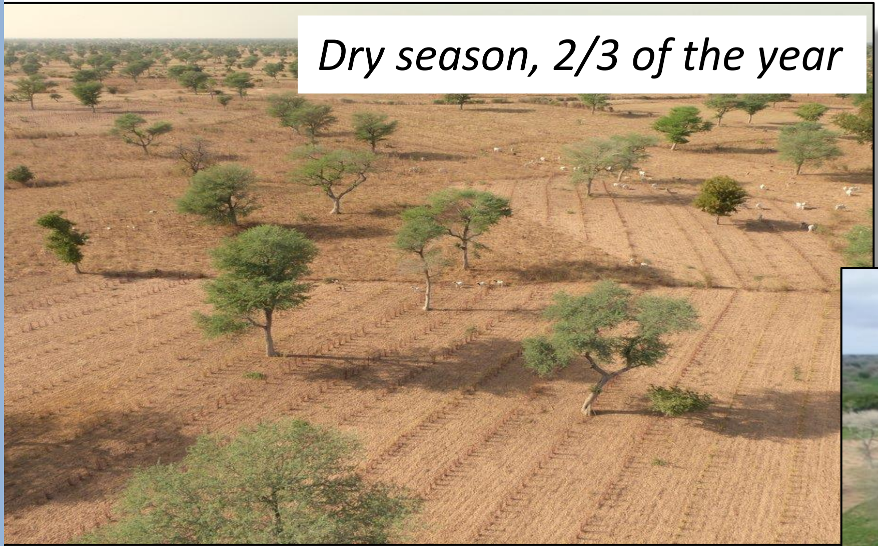
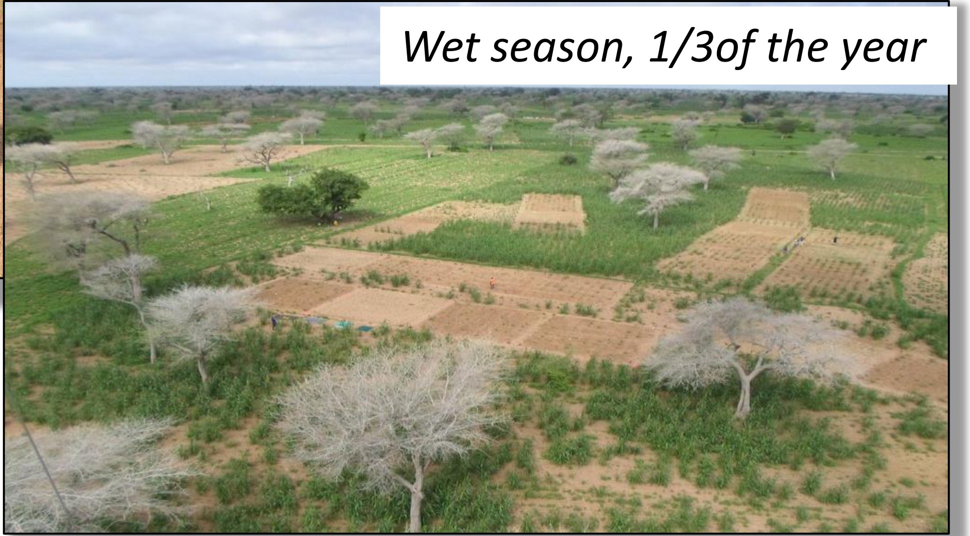
EGU 2020, Vienna, Austria, 3rd to 8th of May, 2020, Session BG3.30 / Land use and climate effects on carbon, greenhouse gas and water dynamics in Africa **/ EGU2020-11203 / https://meetingorganizer.copernicus.org/EGU2020/EGU2020-11203.html**

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)





“Faidherbia-Flux” Web site : https://lped.info/wikiObsSN/?Faidherbia-Flux

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Co-authors & Institutions

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Abstract (Updated)

https://meetingorganizer.copernicus.org/EGU2020/EGU2020-11203.html

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)

Agro-silvo-pastoralism is a highly representative Land Use in Africa, often presented as a strategical option for ecological intensification of cropping systems towards food security and sovereignty. So far, little is known about the contribution of sub-Saharan agro-silvo-pastoral ecosystems to energy and GHG balance, nor regarding their seasonal and inter-annual variability. Such systems are also particularly complex to measure and model considering their horizontally heterogeneous components.

We set up a new long-term observatory ("Faidherbia-Flux") to monitor and model microclimate, energy and C balance in Niakhar (central Senegal, rainfall ~ 500 mm), dominated by the multipurpose tree *Faidherbia albida* (12.5 m high; 7 tree ha^{-1}; 5% canopy cover). *Faidherbia* is an attractive agroforestry tree species in order to partition fluxes, given that it is on leaf during the dry season (October-June) and defoliated during the wet season, just when crops take over. Pearl-millet and groundnut crops were conducted during the wet season, following annual rotation in a complex mixed mosaic of *ca.* 1 ha fields. Transhumant livestock contributed largely to manure, SOM and soil fertility.

The present data are summing up 2 complete years. Early 2018, we installed an eddy-covariance (EC) tower above the whole mosaic (EC1: 20 m high) and monitored microclimate, soil humidity and temperature down to the water-table (-7 m), energy and CO_2 balance since. A second EC system was displayed above the crop (EC2: 4.5 m if pearl-millet, 2.5 m if groundnut) in order to partition ecosystem EC fluxes between tree layer and crop+soil layers. Sap-flow was monitored from April 2019 onwards in 5 *Faidherbia* trees of representative size, taking into account trunk azimutal and radial variability (37 sensors).

The ecosystem displayed moderate but significant daily CO_2 and H_2O fluxes during the dry season, when *Faidherbia* (low canopy cover) was in leaf and the soil was evaporating. At the onset of the rainy season, the soil bursted a large amount of CO_2. Just after the growth of pearl-millet in 2018, CO_2 uptake by photosynthesis increased dramatically. However, this was largely compensated by high ecosystem respiration. Surprisingly in 2019, although the crop was turned to groundnut, the fluxes behaved pretty much the same as with pearl millet in 2018: comparing annual balances between 2018 and 2019 we obtained [454, 513] for rainfall (P: mm yr^{-1}), [3534, 3544] for potential (Allen) evapotranspiration (ETo: mm yr^{-1}), [0.13, 0.14] for P/ETo, [428, 420] for actual evapotranspiration (ETR: mm yr^{-1}), [2788, 2769] for net radiation (R_n: MJ m^{-2} yr^{-1}), [1609, 1452] for sensible heat flux (H: MJ m^{-2} yr^{-1}), [-3.8, -2.8] for net ecosystem exchange of C ($NEE_{\_Lasslop\ 2010}$: tC ha^{-1} yr^{-1}), [-11.2, -8.3] for gross primary productivity ($GPP_{\_Lasslop\ 2010}$: tC ha^{-1} yr^{-1}) and [7.4, 5.4] for ecosystem respiration ($R_{e\_Lasslop\ 2010}$: tC ha^{-1} yr^{-1}). Note that most of crop biomass is exported and that NEP should be much closer to nil. The energy balance ((H+lE)/R_n)) was >90% indicating that the EC system behaved reasonably. ETR was very close to P in 2018 and 4/5 of P in 2019, indicating that little water would recharge the deep soil layers.

Now comparing the dry (2/3 of the year) and wet (1/3) seasons, the Bowen ratio (H/LE) dropped dramatically [2.53, 0.71] and ETR increased nearly by 40% [356, 493]. Surprisingly, $NEE_{\_Lasslop}$ was twice as more effective during the dry season [-4.4, -2.2]. This was the result of $R_{e\_Lasslop}$ being much lower on a daily basis as well as cumulated over the entire seasons [5.1, 7.7]. A lower (diurnal basis) but significant photosynthesis by *Faidherbia* when cumulated over its leafy period (dry season) resulted in $GPP_{\_Lasslop}$ similar during the dry and wet seasons [-9.5, -9.9].

We found a good match between E measured above the whole ecosystem (EC1), and the sum of tree transpiration (T, measured by sapflow) + E measured just above crops + soil (EC2) excepted at the beginning of the dry season (to be investigated further).

The "Faidherbia-Flux" observatory is registered in FLUXNET as SN-Nkr and is widely open for collaboration.

Faidherbia albida, a perfect candidate for ecological intensification?

- Widespread in semi-arid Africa
- Multi-purpose
- Domesticated and maintained by the people in parklands
- Reverse Phenology: minimum competition, forage for animals during the dry season
- N_2 Fixing
- Microclimate and fertility islets effects
- Phreatophytic (hydraulic redistributions?)
- Survived the 1970-2000 severe drought in the Sahel
- Positive effects on most crops
- Compliant with other options: livestock, mixed cropping, precision agriculture etc.

Which crops alternating during the wet seasons ?

1) 2018 : Pearl-Millet (C4 crop)

2) 2019 : Groundnut (C3 crop)

Aims ?

- Documenting agro-silvo-pastoralism and sustainable intensification research, through « Faidherbia-Flux[1] », a collaborative biogeochemical Observatory.
- Comparing wet *vs* dry seasons
- Comparing 2018 (crop = pearl-millet) *vs* 2019 (crop = groundnut)
- Footprinting and Partitioning Evapo-transpiration fluxes : above the whole ecosystem (ETR = trees + crops + soil), over the understorey (Eu = crop + soil only), and from the trees only (T: Tree transpiration by sapflow).
- Energy, CO_2, H_2O balance summed up per year/crop (2018 *vs* 2019) and per season (wet *vs* dry)

[1]Faidherbia-Flux: https://lped.info/wikiObsSN/

Where?

- In the Niakhar Health-Population-Environment Observatory* (> 50 yrs of past research), [Delaunay et al. (2018)](#).

"Faidherbia-Flux" is here

Lat. N: 14°29'44.916"
Long. W: 16°27'12.851"

(*) https://lped.info/wikiObsSN/

Where is the « Faidherbia-Flux » data available ?

European Fluxes Database Cluster

Home | ECO2S | CarboExtreme | CarboAfrica | GHG-Europe | ICOS | InGOS | Page21 | PI Area | Log in

Register your site | Sites List | Guidelines | Data

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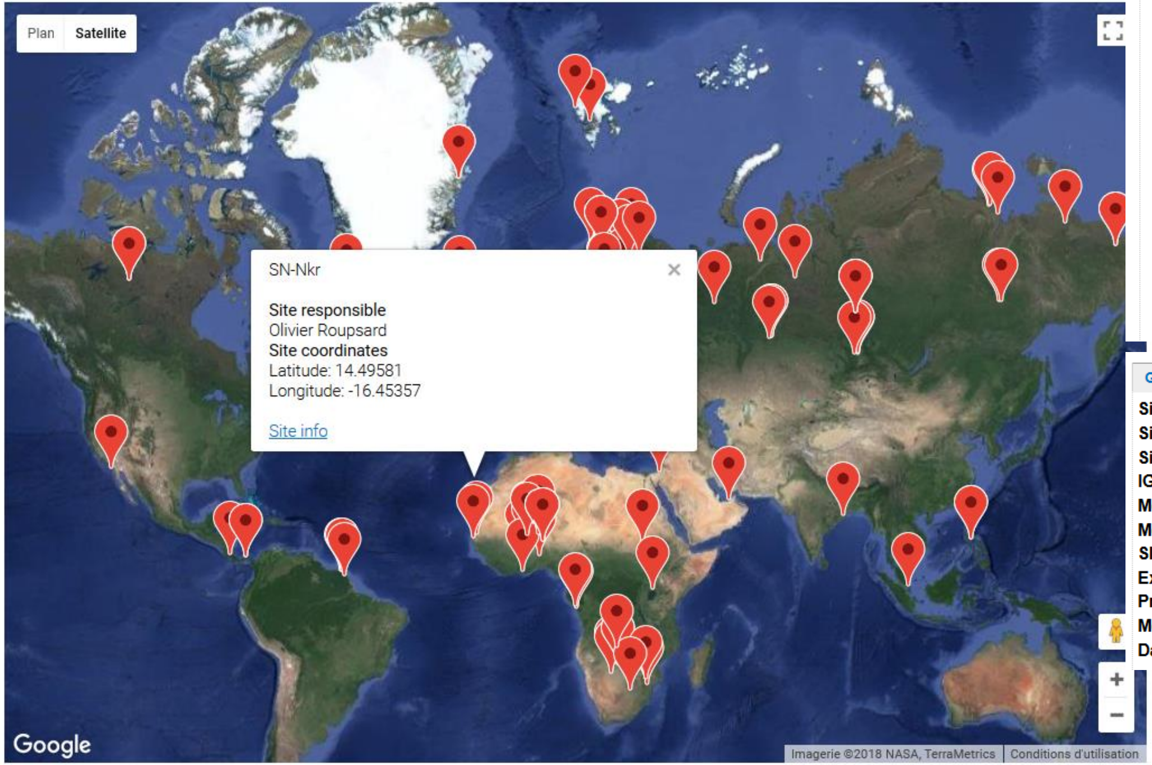
Sites list



GENERAL INFORMATION | STAFF | FLUXES AVAILABLE | DATA POLICY DETAILS

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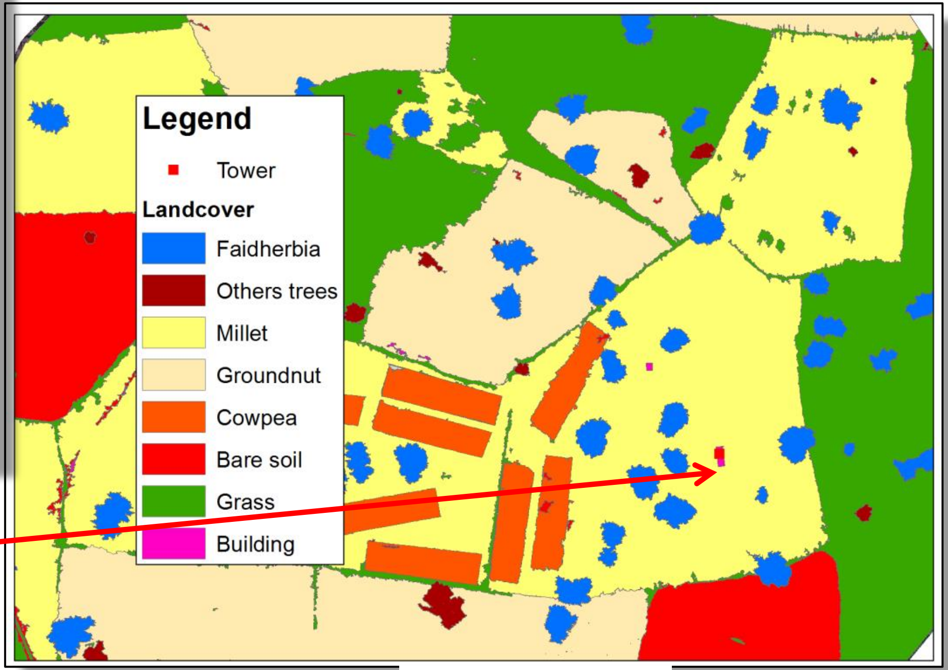
GENERAL INFORMATION | STAFF | FLUXES AVAILABLE | DATA POLICY DETAILS

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

Mosaic of fields…: an issue for the footprint ?

Drone Ortho-image
September 2018, wet season

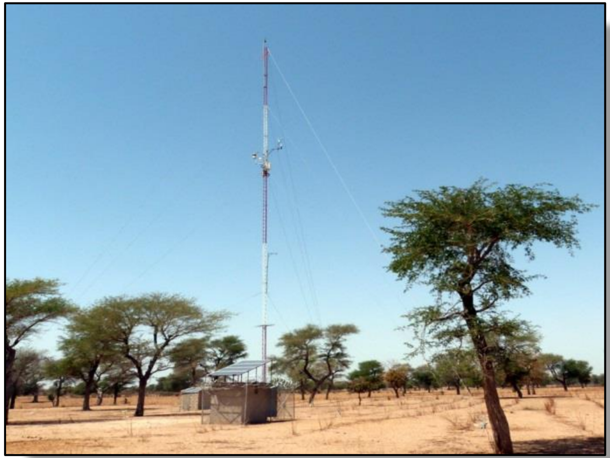
Tall + short antennas



eCognition®

Source: [Roupsard et al., AGEE, 2020]

Equipments ?



3 eddy-covariance towers

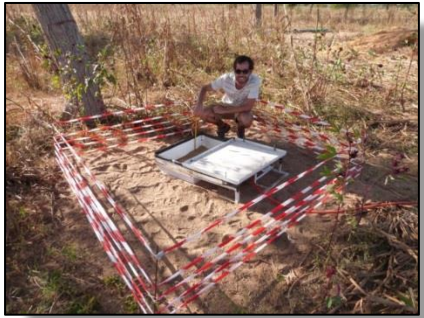
Olivier Roupsard; Laurent Kergoat; Franck Timouk; Manuela Grippa

6 Wells for deep roots and soil monitoring

Christophe Jourdan; Alain Rocheteau; Didier Arnal; Frédéric Bouvery; Fredéric Do

Sap flow, hydraulic redistributions, ecohydrology

Frederic Do; Alain Rocheteau; Didier Orange; Mame Sokhna Sarr

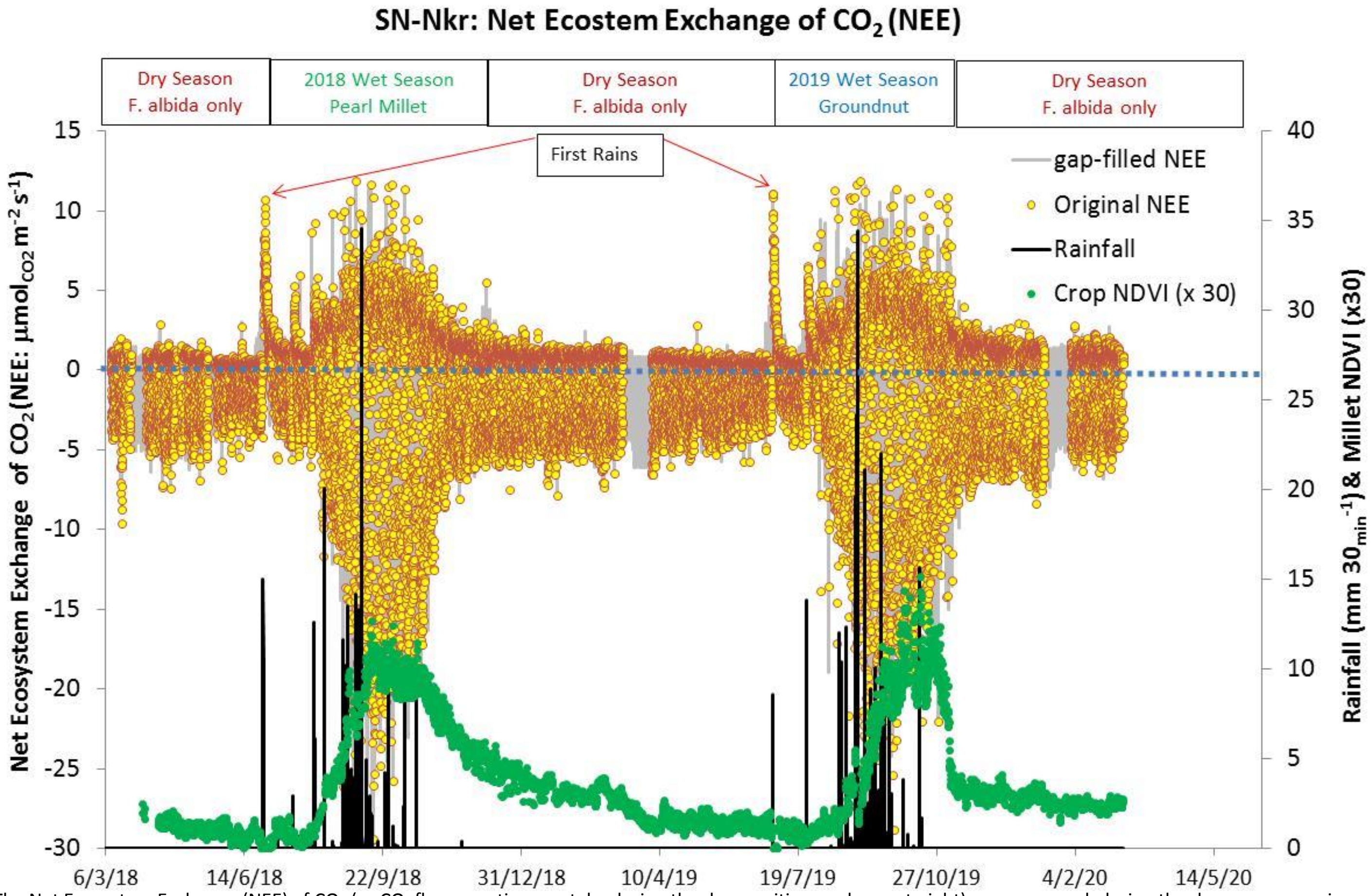


Soil GHG balance

Maxime Duthoit; Karel van den Meersche

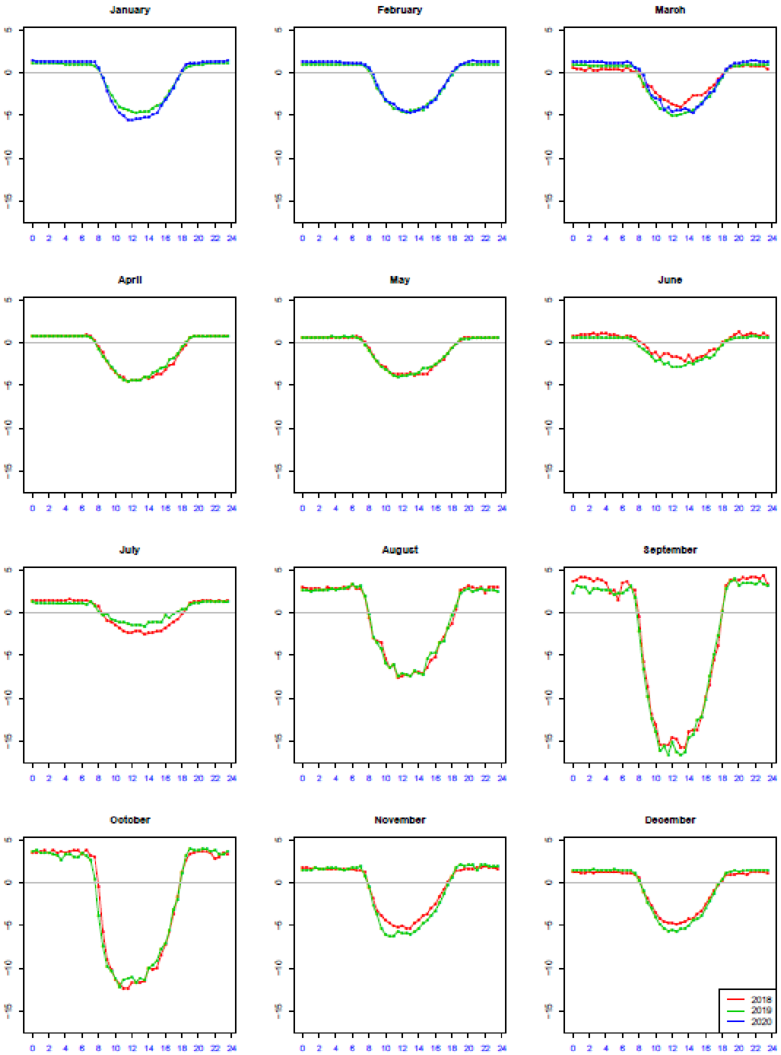
CO_2 fluxes

above the whole ecosystem



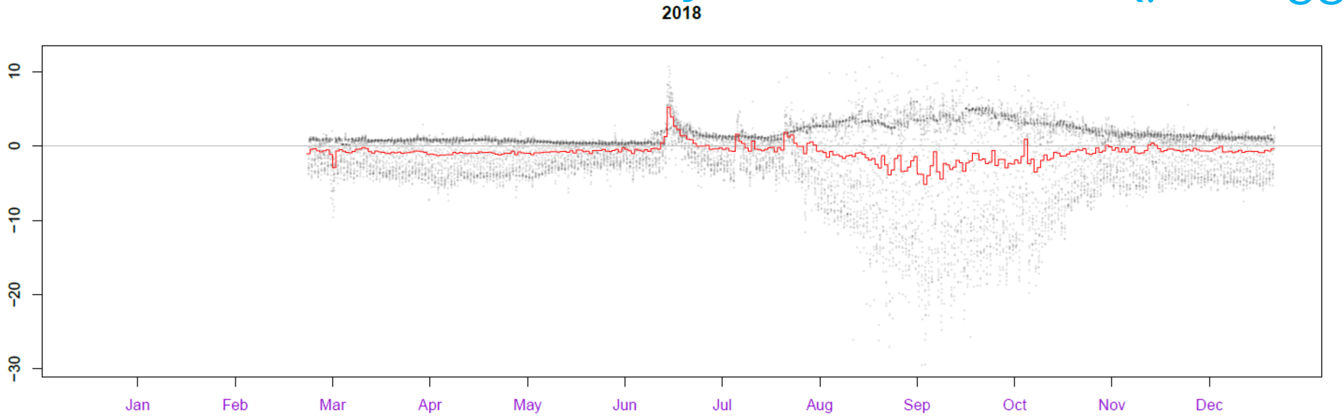
The Net Ecosystem Exchange (NEE) of CO_2 (or CO_2 flux, negative = uptake during the day; positive = release at night) was very weak during the dry season, maximum photosynthesis (GPP) around -5 µmolCO_2 m^{-2} s^{-1} and maximum ecosystem respiration (Re) around 1.5 µmolCO_2 m^{-2} s^{-1}. GPP was from *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 ($\mu mol_{CO_2}\ m^{-2}\ s^{-1}$) above the whole ecosystem

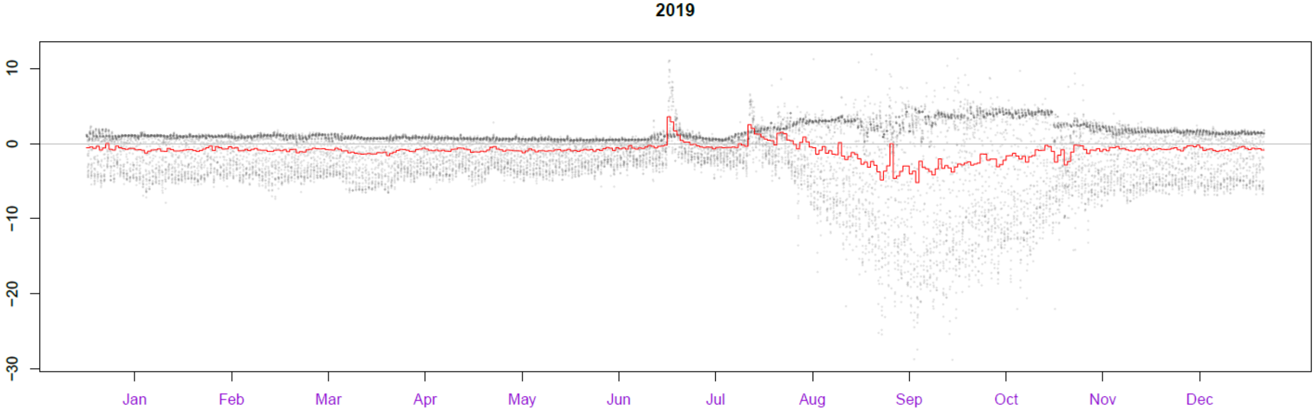


Monthly average of net ecosystem CO_2 exchange (NEE) diel course. During the dry season (November to July), the C uptake was due to *Faidherbia* only, and the ecosystem respiration (R_e) at night was small. During the wet season, note sharp increase of C uptake (negative values during the day) and also R_e, due to the re-greening of the crop system. Surprisingly, the 2 years (2018, crop = pearl millet) and 2019 (crop = groundnut) look very similar. Partitioning and Gap-filling through ReddyProc and Lasslop et al. (2010)].

Diurnal course and daily sums of NEE (μmol_{CO2} m^{-2} s^{-1})



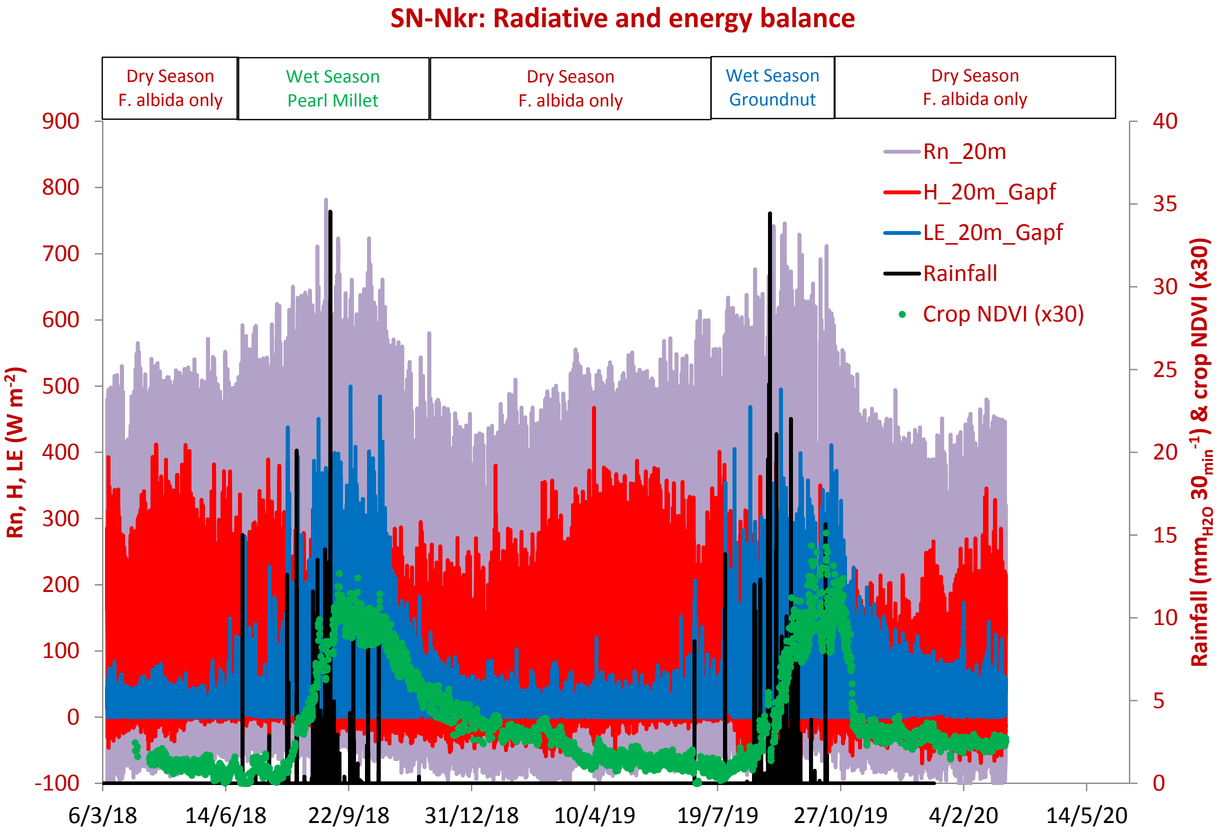
2018
with Millet

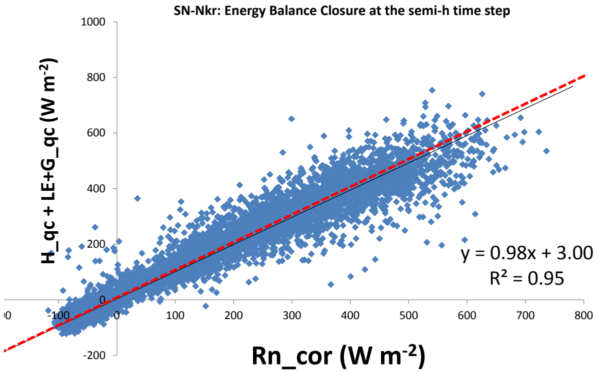


2019
with Groundnut

Daily sums of NEE (red line) during the dry season are around -0.01 gC m^{-2} day^{-1}, in conditions where the canopy cover by *Faidherbia* is less than 5%. Then large CO_2 efflux after the first rains and small replicates during rain events. Net flux becomes important from August to October, during the wet season, then declines again. The net balance is a CO_2 capture for most periods. Partitioning and Gap-filling through ReddyProc and Lasslop et al. (2010).

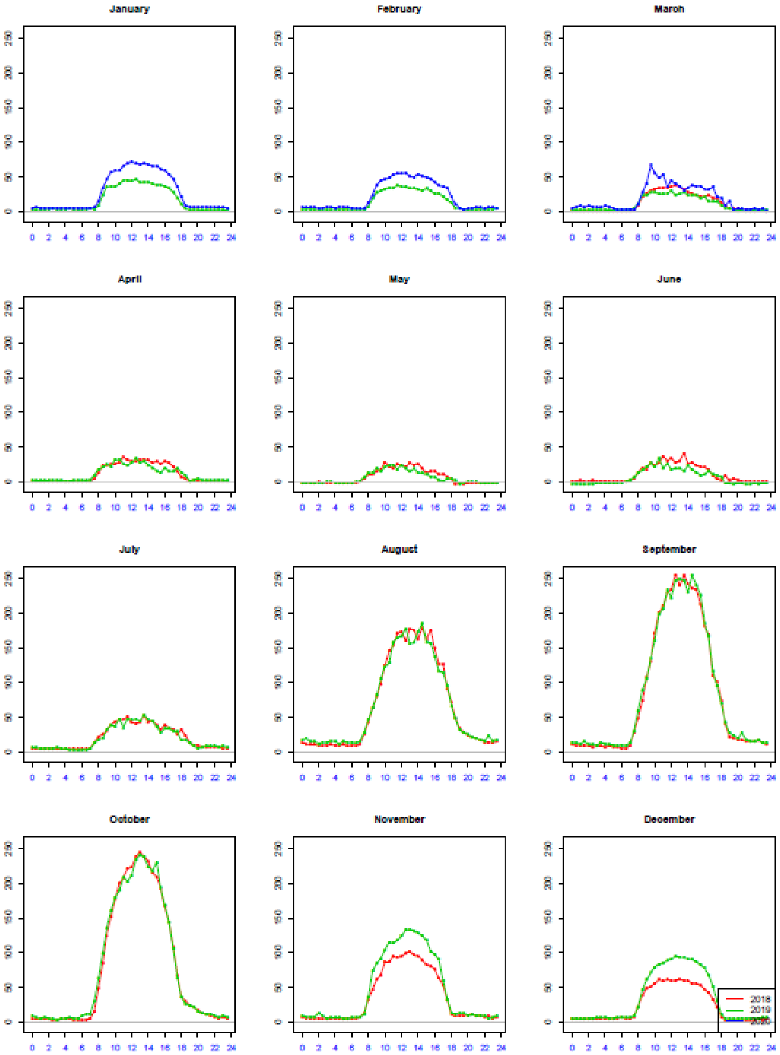
Energy balance and evapo-transpiration, above the whole ecosystem





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.

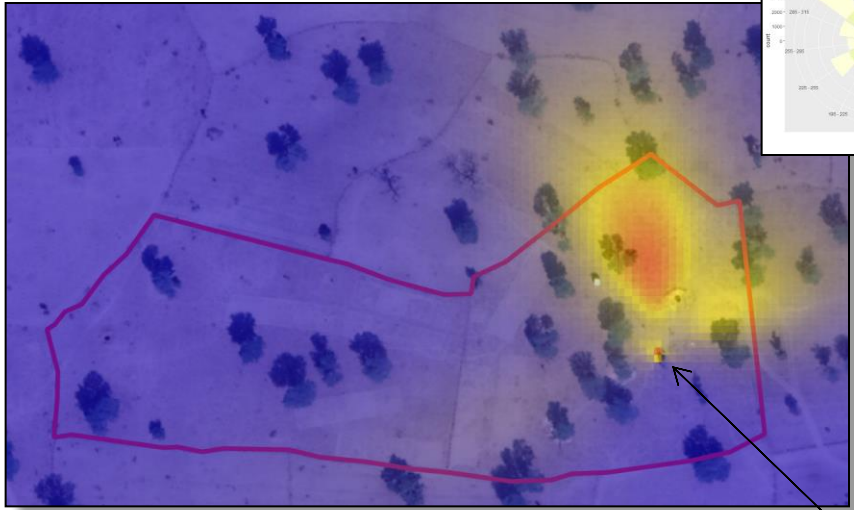


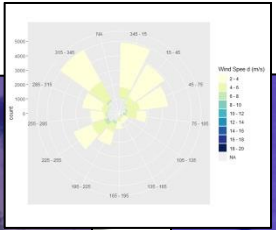
Diurnal course of λE ($W\ m^{-2}$), above the whole ecosystem

Monthly average of 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. The 2 years look similar, except by the end of the year (more soil evaporation by the end of 2019 and beginning of 2020). Gap-filling of H and LE according to ReddyProc.

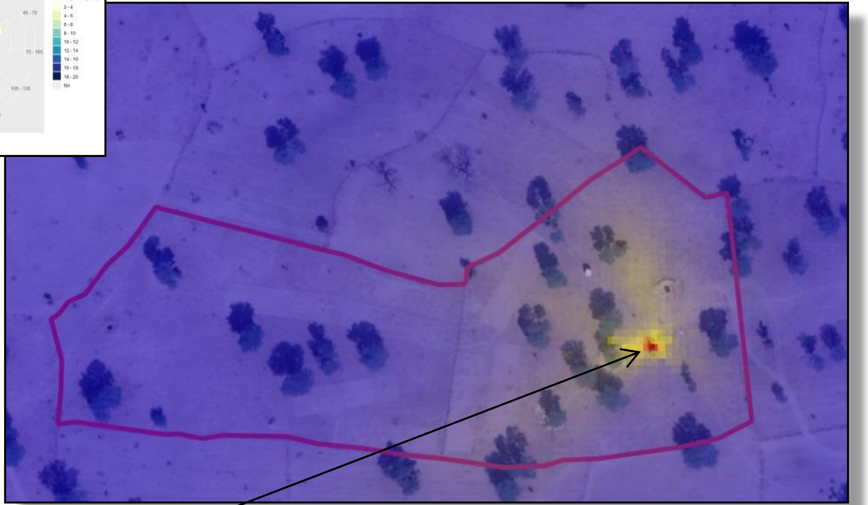
Footprints during Dry and Wet seasons

Dry Season 2018-2019





Wet Season 2018



100 m

Blue	0
Grey	0.000175
Yellow	0.00035
Orange	0.000525
Red	0.0007

100 m

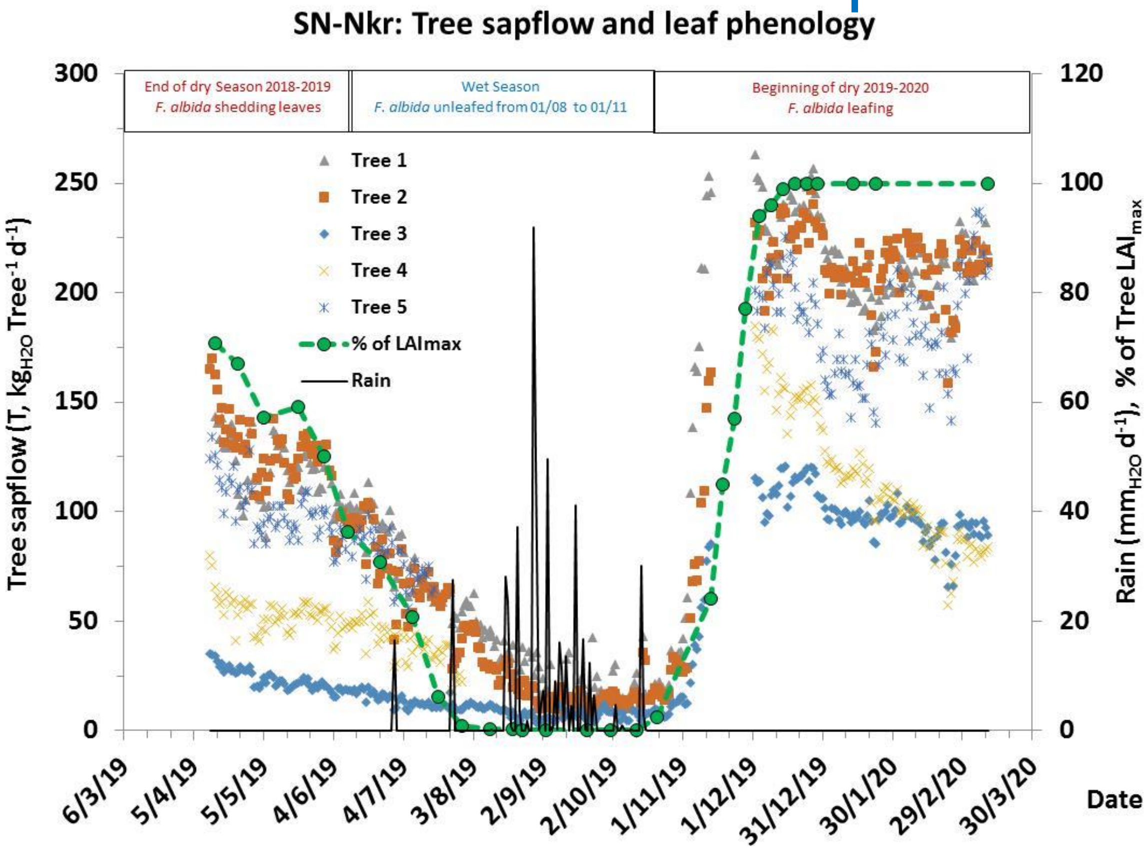
Blue	0
Grey	0.0003
Yellow	0.0006
Orange	0.0009
Red	0.0012

Antennas

Area with millet in 2018
or groundnut in 2019

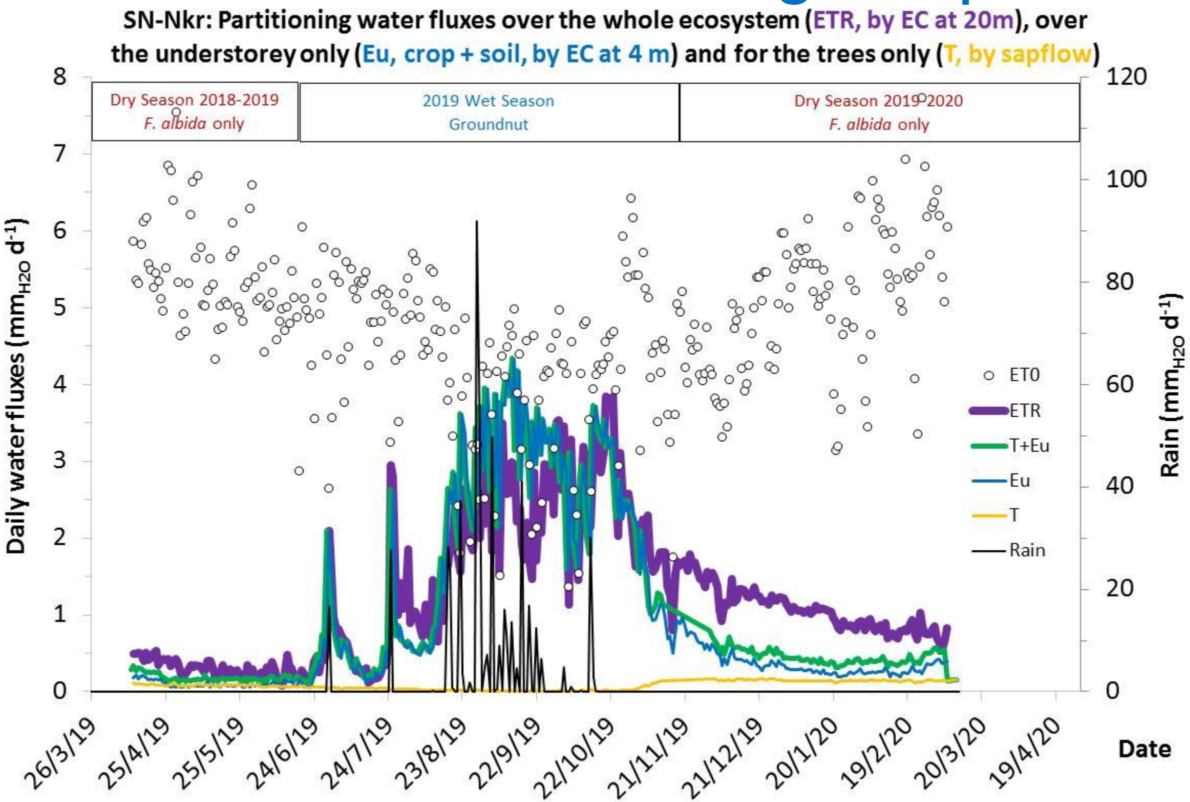
Most fluxes measured on the tall antenna at 20 m high originated from inside the main crop plot of interest (millet in 2018 and groundnut in 2019), whatever the season. During the dry season, winds originated mostly from N and NE (mostly within 100 m of distance), but at that time, it can be assumed 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.

Tree sapflow

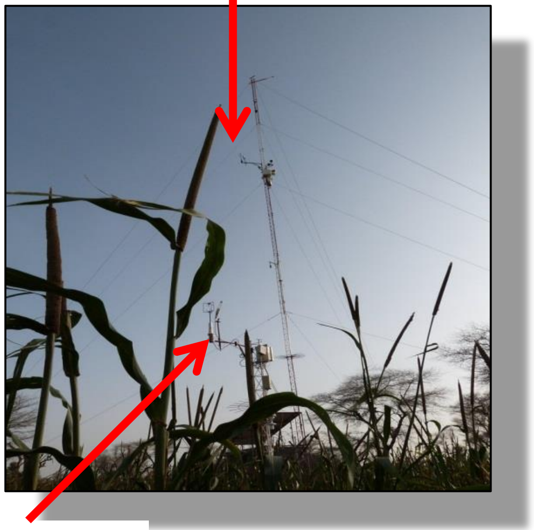


Sapflow was measured on 5 *F. albida* trees using the Thermal Dissipation method (Do and Rocheteau, 2002) with single probe (Do et al. 2011), with probes inserted in the periphery and along radial axes, at breast height and also in roots (N = 57 probes). Leaf phenology was assessed visually ,every 10 days or so, on 12 *F. albida* trees. Despite important differences between trees (according to their canopy sizes), sapflow seasonal patterns remained very consistent between trees, with progressive decay during the end of the dry season and rapid recover just after the rains stop and simultaneously with leaf onset. *Faidherbia albida* expresses reverse phenology (de-leafed during the wet season).

Partitioning evapo-transpiration



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



Fluxes above crop, below tree crowns: 4.5 m high

Potential evapotranspiration (ET0) decreased during the wet season, while remaining high, around 4 mm_{H2O} d^{-1}. Whole plot evapo-transpiration (ETR: tree + understorey + soil) measured by EC at 20 m high on the tall antenna tended to nil by the end of the first dry season, while the surface soil was extremely dry and *F. albida* trees de-leafed. When rainfall resumed, ETR increased sharply, as the result of soil evaporation, first, and second of crop (here groundnut in 2019) transpiration, altogether measured as E_u by EC. After the end of the wet season, the crop was harvested and ETR decreased slowly, as the result of soil evaporation mainly., with little contribution of tree transpiration (T, by sapflow) . It can be seen that T remained a small fraction of the water balance all year-long, according to its low canopy cover (< 10%). Soil evaporation appeared to be a major component of the water balance., but the relative contribution of the crop to Eu was not assessed. Although the energy balance was well closed in this site (see previous graphs), and although there was good consistency between ETR_{max} , ETo and $T+E_u$ during the wet season, T+Eu was only ca. 50% of ETR at the beginning of the next dry season. More data analysis is required to explain this.

2018-millet *vs* 2019-groundnut year-crops: Water, Energy, CO_2

Water balance

Year	P (mm H2O y^{-1})	ETo (mm H2O y^{-1})	P/Eto	ETR (mm H2O y^{-1})	ETR/P
2018-2019	454	3534	0.13	428	0.94
2019-2020	513	3544	0.14	420	0.82

Comparing annual water balance between 2018 and 2019. In this semi-arid site, P/Eto was only *ca.* 15%. ETR was very close to P in 2018 and 4/5 of P in 2019, indicating that little water would recharge the deep soil layers.

Energy balance

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
2018-2019	2788	1609	1050	1.53	0.95
2019-2020	2769	1452	1029	1.41	0.90

Comparing annual energy balance between 2018 and 2019. The energy balance ((H+λE)/R_n)) was >90% (soil heat balance is neglected at the annual scale here), indicating that the EC system behaved reasonably.

CO_2 balance

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})
-3.3	-9.9	6.6	-3.8	-11.2	7.4
-3.3	-8.6	5.3	-2.8	-8.3	5.4

Comparing annual CO_2 balance and partitioning between 2018 and 2019, and comparing results following Reichstein et al. (2005) and Lasslop et al. (2010). Note that most of crop biomass is exported and that NEP should be much closer to nil. Gapfilling and partitioning by ReddyProc.

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

Water balance

Season	Fraction of the years	P (mm_{H2O} y^{-1})	ETo (mm_{H2O} y^{-1})	ETR (mm_{H2O} y^{-1})	ETR/P
Dry	0.66	0	4978	356	-
Wet	0.34	967	2100	493	0.51

Comparing the dry (2/3 of the year) and wet (1/3) seasons, ET_o was reduced by 60% and ETR increased nearly by 40%

Energy balance

Season	Fraction of the years	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	0.66	3126	2207	872	2.53	0.99
Wet	0.34	2432	853	1207	0.71	0.85

Comparing energy balance between the dry (2/3 of the year) and wet (1/3) seasons, the Bowen ratio (H/LE) dropped dramatically by 70%. The energy balance ((H+λE)/R_n)) was >85% (soil heat balance is neglected at the annual scale here), indicating that the EC system behaved reasonably during the wet period very well during the dry period.

CO_2 balance

Season	Fraction of the years	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	0.66	-4.0	-9.6	5.7	-4.4	-9.5	5.1
Wet	0.34	-2.7	-8.9	6.2	-2.2	-9.9	7.7

Comparing CO_2 balance and partitioning between the dry (2/3 of the year) and wet (1/3) seasons, and comparing results following Reichstein et al. (2005) and Lasslop et al. (2010). **Surprisingly, NEE_L_{asslop} was twice as more effective during the dry season [-4.4, -2.2].** This was the result of $Re_{\_Lasslop}$ being much lower on a daily basis as well as cumulated over the entire seasons [5.1, 7.7]. A lower (diurnal basis) but significant photosynthesis by Faidherbia when cumulated over its leafy period (dry season) resulted in $GPP_{\_Lasslop}$ similar during the dry and wet seasons [-9.5, -9.9]. Note that most of crop biomass is exported and that NEP should be much closer to nil. Gapfilling and partitioning by ReddyProc.

Articles

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Projects, networks, partners

- Ongoing projects: SIIL-SIMCO (USAID), RAMSES II (EU-LeapAgri, ANR, AFD), DSCATT (Agropolis+Total Fond.), GLDC (CGIAR), CASSECS (EU-DESIRA), ENCAS (EC2CO); SOCA (Agropolis); SustainSahel (EU-H2020)
- Targeted networks: FLUXNET 2015 (« Sn-Nkr »), AMMA-CATCH, SEACRIFOG, SOERE-ANAEE, ICOS, ECOSTRESS (NASA)…
- Some partners: GET, HSM, LSTM, SELMET, INRA-Bordeaux, U. Copenhagen, U. Lund, UC DAVIS, IPGP, IEES…

PhD Students

- ISRA/UCAD/CNRF: W. Faye (hydrology); E. Gaglo (Crop and landscape modelling); A. Ly (Lanscape soil C); F. Gning (roots and water); S. Sow (Tree+crop modelling with MAESPA + STICS); D.L. Diongue (water isotopes); O. Malou (SOC = f(pratiques culturales)); K. Sadio (SOM and manure); Y. Agbohessou (GHG Modeling);

MSc & Fellowships

- G. Demarchi; S. Diatta; K. Diouf; N. Crequy

Countries, Scientists and Institutions

- Sénégal: ISRA (LNRPV, CNRF, CRZ), UCAD (EDEQUE), UGB, U. Thiès, ENSA Thiès: Y. Ndour; L. Tall; D. Sanogo; M. Sokhna Sarr; C.O. Samb; Prof. S. Faye; O. Ndiaye; Prof. A. Kane; Prof. A.N. Fall; Prof. S.N. Sall
- Burkina Faso: INERA: J. Koala, J. Sanou; B. Bastide
- France: CIRAD , IRD, INRA, CNRS, CNRM, IPGP : O. Roupsard; C. Jourdan; F. Do; A. Rocheteau; D. Orange; L. Cournac; M. Duthoit; I. Bertrand; A. Audebert; J. Seghieri, L. Leroux; L. Chapuis-Lardy; C. Clermont-Dauphin; F. Timouk; L. Kergoat; C. Pierre; J.L. Rajot; G. le Maire; R. Vezy; S. Taugourdeau; P. Salgado; H. Assouma; E. Faye; K. Van den Meersche; D. Masse; P. Moulin; A. Albrecht; V. Delaunay; R. Lalou; L. Fleury; V. Soti; F. Gangneron; M. Grippa;
- A. Le Quéré; T. Wade; C. Peugeot; K. Assigbetse; R. Manlay; C. Coillot; K. Telali; V. Lesur; N. Leroy; M. Vallee; S. Lewicky-Dhainaut; L. Vidal; I. Henry; J-L. Chotte; J.P. Laclau
- Scandinavia: U. Copenhagen + U. Lund: R. Fensholt; J Ardö; T. Tagesson; A. Raebuild
- USA: UC DAVIS: R. Hijmans

Take-home message

- 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+λE+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.

Thank you !!!

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