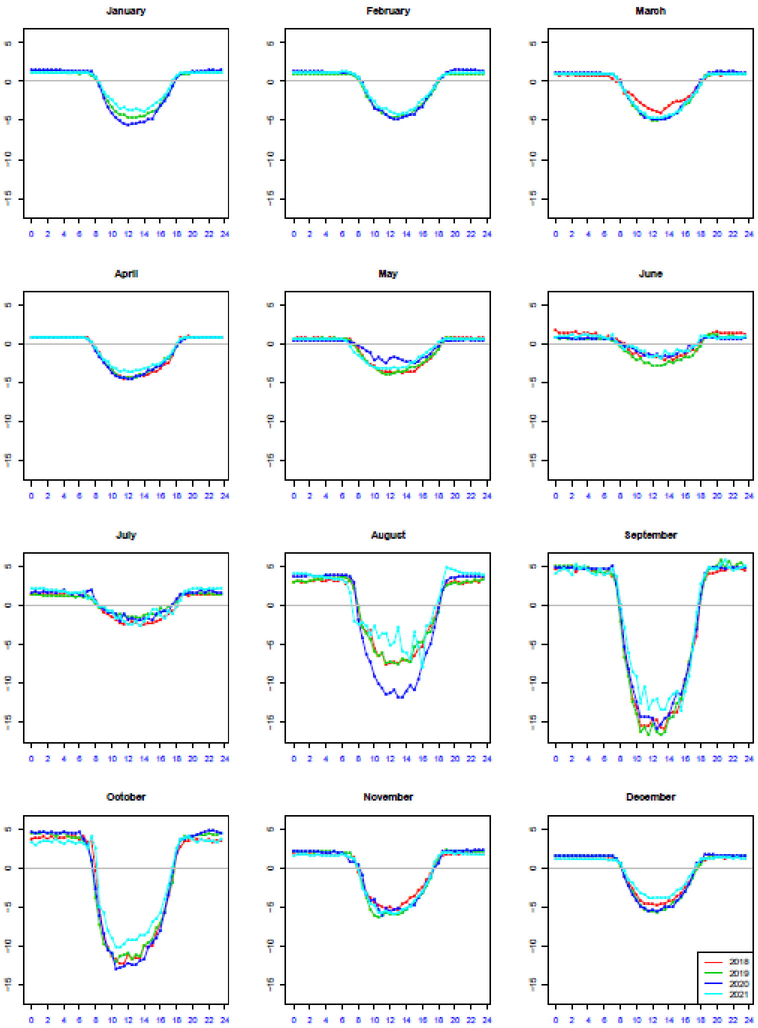
Eddy-covariance antenna (30m) + EC at 20m
+shelter (4.5 m²) + fence + solar panels (4.5 m²) +
Campbell weather station +GNSS.

CO_2 fluxes

above the whole ecosystem



The Net Ecosystem Exchange (NEE) of CO_2 (or CO_2 flux, negative = uptake during the day; positive = release at night) was very weak during the dry season, maximum photosynthesis (GPP) around -5 µmolCO_2 m^{-2} s^{-1} and maximum ecosystem respiration (Re) around 1.5 µmolCO_2 m^{-2} s^{-1}. GPP was from *Faidherbia* trees only at that time. Just after the first rains of 2018 and 2019, a large CO_2 burst was recorded with slow decay during more than one week or so. Other CO_2 peaks in July corresponded to smaller rain events. Early August, crop NDVI took off, followed by a large CO_2 uptake, but also ecosystem respiration. After crop harvest, gas exchanges started to decline. Then the system resumed to dry season behavior again. [Fluxes filtered out for wet sensor, Planar-fitted, WPL and spectral corrected, quality checked. Gaps are due to power failure. Grey dots are from partitioning and gap-filling according to ReddyProc and Lasslop et al. (2010)]



Diurnal course of NEE (μmol_{CO2} m^{-2} s^{-1}) above the whole ecosystem

Rainfall

2018: 454 mm

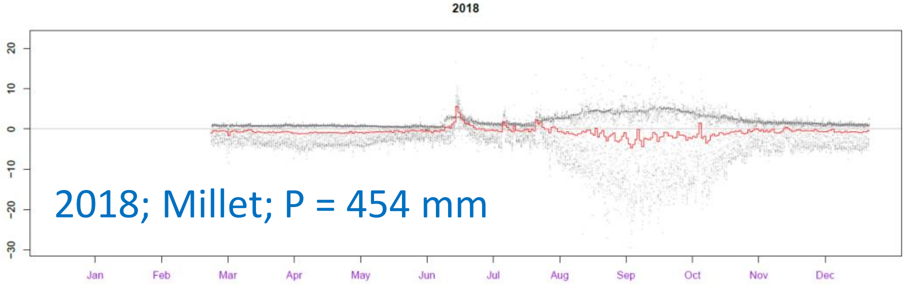
2019: 513 mm

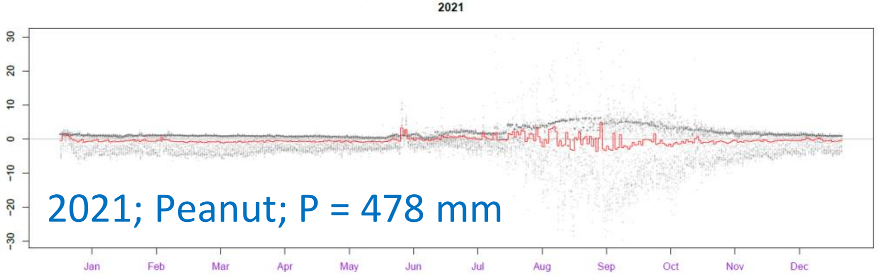
2020: 599 mm

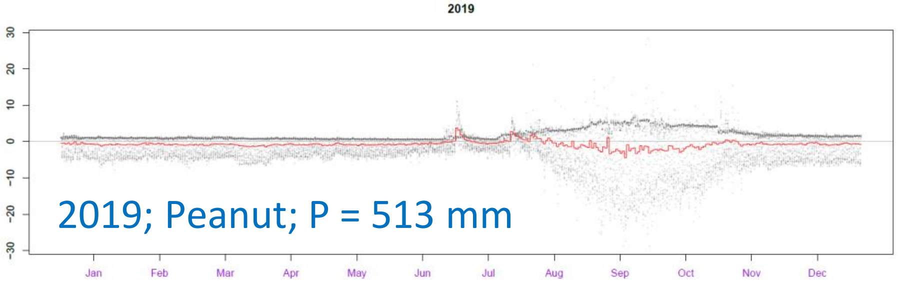
2021: 478 mm

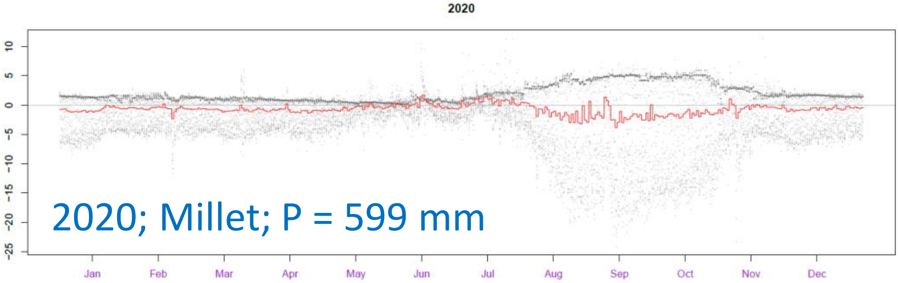
Monthly average of gapfilled net ecosystem CO_2 exchange (NEE) diel course. During the dry season (November to July), the C uptake was due to *Faidherbia* only, and the ecosystem respiration (R_e) at night was small. During the wet season, sharp increase of C uptake (negative values during the day) and also R_e, due to the activity of the crops and wet soil. Surprisingly, the 2 years (2018, crop = pearl millet) and 2019 (crop = groundnut) look very similar. However, during the wettest year (2020), earlier crop growth in August was marked by higher GPP and Reco. Partitioning and Gap-filling through ReddyProc and Lasslop et al. (2010)].

Diurnal course and daily sums of gapfilled NEE ($\mu mol_{CO2}\ m^{-2}\ s^{-1}$)

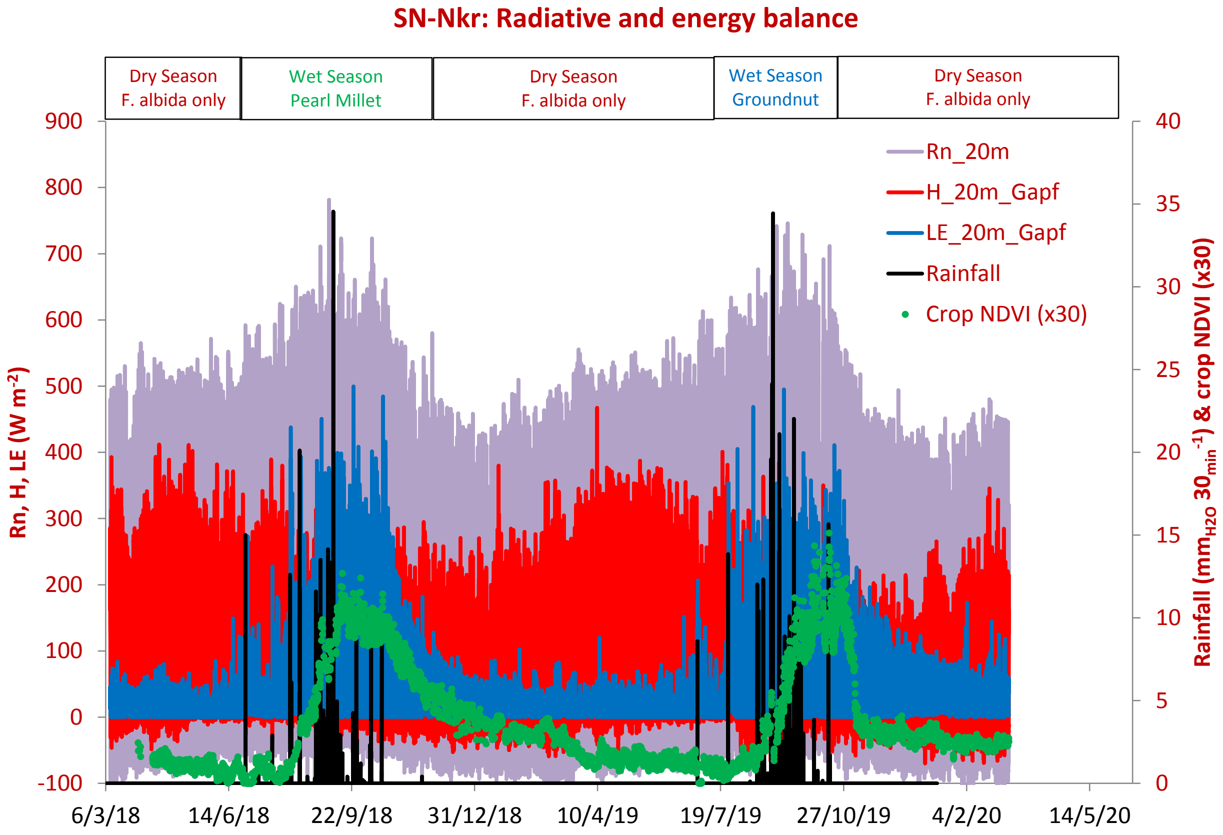






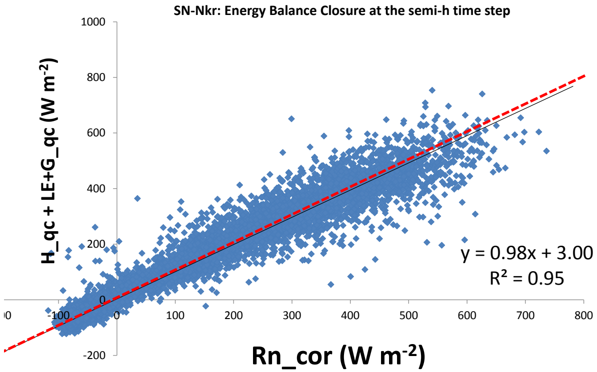


Gapfilled instantaneous (grey dots) and daily sums of NEE (red line) during the dry season are negative (CO2 capture), in conditions where the canopy of *Faidherbia* is active. Large CO_2 efflux after the first rains and small replicates during rain events. Net flux becomes more negative during the cropping season from August to October, during the wet season. The net balance is a CO_2 capture for most periods. Partitioning and Gap-filling through ReddyProc and Lasslop et al (2010).



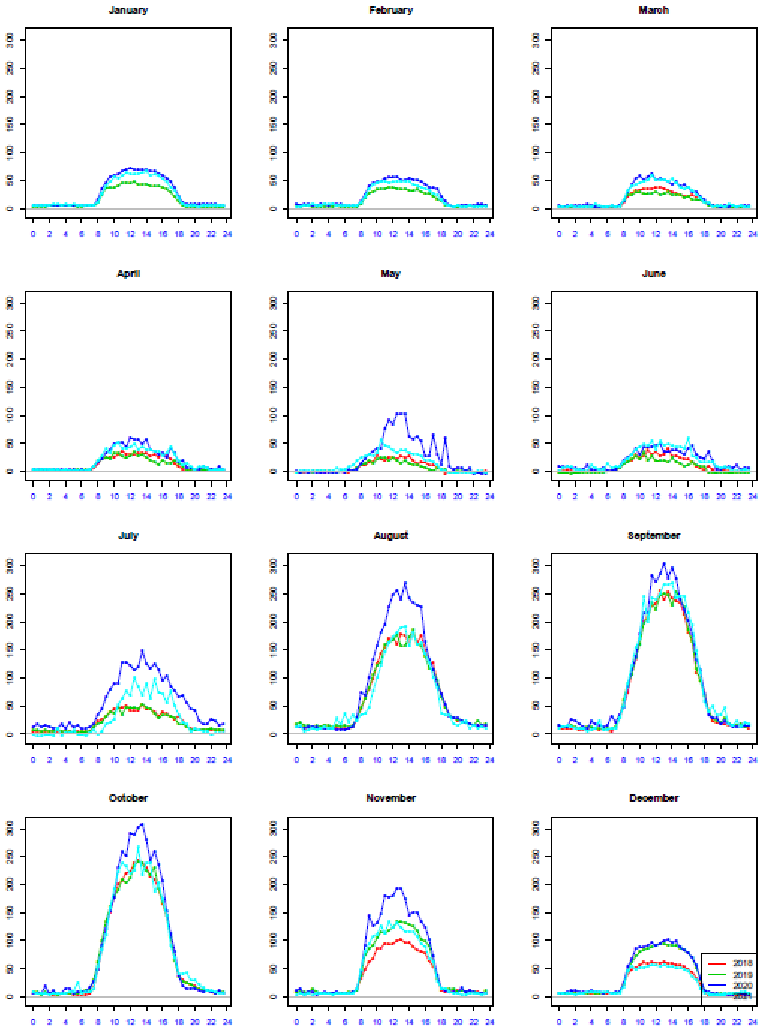
Energy balance and evapo-transpiration,

above the whole ecosystem



Net radiation (Rn) peaks around 800 W m^{-2}. During the dry season, most of this energy (350 W m^{-2}) is dissipated through heat (H), given that the soil is bare (with exception to the *Faidhernia* trees). There is very little evapo-transpiration (LE: 50-100 W m^{-2}), originating from Faidherbia trees mostly. After the first rains each year, note the inversion of H and LE fluxes (drop of the Bowen ratio) when crops cover the soil and soil is wet. Maximum LE is achieved in Sept-Oct. Fluxes were Planar-fitted, WPL and spectral corrected and quality checked. Gap-filling of H and LE according to ReddyProc.

The semi-hourly energy balance closes at 98%, when the soil heat flux is included. The regression is tight.



Diurnal course of λE ($W\ m^{-2}$), above the whole ecosystem

Monthly average of gapfilled λE diel course. λE declines during the dry season between November (maximum activity of *Faidherbia*) and June (*Faidherbia* start shedding leaves and surface soil has dried out). In August-September, note sharp increase due to the re-greening of the crop system. 2018 and 2019 look similar, except by the end of the year (more soil evaporation by the end of 2019 and beginning of 2020). But 2020 is much wetter. Gap-filling of LE according to ReddyProc.

Rainfall

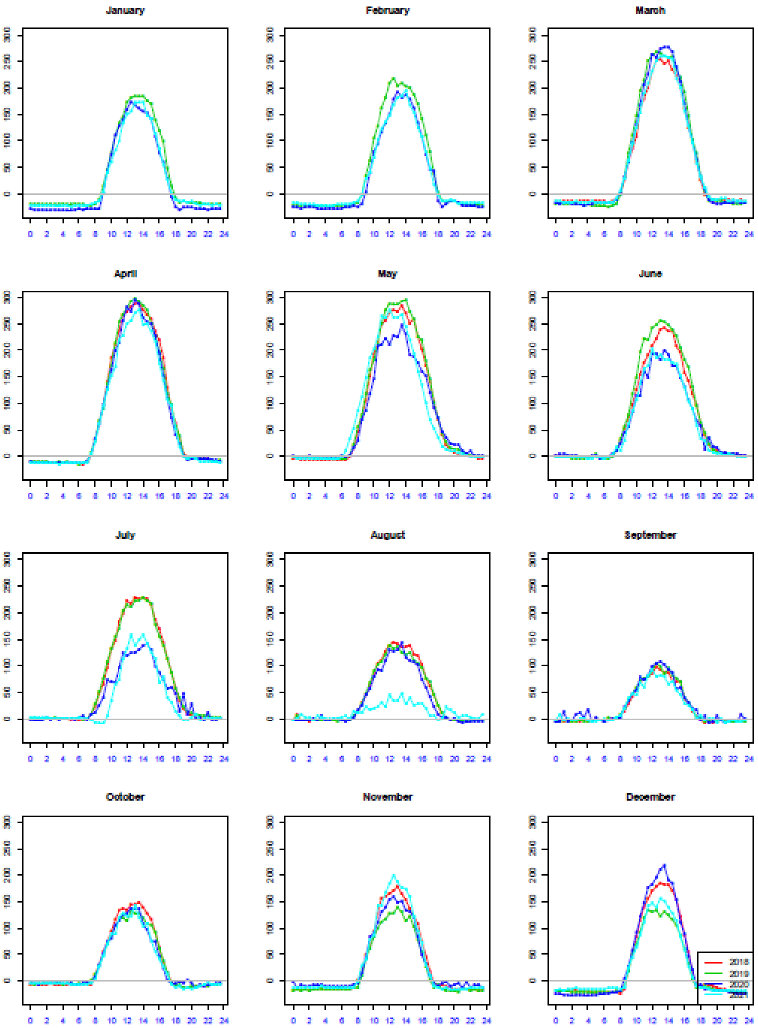
2018: 454 mm

2019: 513 mm

2020: 599 mm

2021: 478 mm

Diurnal course of H (W m^{-2}), above the whole ecosystem



Monthly average of gapfilled H diel course. H increases during the dry season between November and May. It lowest during the wet season between August-September. Gap-filling of H according to ReddyProc.

Rainfall

2018: 454 mm

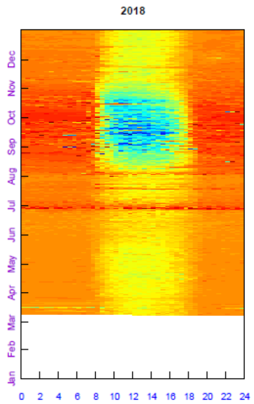
2019: 513 mm

2020: 599 mm

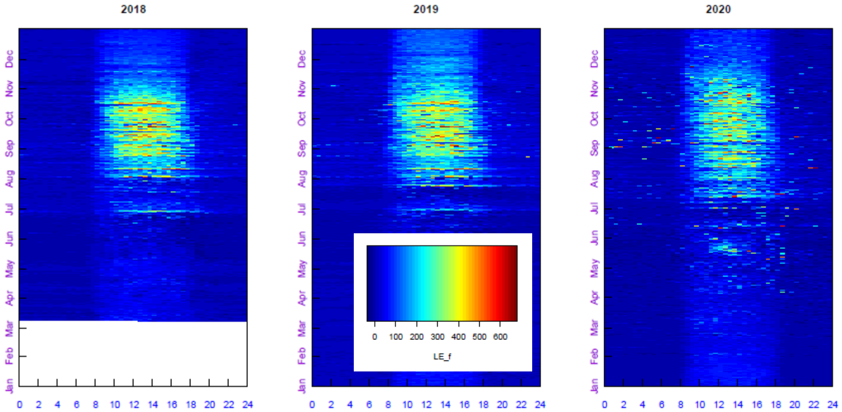
2021: 478 mm

Fingerprints

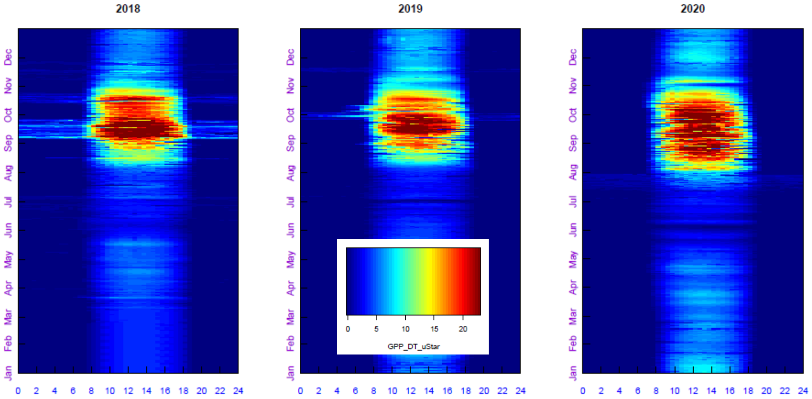
NEE: $\mu mol_{CO2}\ m^{-2}\ s^{-1}$



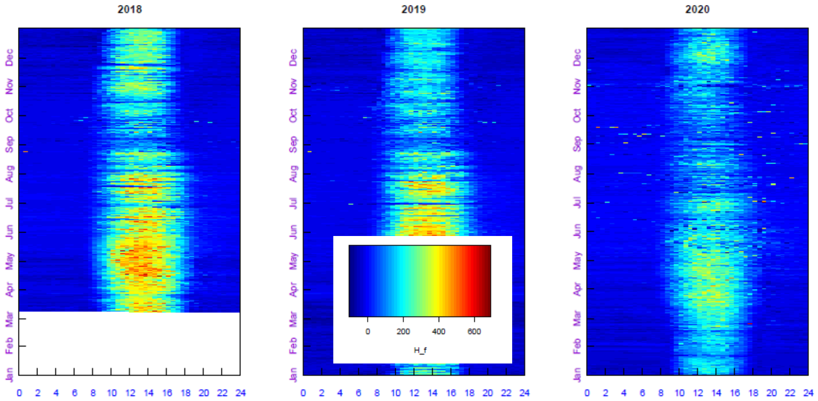
λE: W m^{-2}



GPP: $\mu mol_{CO2}\ m^{-2}\ s^{-1}$

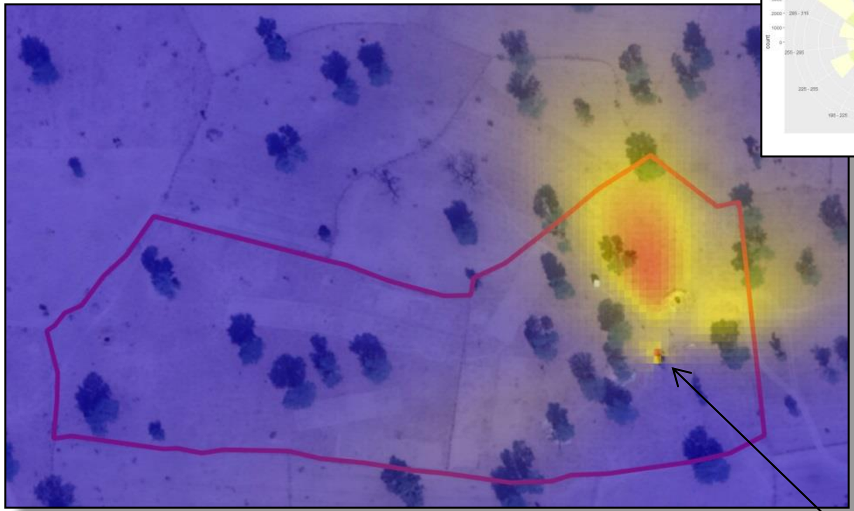


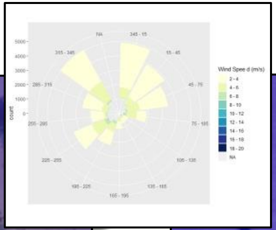
H: W m^{-2}



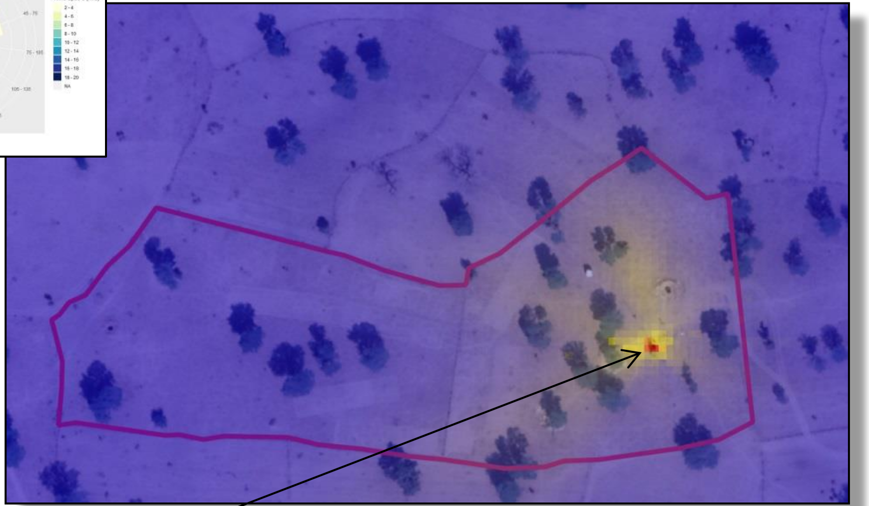
Footprints during Dry and Wet seasons

Dry Season 2018-2019





Wet Season 2018



0	0
0.000175	0.0003
0.00035	0.0006
0.000525	0.0009
0.0007	0.0012

100 m

100 m

Antennas

Area with millet in 2018 or groundnut in 2019

Most fluxes measured on the tall antenna at 20 m high originated from inside the main crop plot of interest (millet in 2018 and groundnut in 2019), whatever the season. During the dry season, winds originated mostly from N and NE (mostly within 100 m of distance), but at that time, it can be assumed that the whole landscape is an equivalent source. During the wet season, fluxes originated from the W sector and very much closer to the antenna, mostly within 50 m of distance, i.e. mostly from the main crop plot of interest, with little contribution from the surrounding plots. Footprints were computed according to Kormann and Meixner (2001), using the FREddyPro R package (Xenakis, 2016). Plotted on QGIS.

Inter-annual comparison: Water, Energy & CO_2 balances

Water balance

Year	Crop	Rain (mm_{H2O} y^{-1})	ETo (mm_{H2O} y^{-1})	Rain/ETo	ETR (mm_{H2O} y^{-1})	ETR/Rain
2018-2019	Millet	454	1446	0.31	424	0.93
2019-2020	Peanut	513	1494	0.34	464	0.90
2020-2021	Millet	600	1431	0.42	610	1.02

Comparing annual water balance for 3 years of increasing rainfall (2018-2020). In this semi-arid site, Rain/ETo was only *ca.* 35%. ETR was close to Rain, indicating that nearly all annual rainfall budget is consumed and little or no water would recharge the deep soil layers, depending on the year

Energy balance

Year	Crop	Rain (mm_{H2O} y^{-1})	Rn (MJ m^{-2} y^{-1})	H (MJ m^{-2} y^{-1})	LE (MJ m^{-2} y^{-1})	Bowen ratio H/λE	(H+λE)/Rn
2018-2019	Millet	454	2788	1581	1030	1.53	0.94
2019-2020	Peanut	513	2763	1491	1130	1.32	0.95
2020-2021	Millet	600	2721	1378	1485	0.93	1.05

Comparing annual energy balance terms between 2018 and 2020. The Bowen ratio decreased much during the wettest years. The energy balance ($(H+\lambda E)/R_n$) was >90% (soil heat balance is neglected at the annual scale here), indicating that the EC system behaved reasonably.

CO_2 balance

Year	Crop	Rain (mm_{H2O} y^{-1})	NEE_Reichstein 2005 (tC ha^{-1} y^{-1})	GPP_Reichstein 2005 (tC ha^{-1} y^{-1})	Re_Reichstein 2005 (tC ha^{-1} y^{-1})	NEE_Lasslop 2010 (tC ha^{-1} y^{-1})	GPP_Lasslop 2010 (tC ha^{-1} y^{-1})	Re_Lasslop 2010 (tC ha^{-1} y^{-1})
2018-201	Millet	454	-3.3	-10.1	6.8	-3.5	-11.5	8.0
2019-202	Peanut	513	-3.6	-10.5	6.9	-3.7	-10.8	7.1
2020-202	Millet	600	-3.6	-11.63	8.0	-3.5	-11.45	7.92

Comparing annual CO_2 balance and partitioning between 2018 and 2020 and comparing results following methods by Reichstein et al. (2005) and Lasslop et al. (2010). There was no clear trend of NEE with rainfall or crop. Note that most of crop biomass is exported and that NEP should be much closer to nil. Gapfilling and partitioning by ReddyProc.

Source: Roupsard et al., EGU-1123, 2020, updated in 2021

Dry *vs* Wet seasons : Water, Energy, CO_2 balance

Water balance

Season	Fraction of the year	Rain (mm_{H2O} y^{-1})	ETo (mm_{H2O} y^{-1})	ETR (mm_{H2O} y^{-1})	ETR/Rain
Dry	0.65	0	996	204	-
Wet	0.35	522	461	296	0.57

Comparing the average (2018-2020) dry (2/3 of the year) and wet (1/3 of the year) seasons. During the wet season, ET_o was reduced by 55% and ETR increased by 45%

Energy balance

Season	Fraction of the year	Rn (MJ m^{-2} y^{-1})	H (MJ m^{-2} y^{-1})	λE (MJ m^{-2} y^{-1})	Bowen ratio H/λE	(H+λE)/Rn
Dry	0.65	1556	1053	495	2.13	0.99
Wet	0.35	1201	431	720	0.60	0.96

Comparing the average (2018-2020) energy balance between the dry (2/3 of the year) and wet (1/3 of the year) seasons. During the wet season, the Bowen ratio (H/LE) dropped dramatically by 72%. The energy balance ((H+λE)/R_n) was >95% (soil heat balance is neglected at the annual scale here), indicating that the EC system behaved very well during both dry and wet periods.

CO_2 balance

Season	Fraction of the year	$NEE_{\_Reichstein\ 2005}$ (tC ha^{-1} y^{-1})	$GPP_{\_Reichstein\ 2005}$ (tC ha^{-1} y^{-1})	$Re_{\_Reichstein\ 2005}$ (tC ha^{-1} y^{-1})	$NEE_{\_Lasslop\ 2010}$ (tC ha^{-1} y^{-1})	$GPP_{\_Lasslop\ 2010}$ (tC ha^{-1} y^{-1})	$Re_{\_Lasslop\ 2010}$ (tC ha^{-1} y^{-1})
Dry	0.65	-1.9	5.8	3.1	-1.9	-4.9	3.0
Wet	0.35	-1.6	5.0	4.1	-1.7	-6.4	4.7

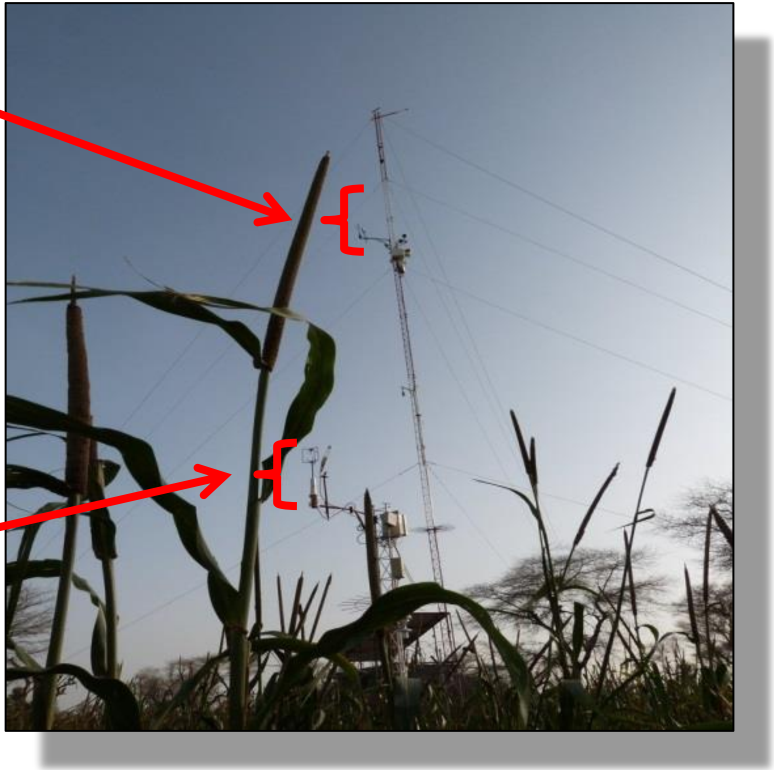
Comparing CO_2 balance and partitioning between the dry (2/3 of the year) and wet (1/3 of the year) seasons, and comparing results following Reichstein et al. (2005) and Lasslop et al. (2010). **Surprisingly, NEE was more effective during the dry season.** This was the result of Re being much lower on a daily basis as well as cumulated over the entire seasons . A lower (diurnal basis) but for a longer period (2/3 of the year) photosynthesis by Faidherbia resulted in $GPP_{\_Reichstein}$ being higher during the dry and wet seasons . Note that most of crop biomass is exported and that NEP should be much closer to nil. Gapfilling and partitioning by ReddyProc.

Source: Roupsard et al., EGU-1123, 2020, updated in 2021

Results from small Eddy Covariance antenna, below the trees and above crops + soil

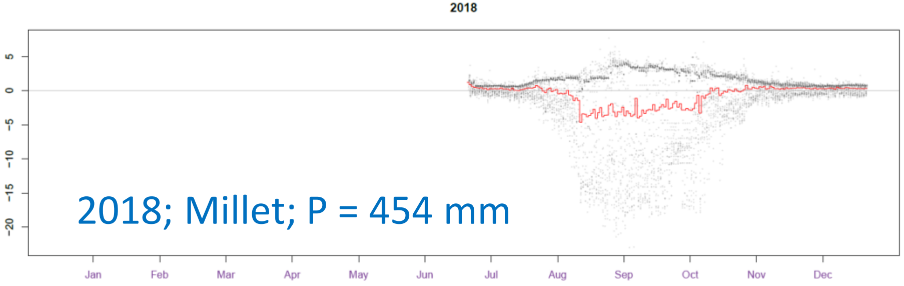
Fluxes at ecosystem level, above tree crowns: 20m high

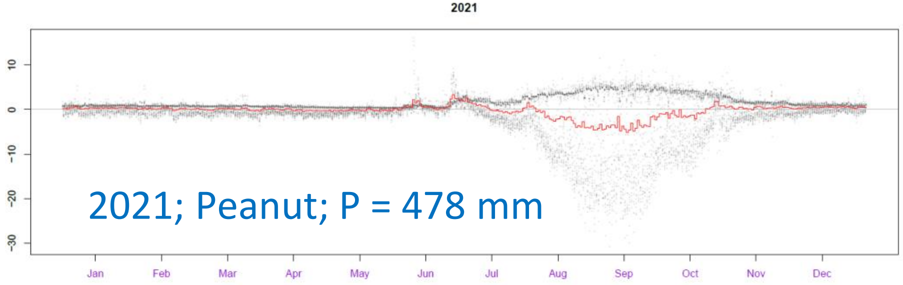
Fluxes above millet, below tree crowns: 4.5 m high

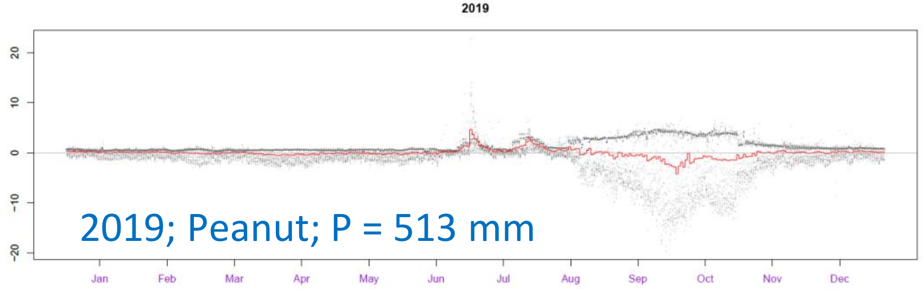


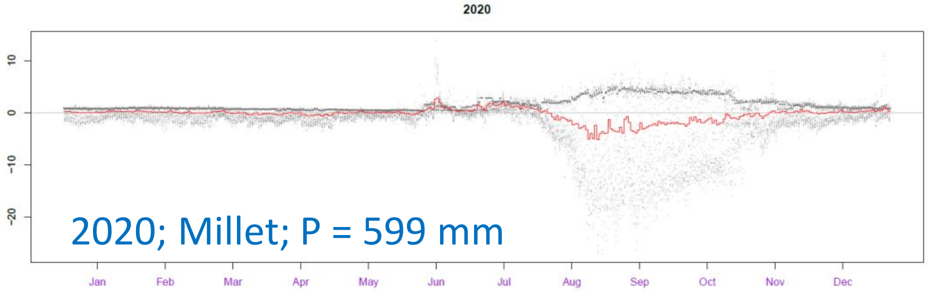
Eddy-covariance antenna (4m) + EC at 4.5m + Campbell weather station

Diurnal course and daily sums of gapfilled NEE ($\mu mol_{CO2}\ m^{-2}\ s^{-1}$)



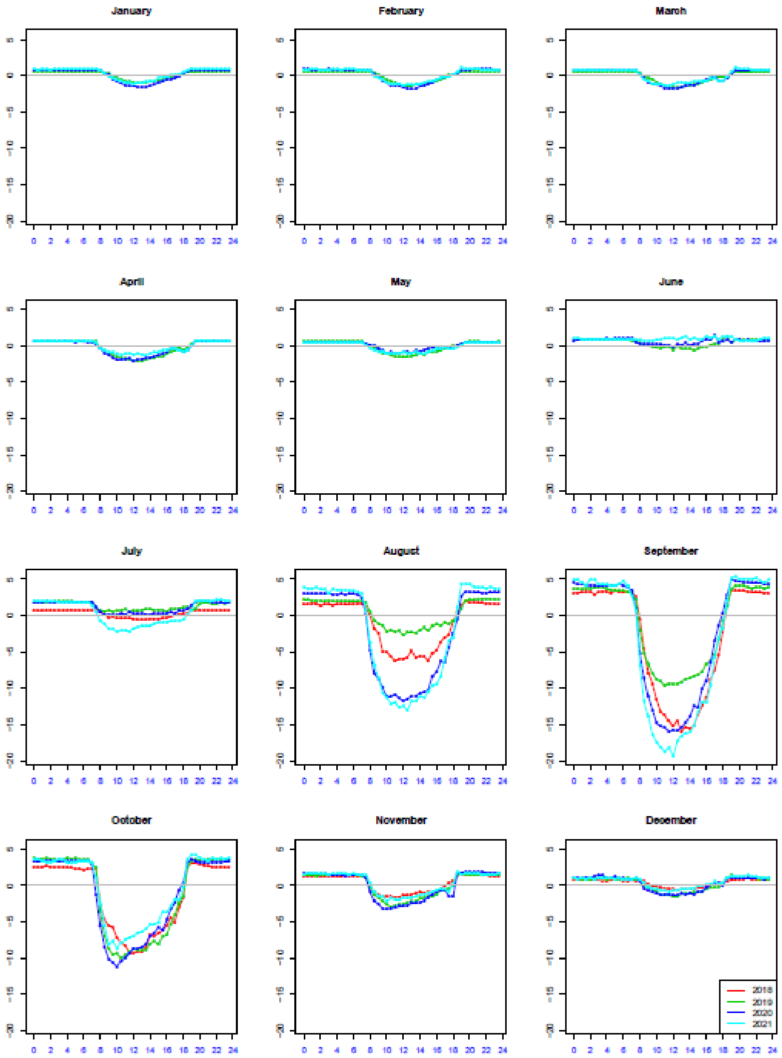






Gapfilled instantaneous (grey dots) and daily sums of NEE (red line) during the dry season close to nil, in bare soil conditions . Large CO_2 efflux after the first rains and small replicates during rain events. Net flux becomes more negative during the cropping season from July to October, during the wet season. The net balance is a CO_2 capture for most periods. Partitioning and Gap-filling through ReddyProc and Lasslop et al (2010).

Diurnal course of NEE ($\mu mol_{CO2}\ m^{-2}\ s^{-1}$) above soil+crops



Rainfall

2018: 454 mm

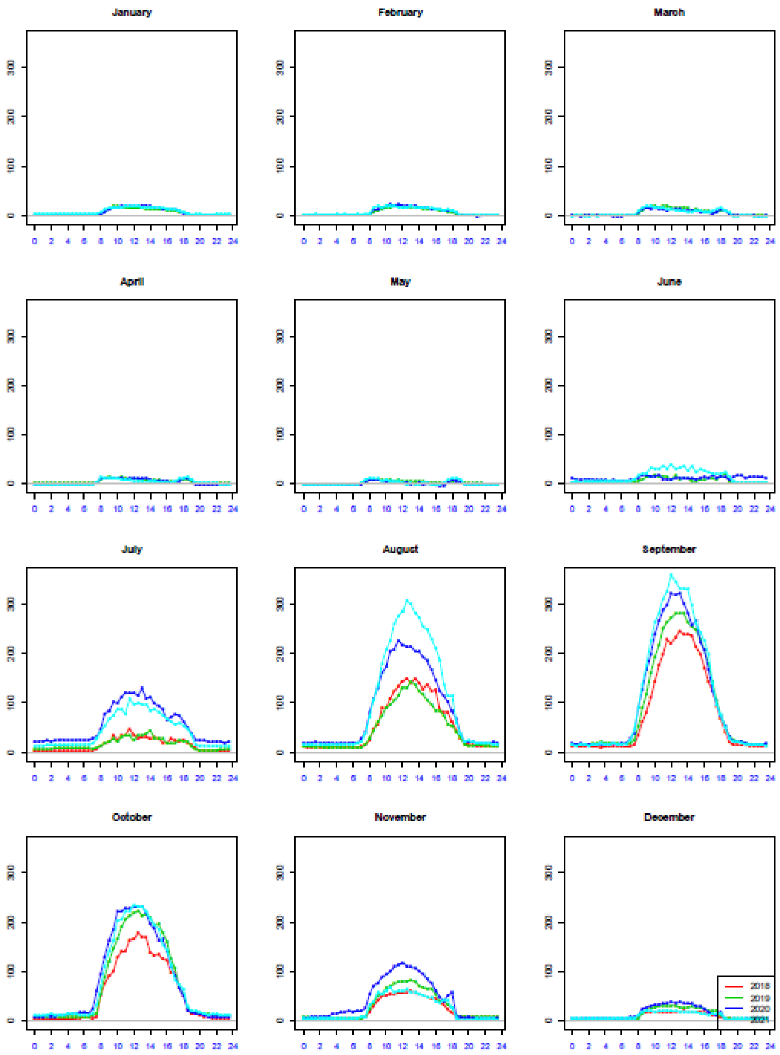
2019: 513 mm

2020: 599 mm

2021: 478 mm

Monthly average of gapfilled net ecosystem CO_2 exchange (NEE) diel course above soil+crops. During the dry season (November to July), there is a residual C is uptake which was likely due contamination by the upper layer with *Faidherbia* , and the ecosystem respiration (R_e) at night was small. During the wet season, sharp increase of C uptake (negative values during the day) and also R_e, due to the activity of the crops and wet soil. Partitioning and Gap-filling through ReddyProc and Lasslop et al. (2010)].

Diurnal course of λE (W m^{-2}), above soil+crops



Monthly average of gapfilled λE diel course above soil+crops. λE declines during the dry season between and May, indicating a reduction in soil evaporation which becomes almost nil in May Soil + crop evapotranspiration is increasing during the wet season, following soil rewetting and crop LAI, being maximim in September. 2020 is wettest but rainfall is better distributed in 2021, allowing higher crop LAI. Gap-filling of LE according to ReddyProc.

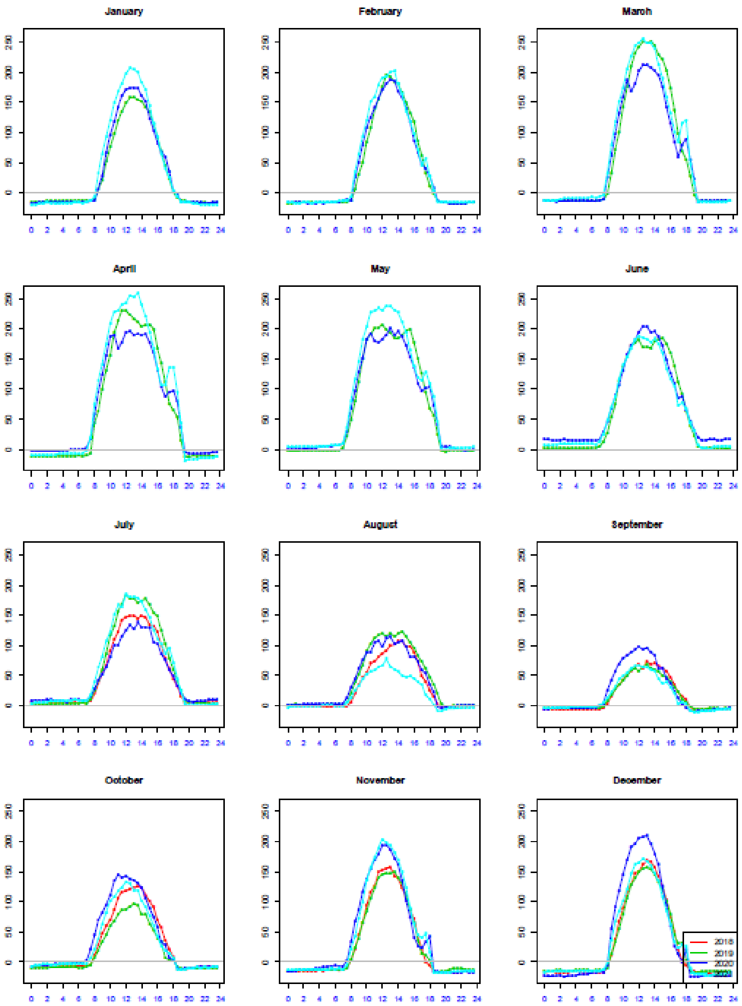
Rainfall

2018: 454 mm

2019: 513 mm

2020: 599 mm

2021: 478 mm



Diurnal course of H (W m^{-2}), above soil+crops

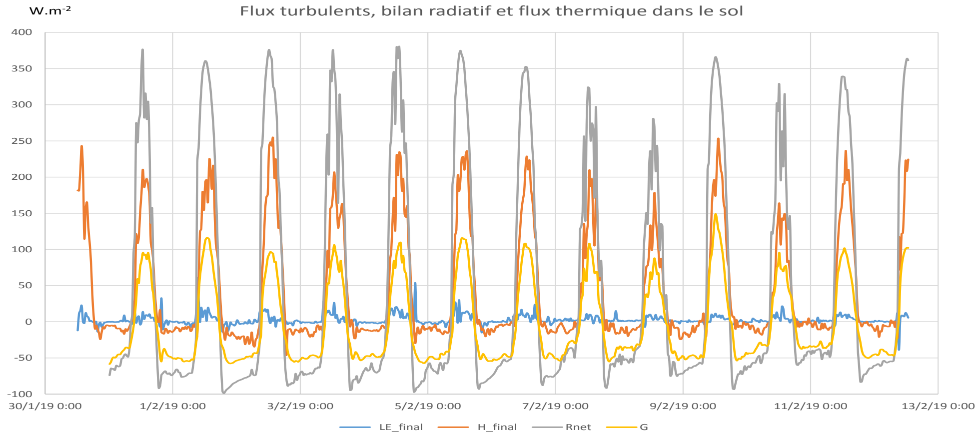
Monthly average of gapfilled H diel course above soil+crops. H increases during the dry season to reach maximum between April and June. It is lowest during the wet season between October. Gap-filling of H according to ReddyProc.

Rainfall
2018: 454 mm
2019: 513 mm
2020: 599 mm
2021: 478 mm

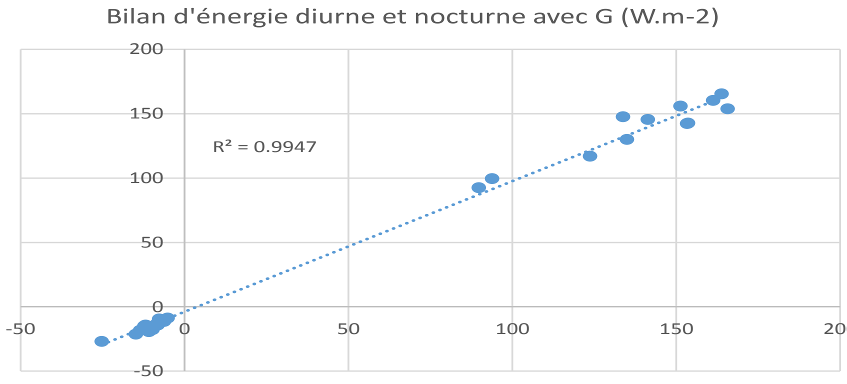
Counter-crop +soil Antenna (Ragola)

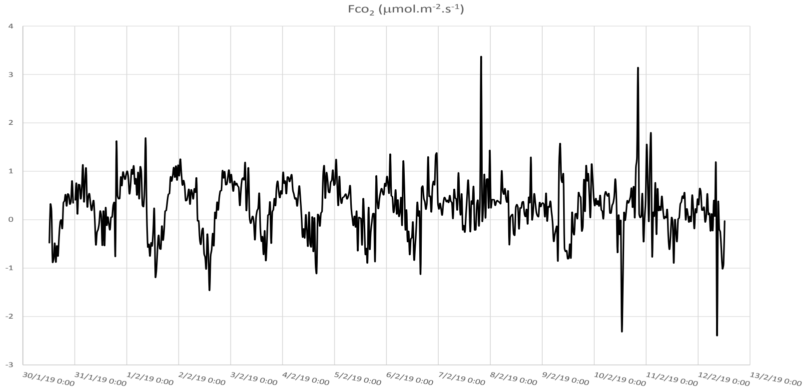
Eddy-covariance antenna (4m) + shelter (4.5 m^2) + fence + solar panels + Campbell weather station +RN 4 components + soil heat flux plates

Fluxes over ex-Peanut (GET antenna) during the dry season (2019)



Energy balance

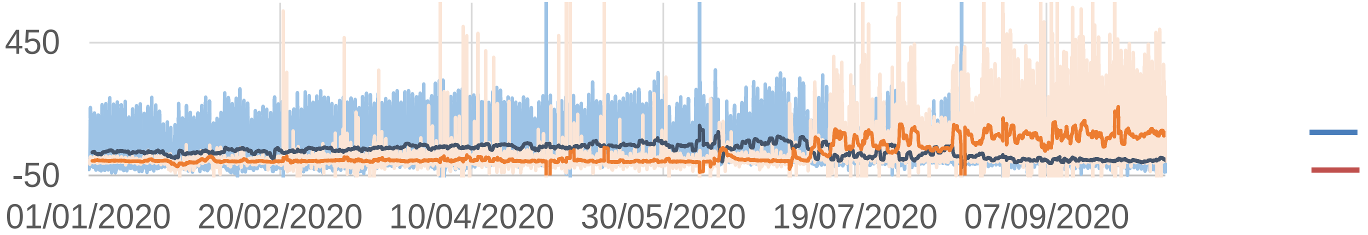




CO2 fluxes

franck.timouk@ird.fr; manuela.grippa@get.omp.eu;
laurent.kergoat@get.obs-mip.fr; fabrice.gangneron@get.obs-mip.fr;

Station Ragola, Niakhar, Sénégal
Flux turbulents, Bilan Radiatif, Bilan d'Energie, Météo, température et humidité du Sol
Rotation Arachide-Niébé/Mil



Flux de Chaleurs en 2020
30’ et journaliers en W/m²

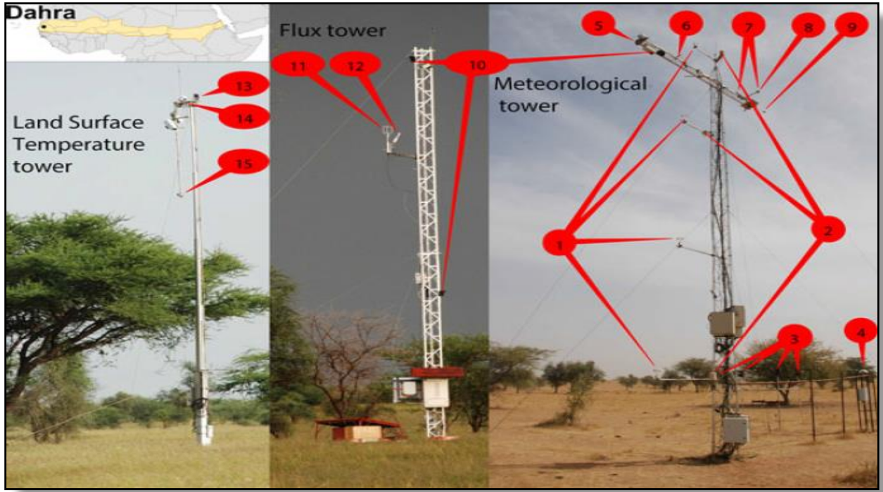
Complementarity of 2 Flux tower observatories

Faidherbia-Flux

(agro-silvo-pastoral / Sudanian savanna ecoclimatic zone (Olson et al., 2001))

Dahra

(silvo-pastoral): / Sahel ecoclimatic zone (Olson et al., 2001))



Opportunities for multi-site comparisons & regional studies

https://doi.org/10.5194/gmd-2020-417
Preprint. Discussion started: 5 February 2021

Geoscientific Model Development Discussions
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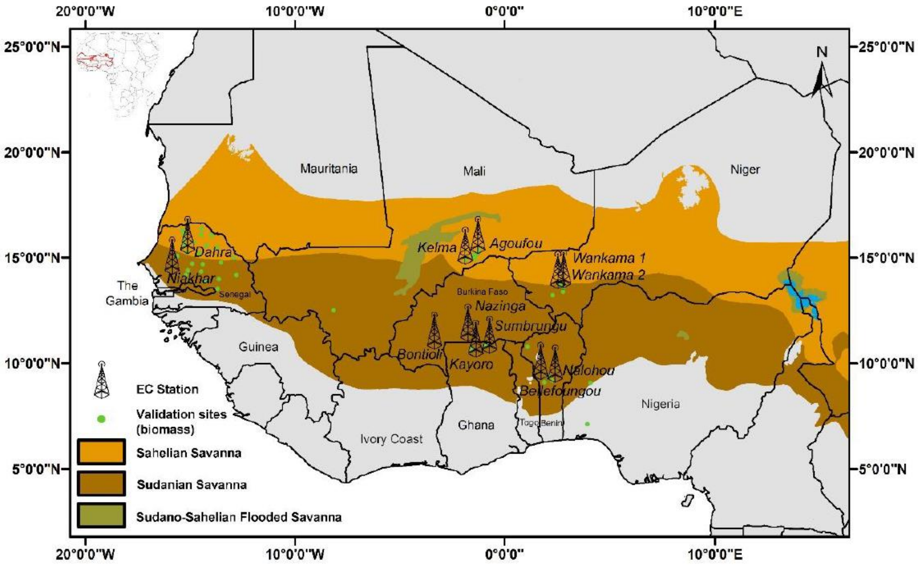

Figure 1: Map of West Africa showing the Sudanian and Sahelian ecological zones that were derived after Olson et al. (2001). Locations of measurements are indicated as towers (eddy covariance flux stations) or green dots (biomass production).

Modelling Gas Exchange and Biomass Production in West African Sahelian and Sudanian Ecological Zones

Jaber Rahimi[1], Expedit Evariste Ago[2,3], Augustine Ayantunde[4], Sina Berger[1,5], Jan Bogaert[3], Klaus Butterbach-Bahl[1,6], Bernard Cappelaere[7], Jérôme Demarty[7], Abdoul Aziz Diouf[8], Ulrike Falk[9], Edwin Haas[1], Pierre Hiernaux[10], David Kraus[1], Olivier Roupsard[11,12,13], Clemens Scheer[1], Amit Kumar Srivastava[14], Torbern Tagesson[15,16], Rüdiger Grote[1]

https://gmd.copernicus.org/preprints/gmd-2020-417/

Take-home message regarding fluxes

- African flux sites are very scarce: a new (2 year-old) semi-arid, agro-silvo-pastoral, African subsaharian site is contributing to FLUXNET (Sn-Nkr)
- Fluxes are globally reliable : few gaps in the data; footprint study indicates most of the fluxes originate from inside the main crop plot, thus EC data from tall and short antennas can be compared; energy balance ($H+\lambda E+G$) is closed at the 30 min time-step; ETR_{max} ~ 0.9*ETo during the wet season; ETR ~ P, confirming that little water is recharging the aquifer; ETR ~ E_u+T globally, except at the beginning of the dry season (to be investigated); Bowen ratio is behaving reasonably.
- NEE ~ 3.3 t_C ha^{-1} y^{-1}, but most of crop residues are being exported, therefore NEP should come closer to nil
- Although the highest fluxes occur during the wet season, this is only for 1/3 of the year: as a consequence, cumulated GPP is similar during the dry (from trees) and wet (frop crops) seasons, R_e is lower and finally, NEE is twice as much during the dry season (not deducting the crop residues yet)
- *Faidherbia-Flux* is maintained by permanent staff, hosts many projects and students and is wide open for more international data sharing and collaboration. Please contact us.

Articles

- Rahimi, J., Ago, E.E., Ayantunde, A., Berger, S., Bogaert, J., Butterbach-Bahl, K., Cappelaere, B., Demarty, J., Diouf, A.A., Falk, U., Haas, E., Hiernaux, P., Kraus, D., Roupsard, O., Scheer, C., Srivastava, A.K., Tagesson, T., Grote, R., 2021. Modelling Gas Exchange and Biomass Production in West African Sahelian and Sudanian Ecological Zones. **Geosci. Model Dev. Discuss.** https://gmd.copernicus.org/preprints/gmd-2020-417/ 2021, 1-39.

Communications

- Roupsard, O., Do, F., Rocheteau, A., Diouf, K., Sarr , M.S., Faye, W., Diongue, D.M.L., Orange, D., Faye, S., Timouk, F., Kergoat, L., Grippa, M., Jourdan, C., Bouvery, F., Tall, L., Gaglo, E., Sow, S., Agbohessou, Y., Diatta, S., Sanogo, D., le Maire, G., Vezy, V., Seghieri, J., Chapuis-Lardy, L., Cournac, L., 2020. More C uptake during the dry season? The case of a semi-arid agro-silvo-pastoral ecosystem dominated by Faidherbia albida, a tree with reverse phenology (Senegal). Oral presentation Monday 4rth of May 11h45. Session BG3.30: Tropical landscapes and peatlands: Biogeochemistry, ecohydrology and land use impacts. https://meetingorganizer.copernicus.org/EGU2020/EGU2020-11203.html. Austria, EGU, Vienna, 3-8 May 2020, Session BG3.30 / Land use and climate effects on carbon, greenhouse gas and water dynamics in Africa / EGU2020-11203 /
- Roupsard, O. et al., 2019. “Faidherbia-Flux”, an open observatory for GHG balance and C stocks in a semi-arid agro-sylvo-pastoral system (Senegal). Poster, 4rth World Congress on Agroforestry. . France, 20-22 of May 2019. Le Corum Conference Centre, Montpellier, France. Poster. Session 1: Mitigating Climate change with agroforestry.

Shared database in R

Faidherbia-Flux_Collaboratif\Database

https://baobab.sedoo.fr/