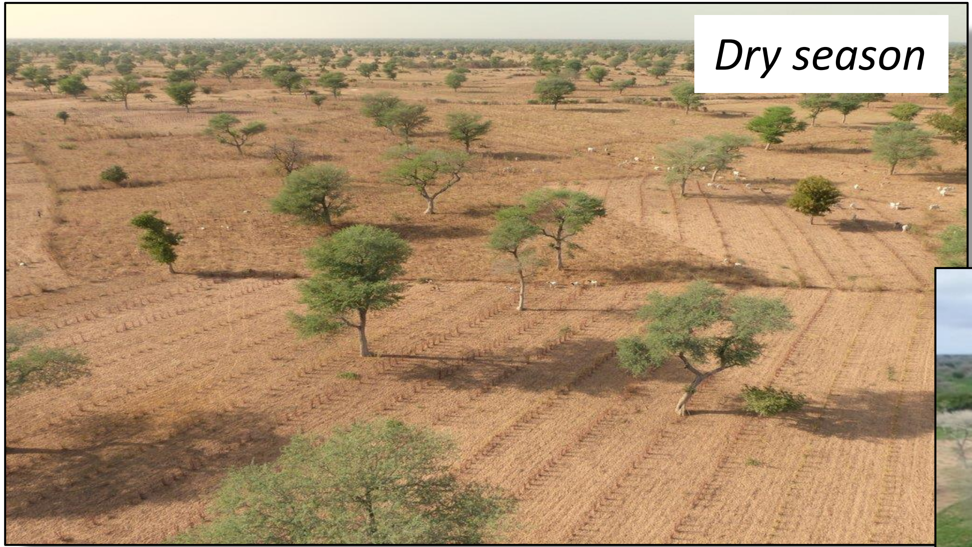
"Faidherbia-Flux": A long-term Collaborative Observatory on food security, GHG fluxes, ecosystem services, mitigation and adaptation in a semi-arid agro-silvo-pastoral ecosystem (groundnut basin in Niakhar/Sob, Senegal)



Web site: AGRAF / Faidherbia-Flux:
http://agraf.msem.univ-montp2.fr/Senegal.html

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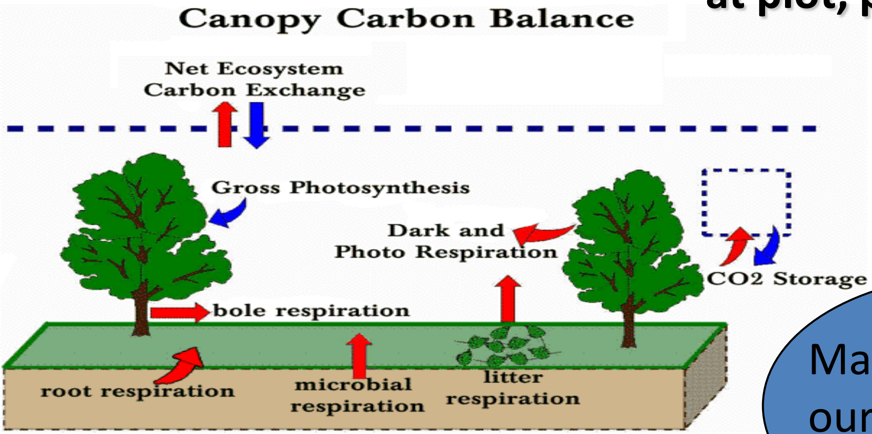
Aims

- To foster agro-silvo-pastoralism and sustainable intensification research, through a Collaborative & highly instrumented Observatory
- To run the Observatory on the long term (> 10 years), through projects
- To assess ecosystem services, NPP, GHG (CO_2, H_2O, N_2O, CH_4) fluxes and balances, 4‰, crop yield (millet, groundnut, cowpea…), the role of livestock, the effects of management options …

Our Philosophy

- We offer to mutualize efforts in one complex but representative ecosystem;
- Any scientist, student, institution, NGO… can apply;
- Complementarity and facilitation will be fostered, overlaps will be minimized;
- Outcomes include high-level trans-disciplinary research, common projects, training, networking, international visibility…

Our approaches: Monitoring + Modeling
of fluxes, balances and ecosystem services at plot, plant and soil levels



Main research at our study sites

Carbon cycle

- Carbon sequestration
- Main fluxes (GPP, respiration, ANPP, NEP, C allocation)
- Dynamic of C stocks (soils, biomass)

Water cycle

Evapotranspiration, stomatal regulation, dynamic of soil water content, water-use efficiency, watershed hydrology, root hydraulic redistributions, water isotopes

Nutrient cycles

Nutrient inputs and outputs, nutrients fluxes between ecosystem compartments, evolution of soil fertility, etc.

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.

Where?

- In the Niakhar Health-Population-Environment Observatory* (> 50 yrs of past research)

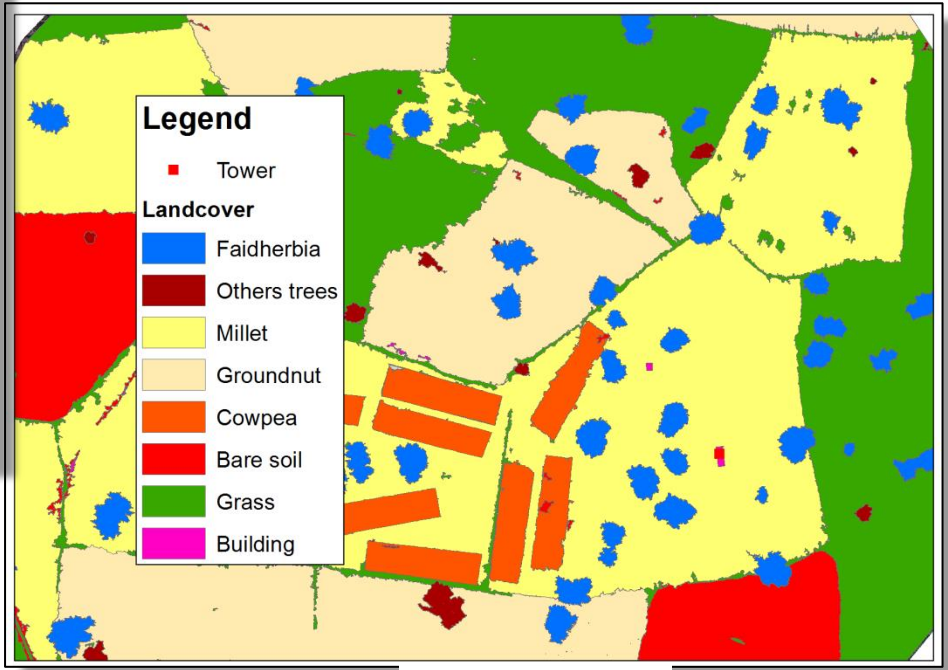
"Faidherbia-Flux" is here

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

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

Land Cover ?

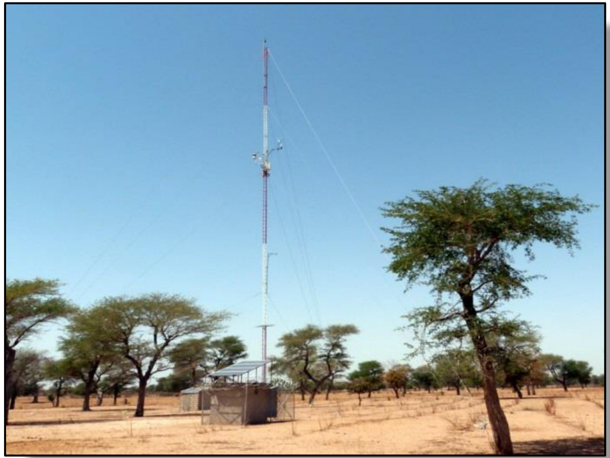
Drone Ortho-image
September 2018, wet season



Source: Emile Faye (CIRAD)

eCognition®

Equipments ?



3 eddy-covariance towers

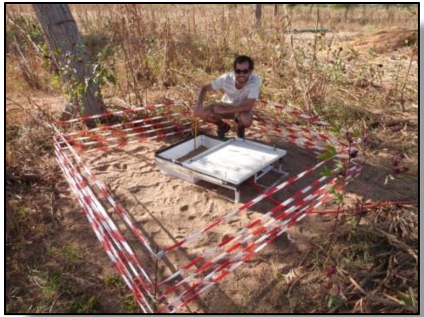
Olivier Roupsard; Laurent Kergoat; Franck Timouk; Manuela Grippa

6 Wells for deep roots and soil monitoring

Christophe Jourdan; Alain Rocheteau; Didier Arnal; Frédéric Bouvery

Sap flow, hydraulic redistributions, ecohydrology

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



Soil GHG balance

Maxime Duthoit; Karel van den Meersche

Net Primary Productivity

- From the database of the Observatory:

-F. albida surveys since 1965 and FA database (R. Lalou, V Delaunay, N. Montes)

- F. albida allometric relationships: (MSc MJ Rodriguez, 2015)

- F. albida survey of circumferences in 2015 by LPED Marseille (N. Montes)

- 2018, 2019:

-32 Faidherbia trees monitored for girth, LAI on a 10-day periodic basis. GIS of tree dimensions measured in the field and on high resolution images (G. Demarchi, Seydou Diatta)

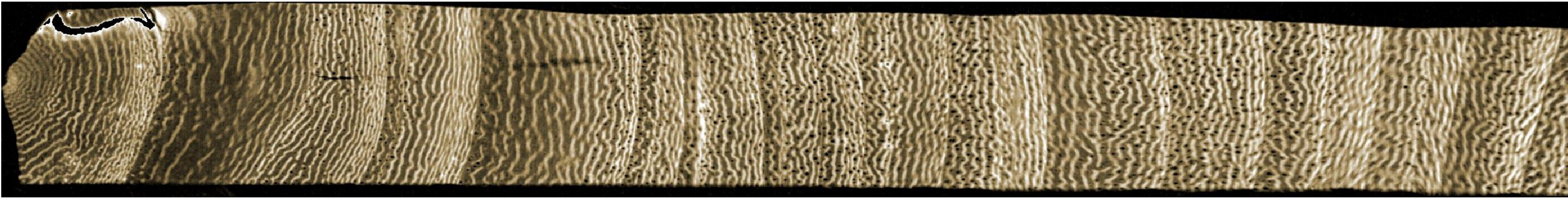
-Drone flights in RGB, NIR and TIR, 3D reconstruction of tree crowns with very high precision (A. Audebert and E. Faye)

-Millet and groundnut harvest (C. Clermont)

Dendrochronology: S. Diatta; C.O. Samb; R. Marchal; J. Gérard, D. Dougba; J. Ruelle

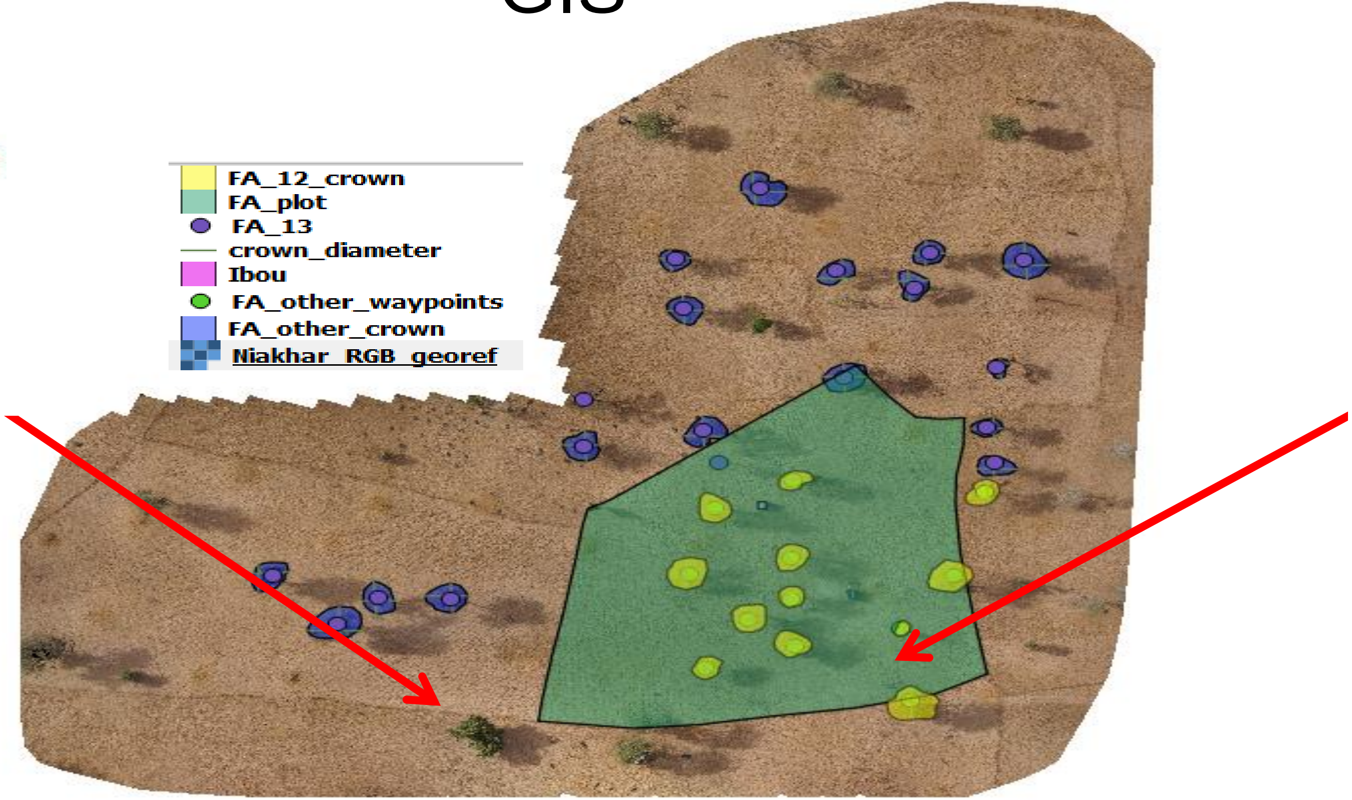
- 10 discs sampled from recently fallen/dead *Faidherbia* trees

- Ring analysis in INRA-Nancy and CIRAD (BioWooeb)



GIS

SIMCO Trial

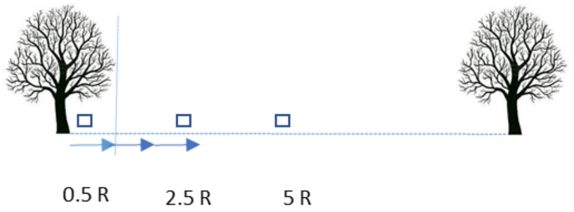


Tower plot = 1.24 ha

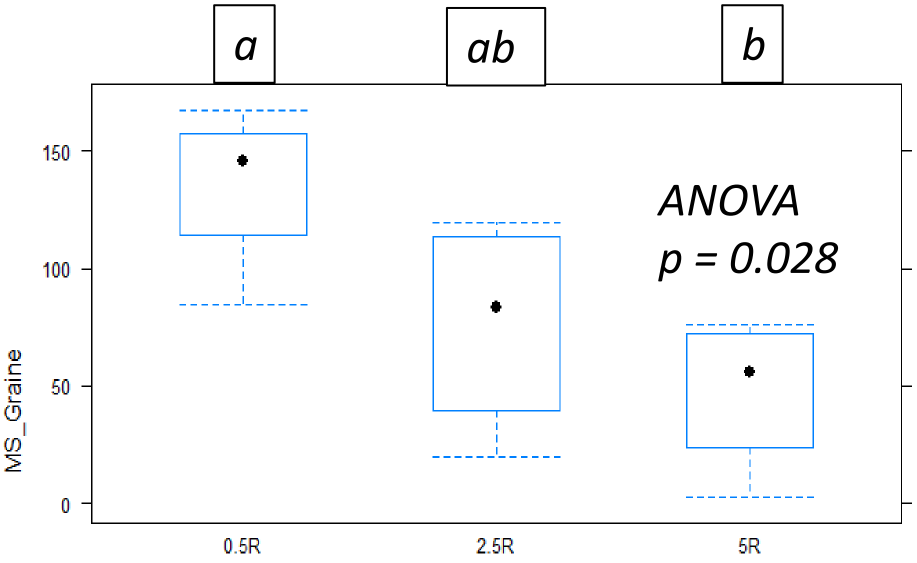
Scale:100 m

Orthomosaic of the 1.24 ha experimental plot, with the position of the Faidherbia (FA) trees. Mosaic image from UAV (drone) flight in May 2018 (A. Audebert and E. Faye). GIS from Demarchi G., Adama Ndour, Y. Agbohessou

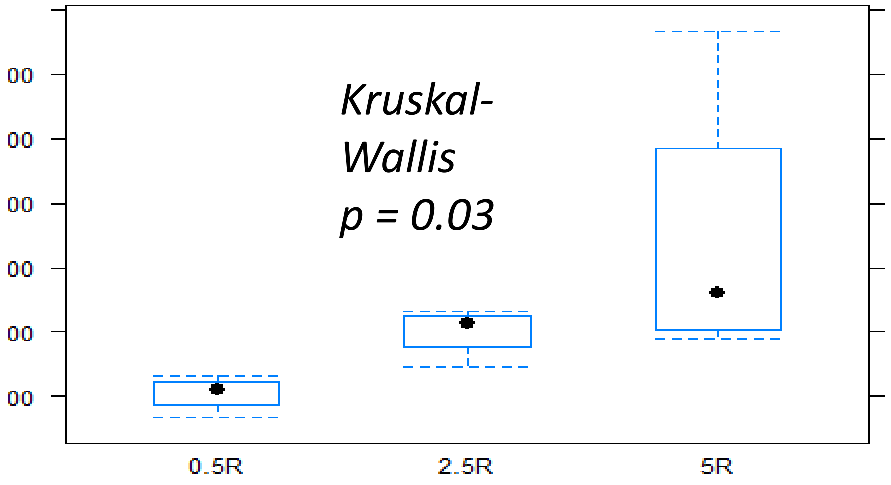
How much are the "*Faidherbia* effects"?



Millet yield (DM_grain, g m^{-2})



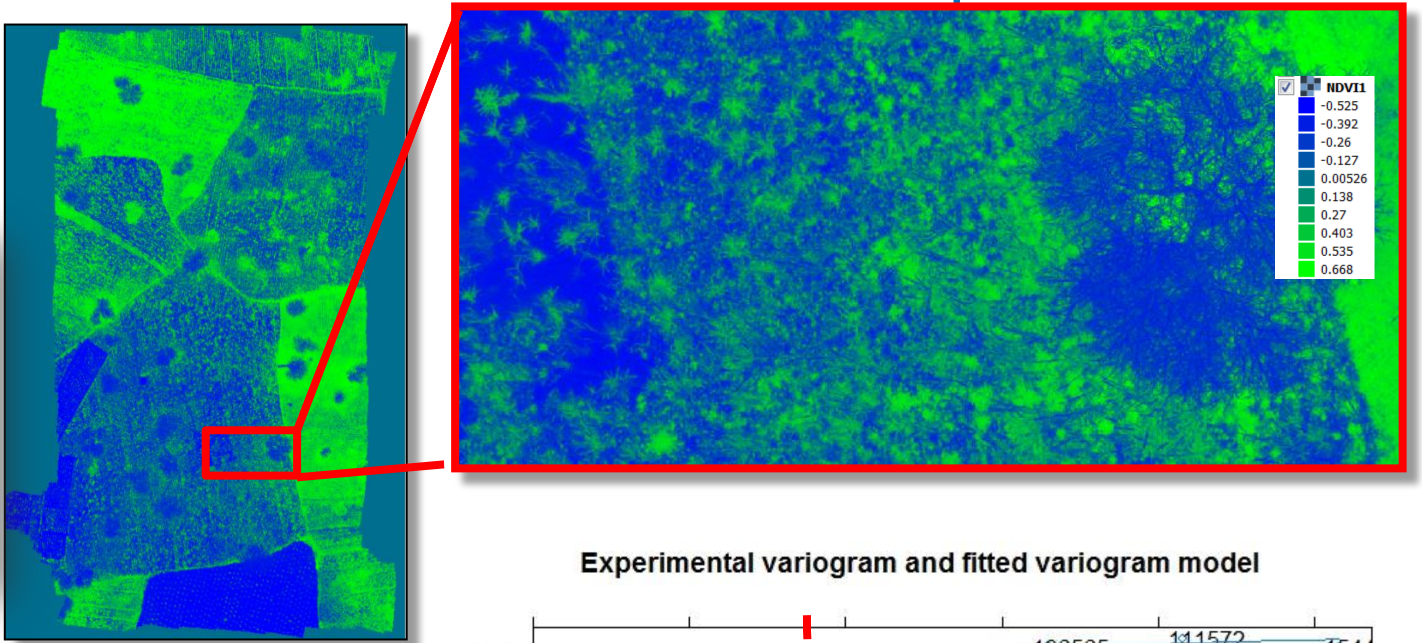
Weeds_aerial biomass (ADM, g m^{-2})



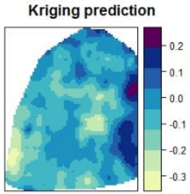
All other positive effects on biomass per compartment and LAI are significant

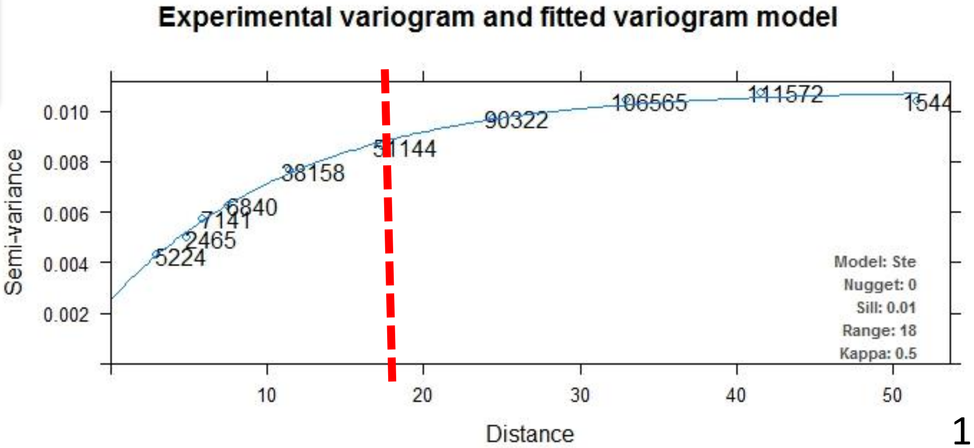
Effects on root:shoot, SLA, impact of leafminer are NOT significant

How far do trees benefit to crops ?



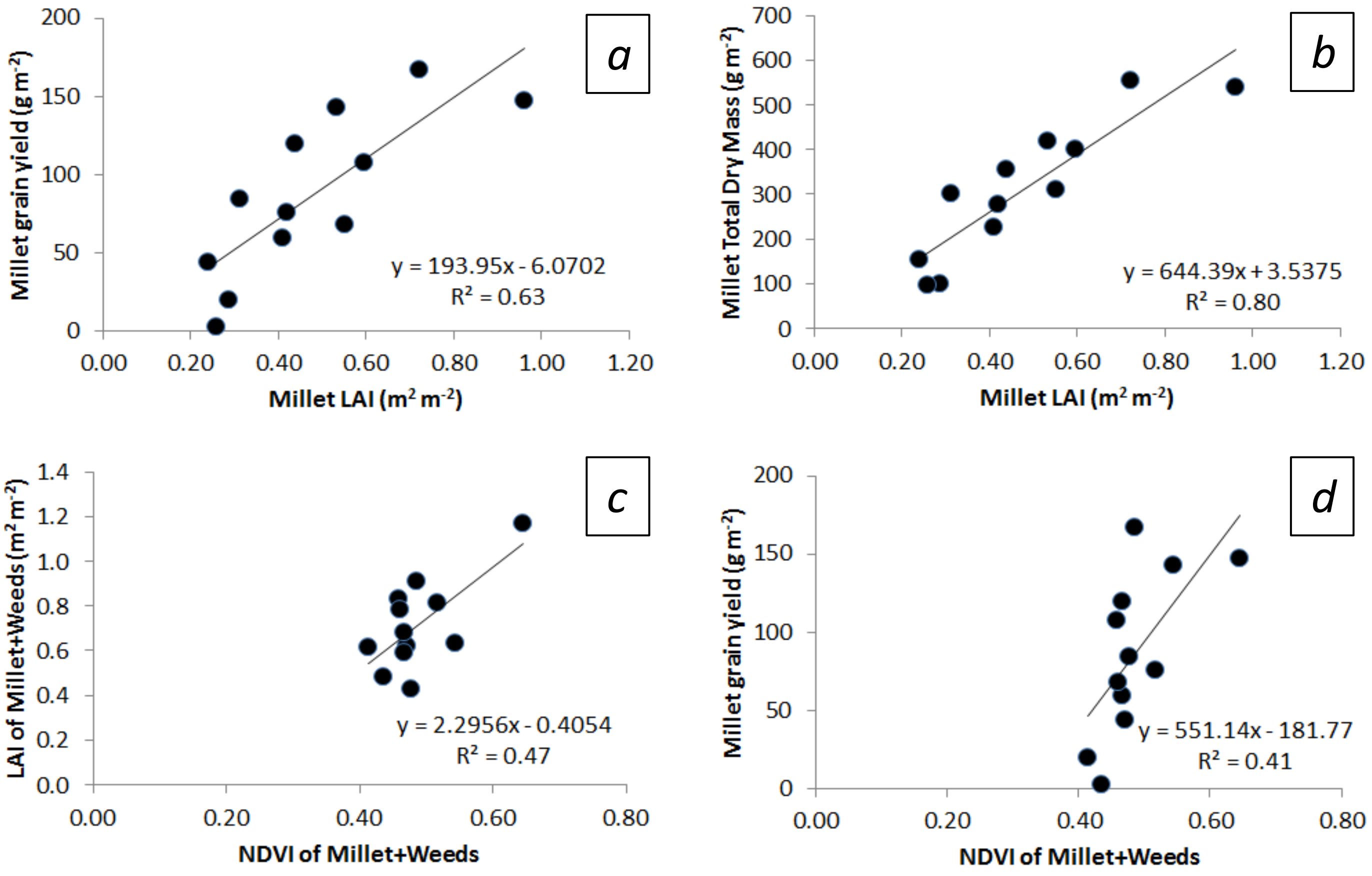
Drone NDVI October 2018, just before harvest





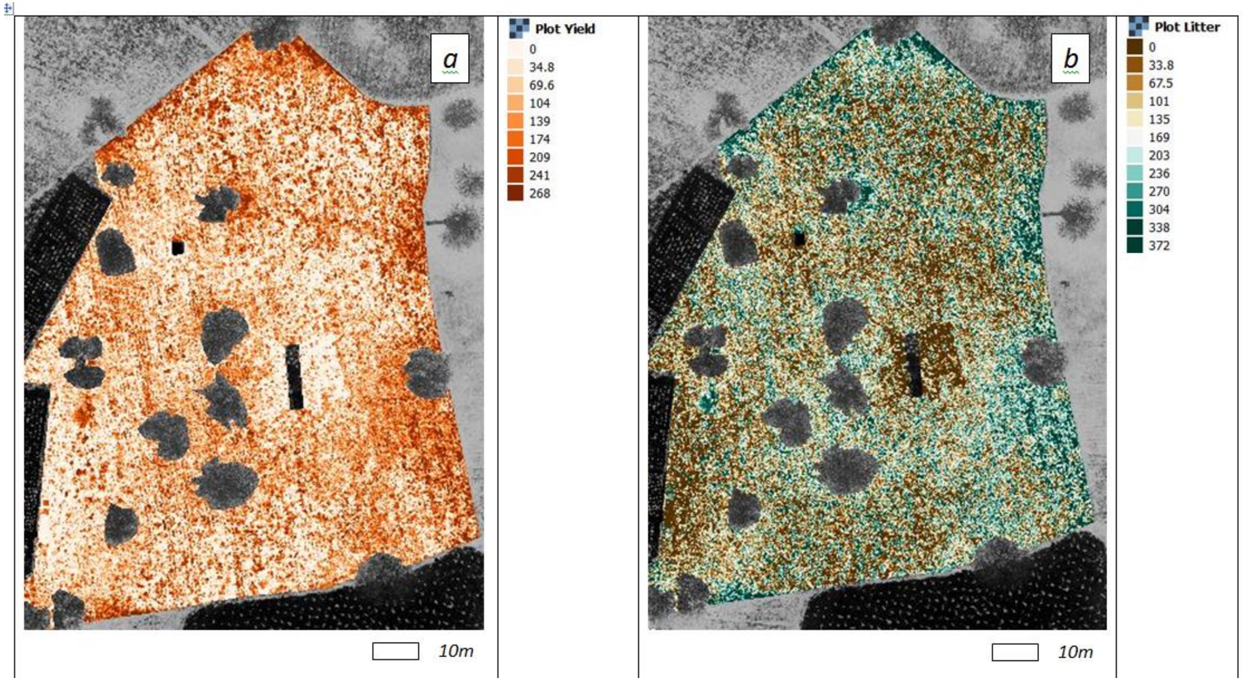
Source: Alain Audebert (CIRAD); Adama Ndour (ISRA/CERAAS)

Can we upscale yield from small plots to the whole stand ?



NB: this NDVI model of yield is just preliminary. To be completed further with other indices, CIgreen, CIgreenRedEdge, gNDVI, Surface temperature, etc.

Using UAV (Drone) to upscale yield and litter C to the whole-plot



Maps derived from UAV vegetation indices calibrated with subplot sampling of biomass. a/ Plot millet yield map (g_{grain} m^{-2}); b/Plot millet + weeds litter map (g_C m^{-2})

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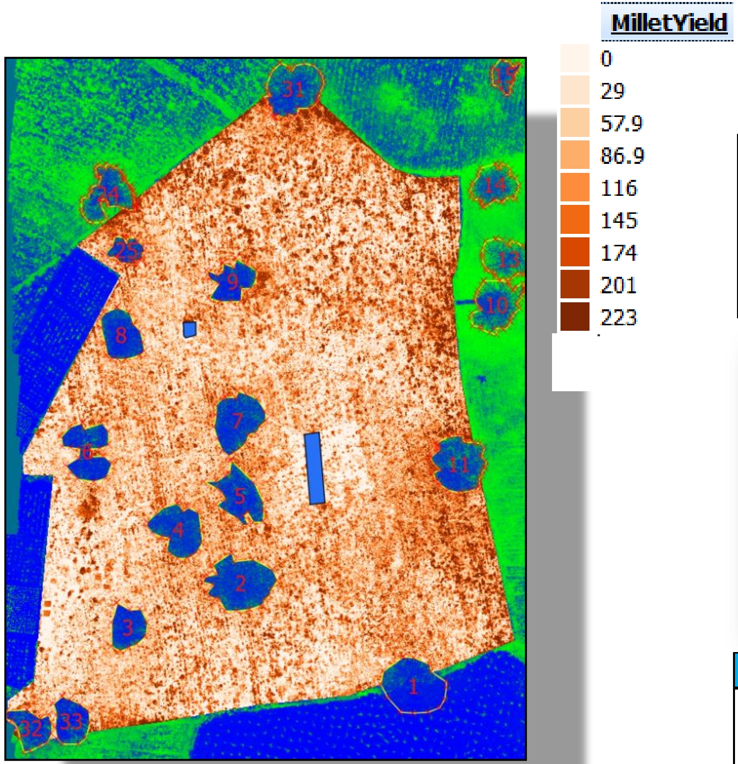
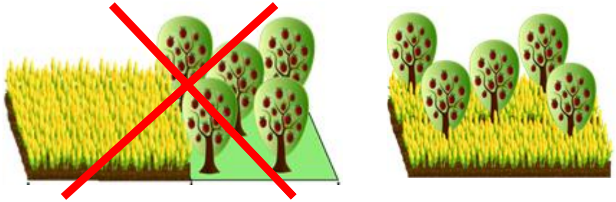
A new method to estimate whole-stand yield and LER (with drone & without sole crop field)

Millet yield



Millet yield map (DM_grain, g m^{-2})

Method	Variable of interest	Value	Unit
Measured	Whole Plot harvest	632.0	kg DM grain
NDVI (Estimated)	Estimated Whole Plot harvest	747	kg DM grain
Measured	Measured Whole Plot Yield	0.73	t ha^{-1}
NDVI (Estimated)	Estimated Whole Plot Yield	0.84	t ha^{-1}

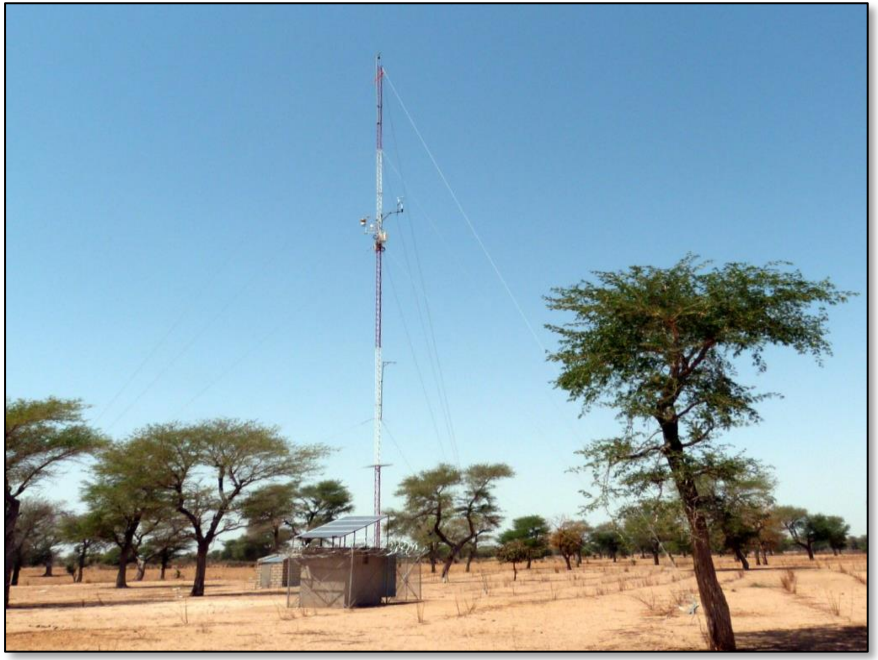


$$LER_{(millet\ only)} = \frac{Yield_{AFS}}{Yield_{sole}}$$

Method	Variable of interest	Value	Unit
Measured	Millet yield in Full Sun	0.48	t ha^{-1}
Measured	Millet yield below Faidherbia	1.36	t ha^{-1}
Measured	Measured Whole Plot Yield	0.73	t ha^{-1}
LER	Land Equivalent Ratio (Millet only)	1.52	

3 Eddy Covariance antennas

1) Above the whole ecosystem



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

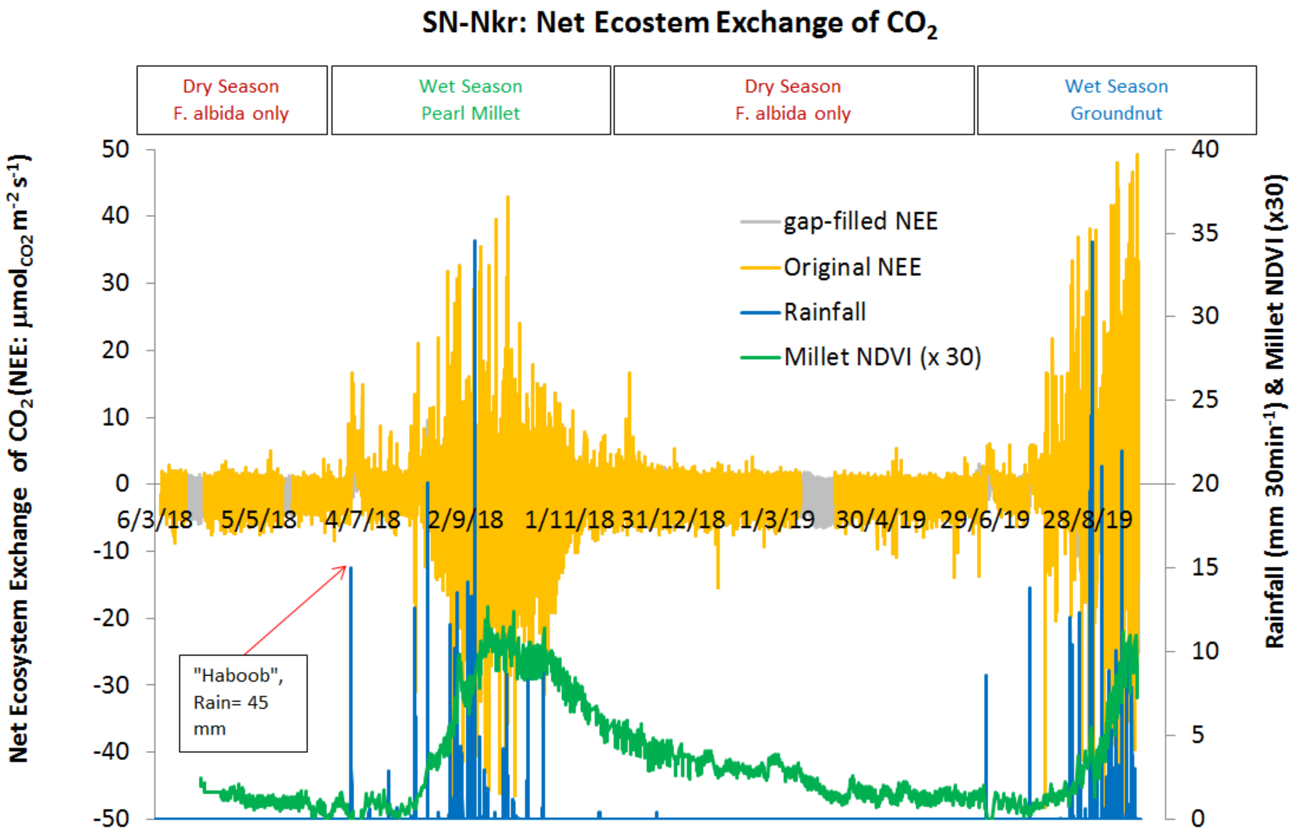
2) Above Millet

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

Fluxes above millet, below tree crowns: 4.5 m high

3) Above Groundnut

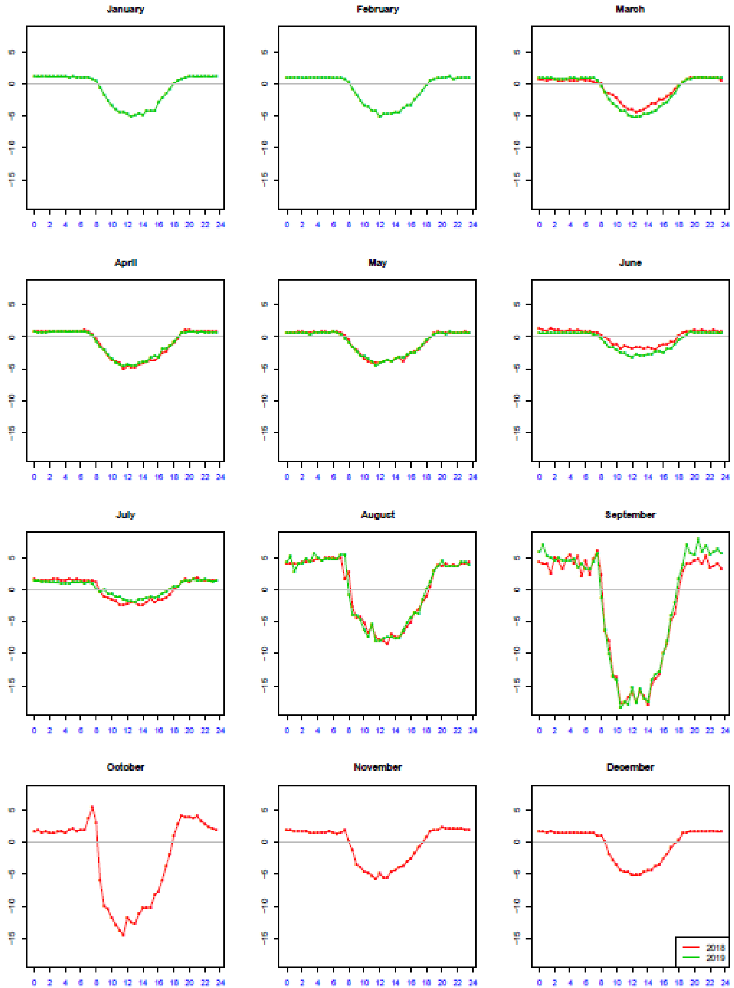
CO_2 fluxes



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 10 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 "Haboob", a large CO_2 burst was recorded with slow decay during more than one week or so. Other CO_2 peaks in July correspond to smaller rain events. Early August, millet NDVI took off, followed by a large CO2 uptake, but also ecosystem respiration. After millet harvest, gas exchanges started to decline. Then the system resumed to dry season behavior again.

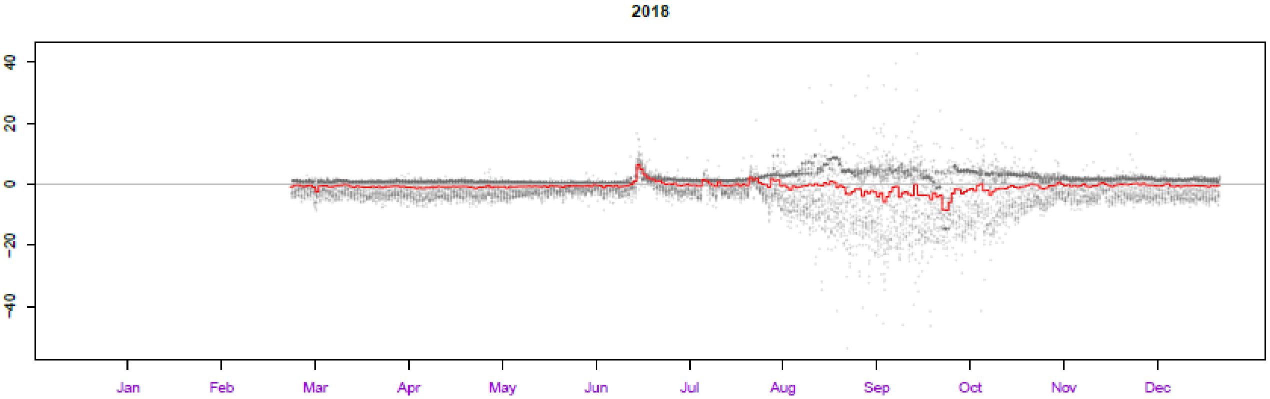
[Fluxes filtered out for wet sensor, Planar-fitted, WPL and spectral corrected, quality checked. Gaps are due to power failure. Grey dots are from gap-filling according to Lasslop et al. (2010)]

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



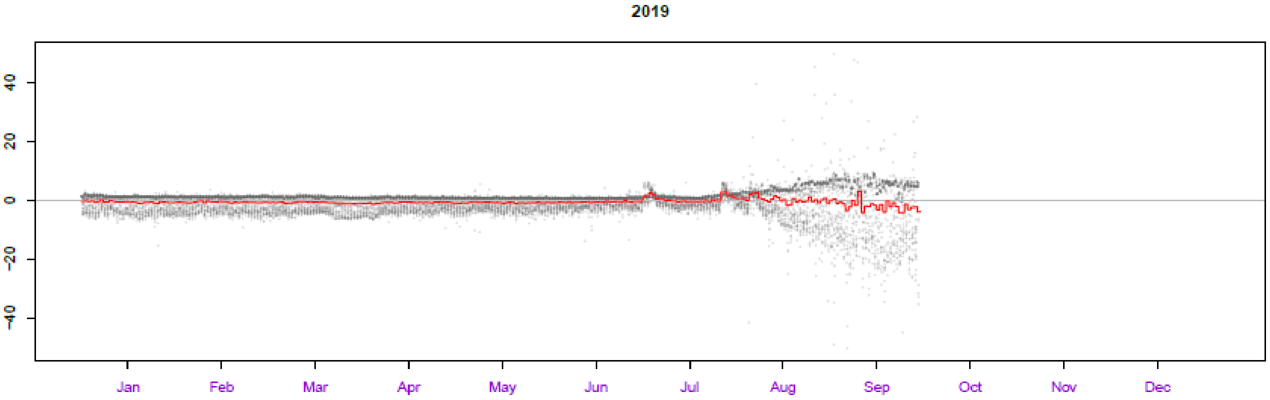
Monthly average of net ecosystem CO_2 exchange (NEE) diel course. During the dry season (November to July), the C uptake was due to *Faidherbia* only, and the ecosystem respiration (Re) at night was small. During the wet season, note sharp increase of C uptake (negative values during the day) and also Re, due to the re-greening of the crop system. Note apparent C uptake at night in September, to be confirmed. The 2 years look consistent.

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



2018

Wet season with Millet

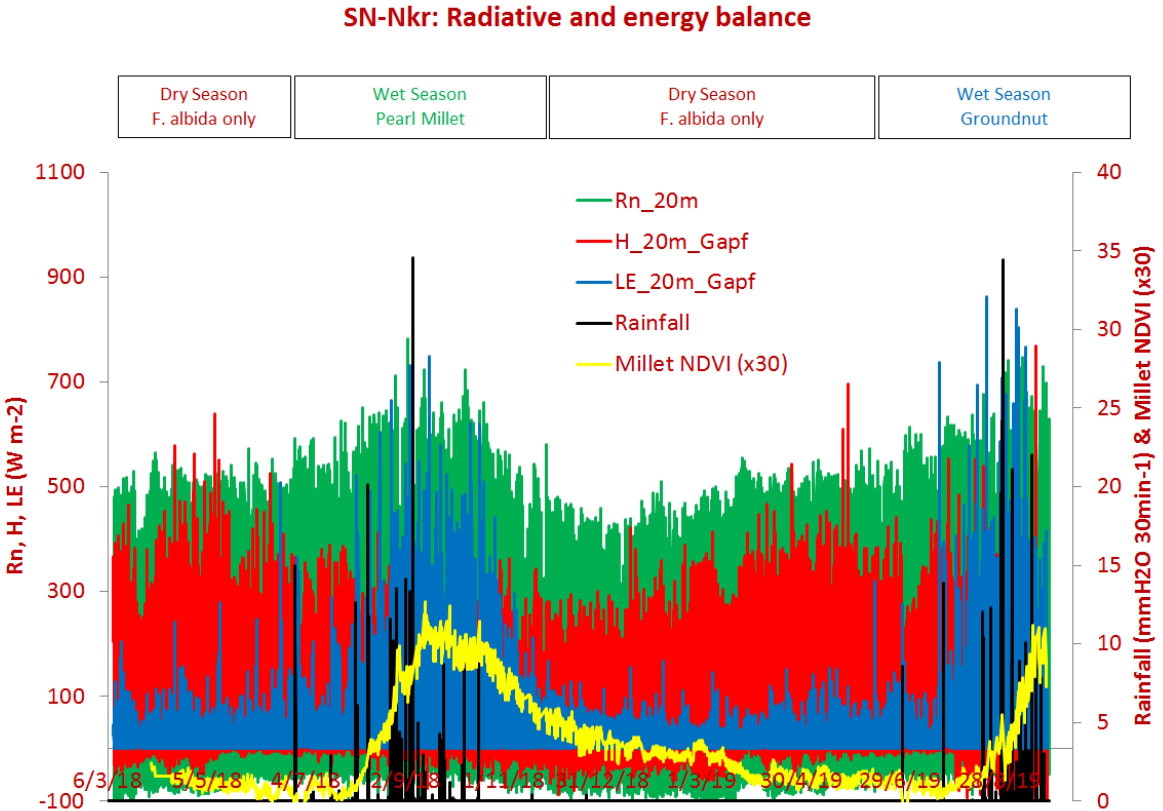


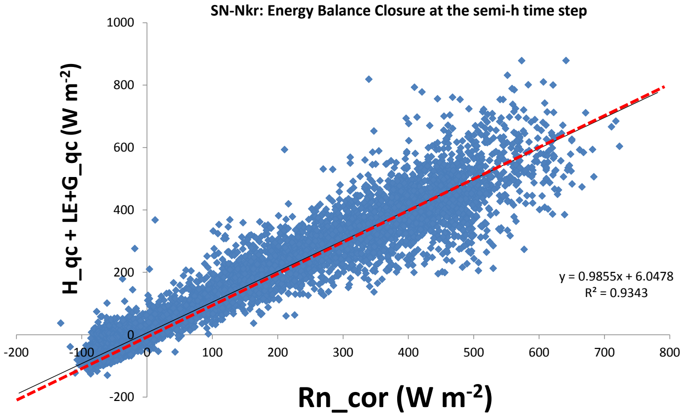
2019

Wet season with Groundnut

Daily sums of NEE (red line) during the dry season are around -0.01 gC m^{-2} day^{-1}, i.e. very close to nil in conditions where the canopy cover by *Faidherbia* is less than 5%. Then large CO_2 efflux after the “Haboob” and small replicates during rain events. Net flux becomes important from August to October, during the wet season, then decline again. The net balance is a capture.

Energy balance and evapo-transpiration

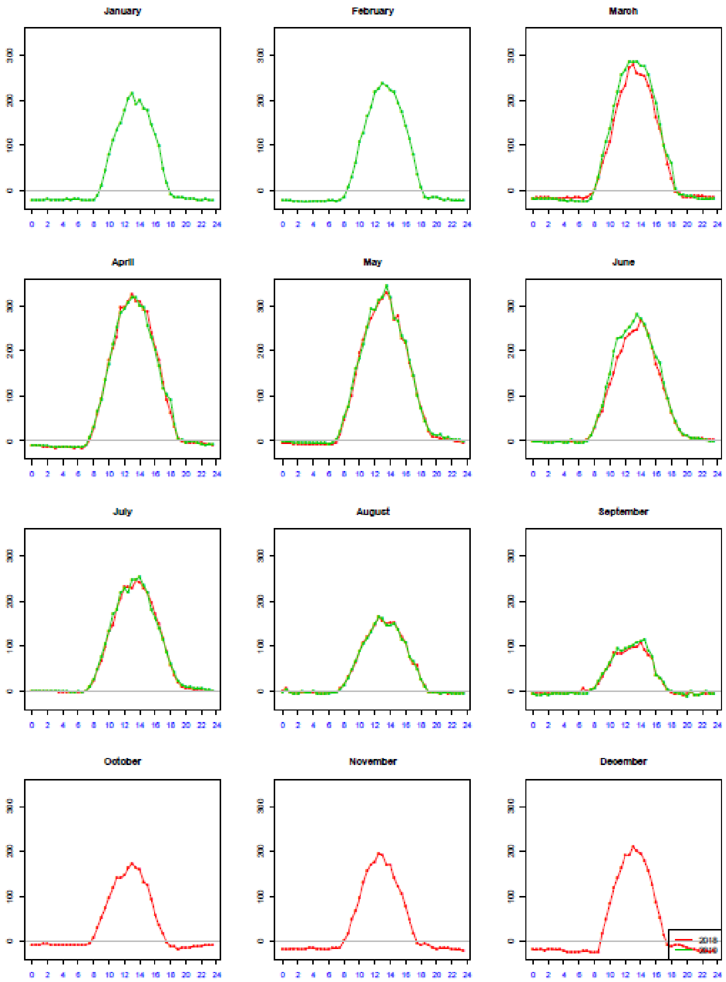




Net radiation (Rn) peaks around 800 W m^{-2}. During the dry season, most of this energy (350 W m^{-2}) is dissipated through heat (H), given that the soil is bare (with exception to the *Faidhernia* trees). There is very little evapo-transpiration (LE: 50-100 W m^{-2}), originating from Faidherbia trees mostly. After the "Haboob", note the inversion of H and LE fluxes (drop of the bowen ratio). 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 Lasslop et al. (2010).

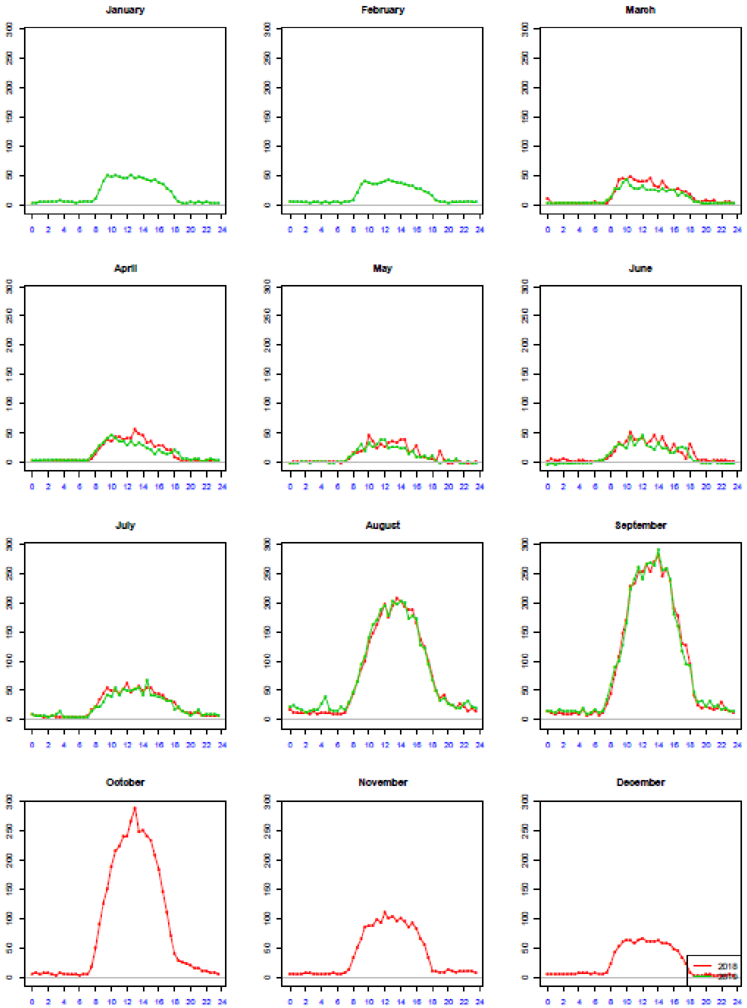
The semi-hourly energy balance closes at 99%, when the soil heat flux is included. The regression is tight.

Diurnal course of H (W m^{-2})



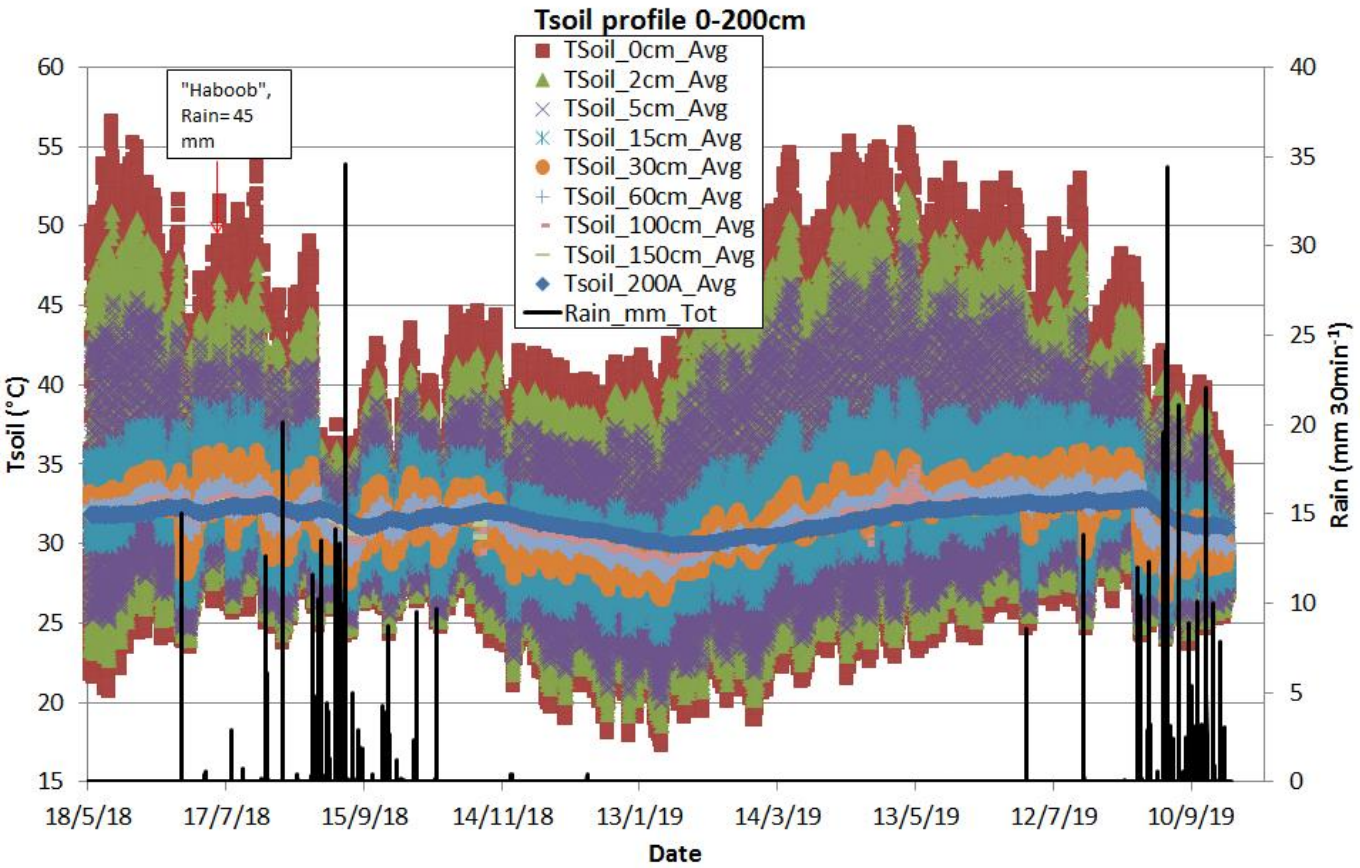
Monthly average of H diel course. The maximum during the dry season was achieved in April. In June, H night values are close to nil. Note H drop after the "Haboob" in late June. In August-September, note sharp decrease due to the re-greening of the system, reduction of soil heat flux and reduction of the bowen ratio /LE. In October, H starts to esume.

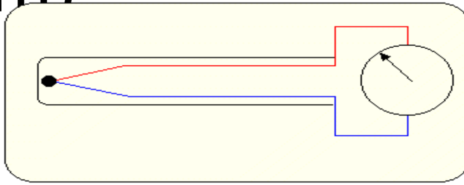
Diurnal course of λE (W m^{-2})



Monthly average of LE diel course. The maximum of the dry season was achieved in April when LAI of *Faidherbia* was maximum too. In June, LE becomes lower. In August-September, note sharp increase due to the re-greening of the crop system. From October, LE drops again, to the benefit of H. The 2 years look consistent.

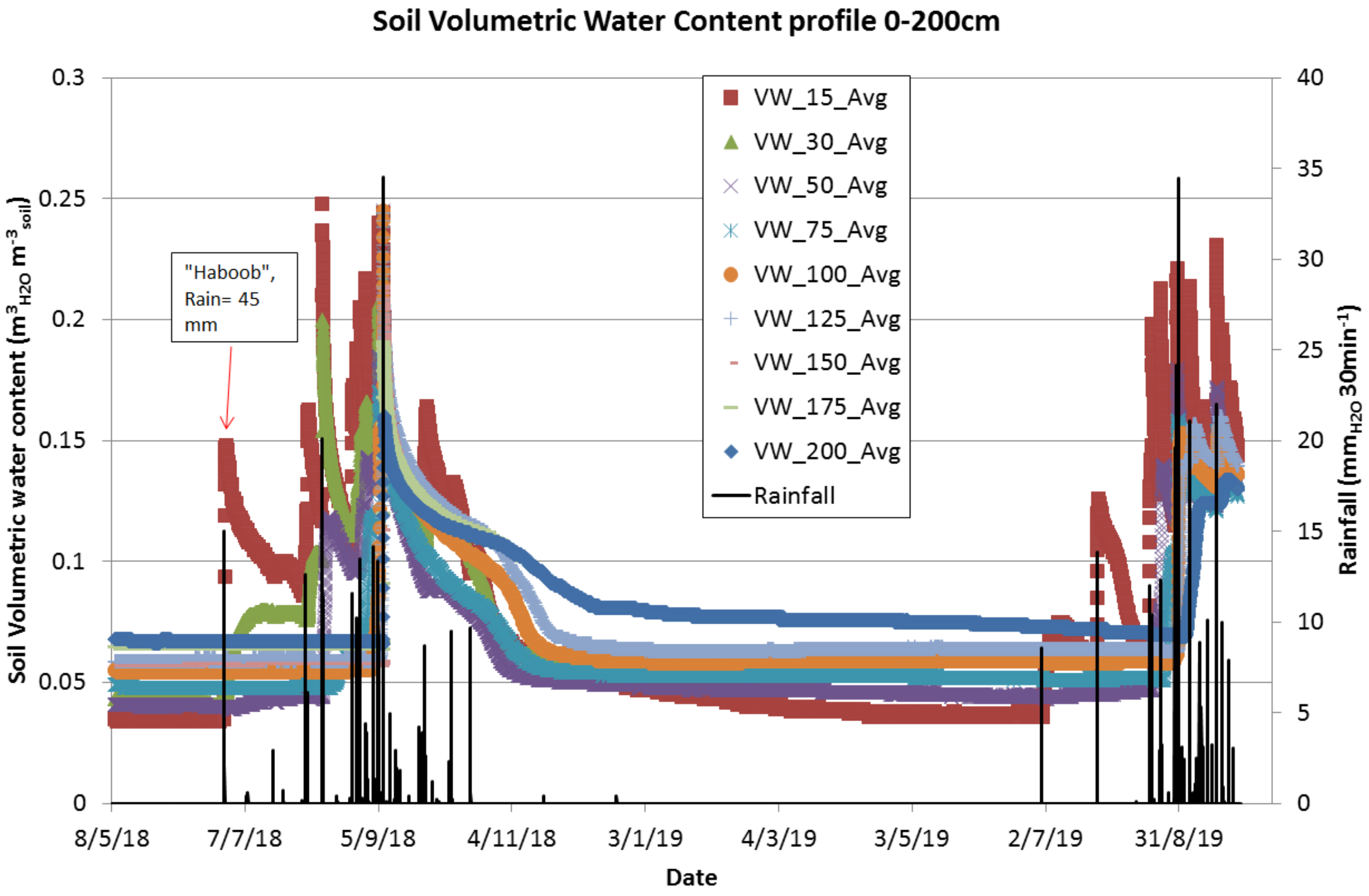
Soil temperature profile (0-200 cm)





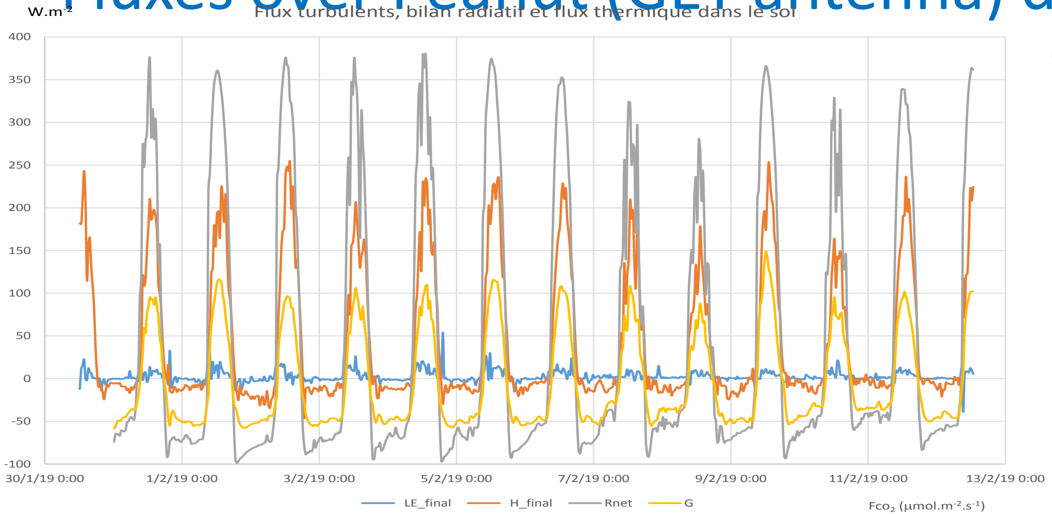
Soil temperature dynamics according to depth (0-200 cm). At 0 cm, Tsoil shows large (37°C) diurnal magnitude between 20°C at dawn and 57°C around noon. Deeper, the magnitude decreases progressively, until 150 cm where Tsoil is stable all year long at ca. 32°C. Note time shift between maxima, from surface to deep layers. Soil temperature drops in upper layers during the wet season.

Soil Moisture TDR profile (0-200 cm)

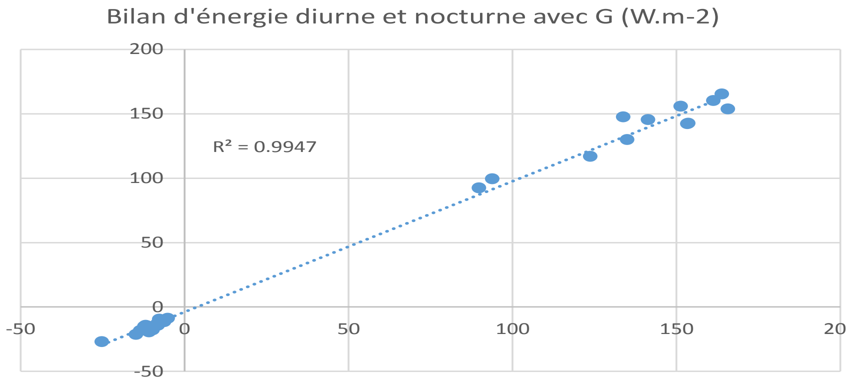


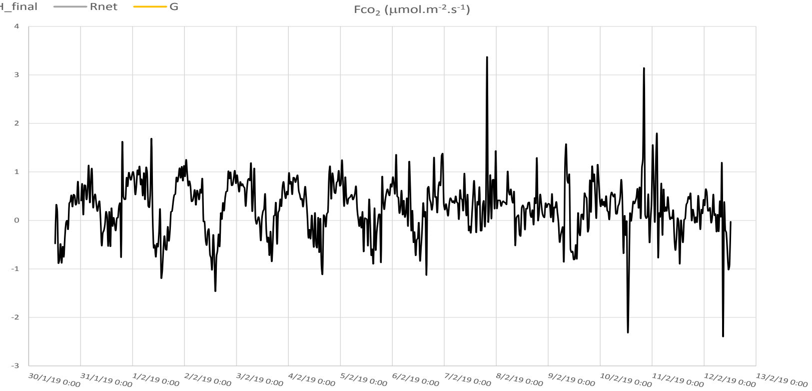
Soil moisture dynamics according to depth (0-200 cm). Values during drought started 3.5% (15 cm) and 6.7% at 200 cm. After the "Haboob", values in the 0-30cm soil layer increased to 15%, then, after 24h, started to flow into the next layer. Water reached deeper layers, progressively. 25% could be the field capacity of the upper layers. NB, the TDR equations still need to be calibrated for this specific soil. The minima were slightly higher in 2019

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



Energy balance





CO2 fluxes

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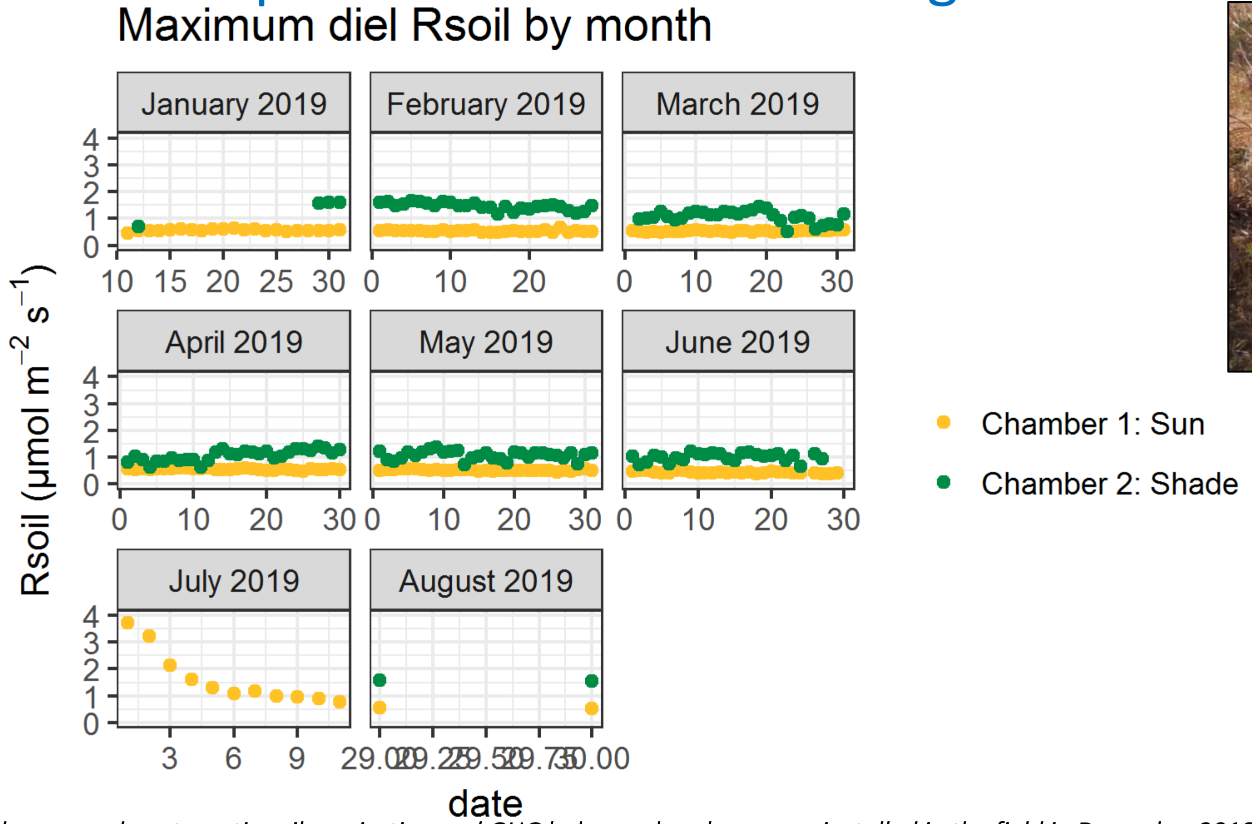
manuela.grippa@get.obs-mip.fr; fabrice.gangneron@get.obs-mip.fr;

Soil respiration and GHG exchanges with automatic chambers



2 home-made automatic soil respiration and GHG balance chambers were installed in the field in December 2018, under a Faidherbia tree (photo) and in full sun. Just before closing (every 30 min), each chamber measures ambient [CO2] nearby the soil level. After closing, [CO2] raises much faster under the tree than in full sun. Rsoil is computed from the slope. The maximum values of each day are presented here below the tree (green) and far from the tree (yellow). Due to heavy rainfall, the system broke down in August. Under repair.

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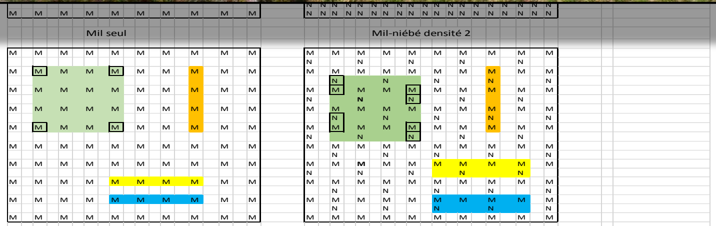
Modeling Millet & Cowpea with Stics from field trials



4 traitements
- Mil
- Niébé
- Mil/niébé densité 1
- Mil Niébé densité 2

2 fertilisations
- Avec fert. Minérale
- Sans fert. Minérale

Suivi Plantes
- Phénologie mil/ niébé
- Biomasse à 3 phases
- Mesure de LAI - 15 jours
- Nodulation/fixation
- Dynamique racinaire
- Rendements
- Exportations (N, P et K)

Suivi Sol
- Etat initial (Physico-chimie)
- Profil de N minéral (3-5 fois)
- Humidité du sol – 15 jours
- Autres parametres/fréquence sur le site de Sob

Suivi Météorologique
- Température
- Puviométrie
- Rayonnement
- Autres paramètres sur le site de Sob

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Root phenology in shallow soil and pits deep down to the water table

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Mini-rhizotrons in Millet – Cowpea; Automatic root scanners

- Root traits (SRL, RLD, …)
- Root dynamics
- Turnover – Litter

Three 8m-deep pits (down to the water table) + 3 shallow pits, ready to study interactions between soil and roots, comparing ‘under trees’ and ‘full sun’

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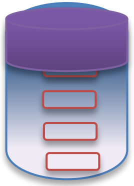
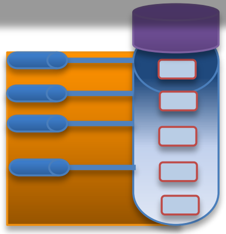
frederic.bouvery@inra.fr

Pits under construction. They now reach the water table (-8 m). Windows are equipped with automatic root scanners and TDR



Mycorhization
Traits, root dynamics
Turnover, root litters

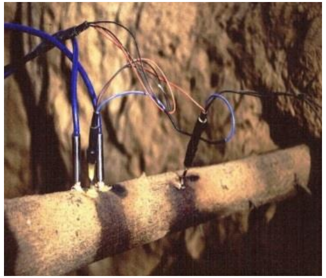


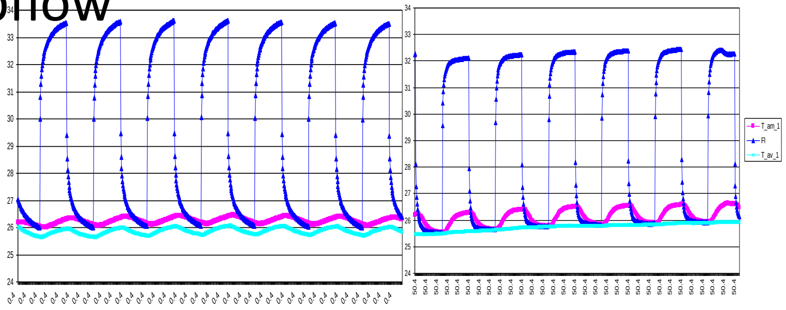
Root sapflow, root hydraulic redistributions
Nutrient fluxes, soil humidity (TDR)
Water istotopes, N…

SAPFLOW (directional) and Hydraulic Redistributions (HR)

Transient thermal dissipation sapflow

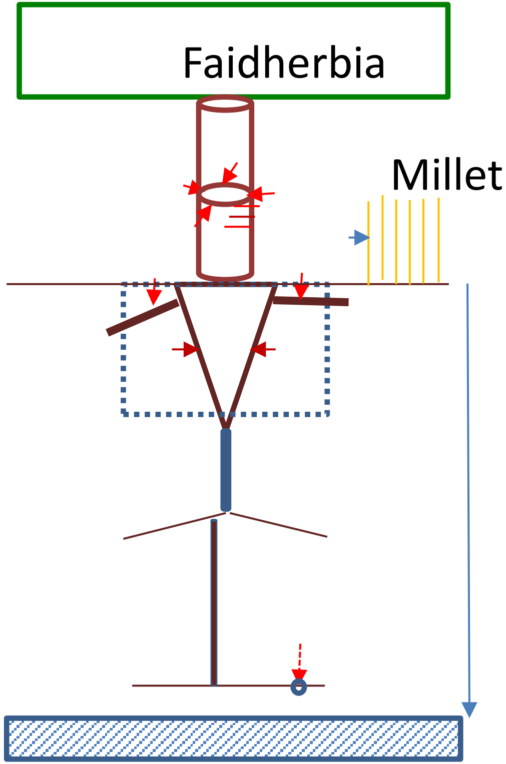
- Sapflow velocity
- Xylem water content and potential
- Directional sapflow





Zero flow

flow (2.5 l dm^{-2} h^{-1})



- Sap nutrient content

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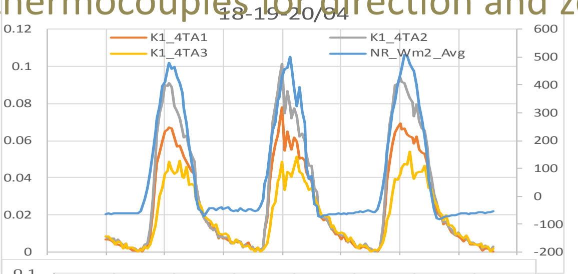
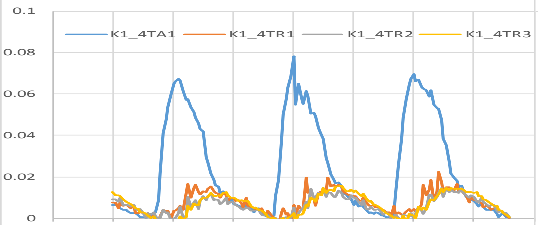
Tree transpirations and Root Hydraulic Redistributions by sap flow measurements

« Hydroseve »
Set up in April 2019

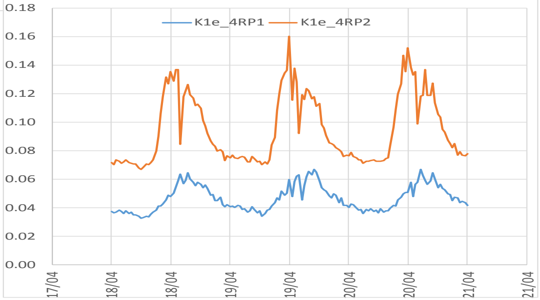
- 5 trees of growing size, representatives of the Faidherbia parkland
- 57 TTD flowmeter probes: trunks (azimutal, radial) roots (lateral,tap)
- 20 pairs of thermocouples for direction and zero flow assessment (roots)



Trunk azimuts with large variations



Trunk profile with quick flow decrease in the depth



Tap roots with high nocturnal upward flows

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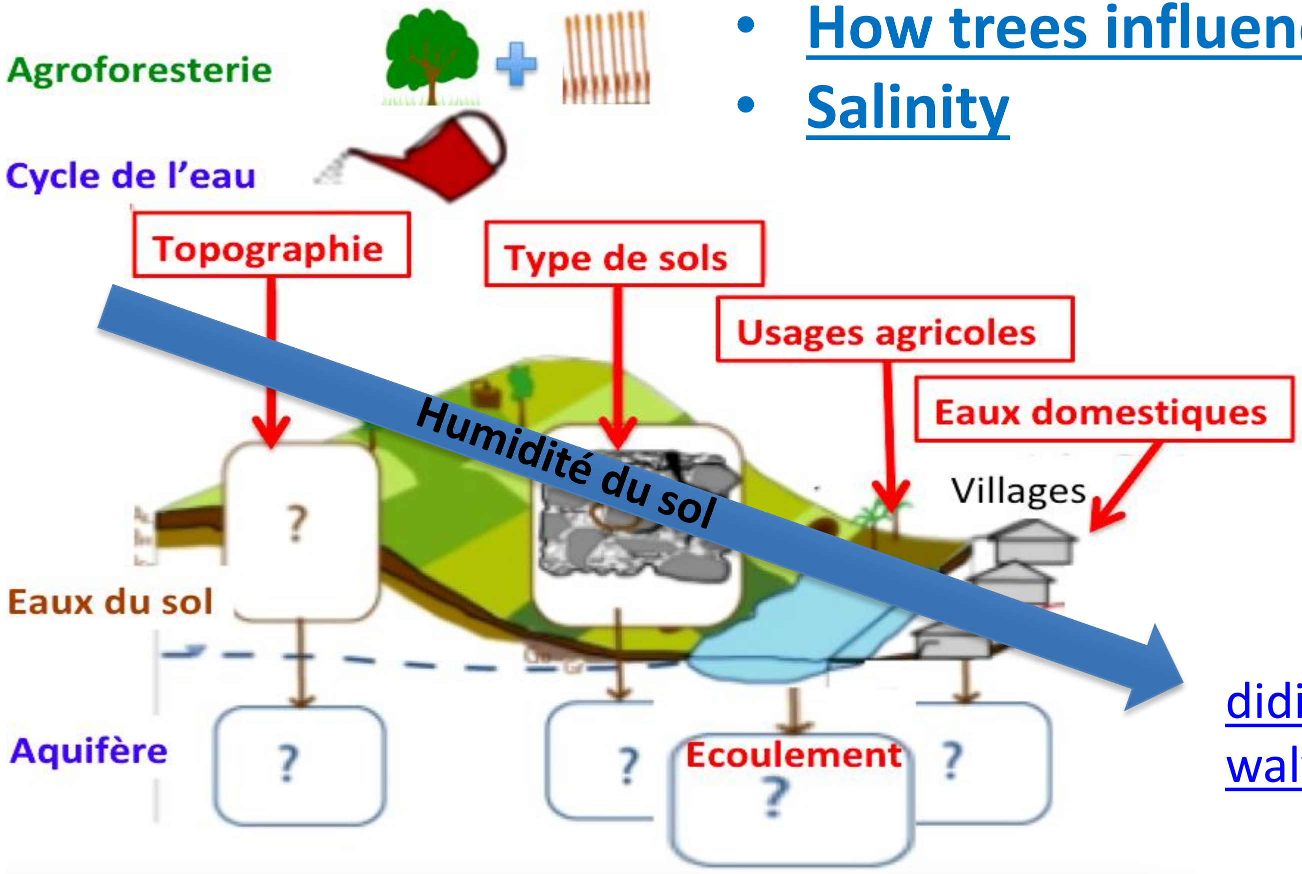
Ecohydrology

- **Watershed hydrology**
- **How trees influence hydrology**
- **Salinity**



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Communications

- Dangléant, C. et al., 2019. L’agroforesterie à la rescousse des cultures au Sahel. Video. In: World Congress of Agroforestry (Editor). CIRAD, France, https://www.cirad.fr/actualites/toutes-les-actualites/articles/2019/science/video-agroforesterie-au-sahel.
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- Roupsard, O. et al., 2019. “Faidherbia-Flux”: adapting crops to climate changes in a semi-arid agro-sylvo-pastoral open observatory (Senegal). Oral Presentation, 4rth World Congress on Agroforestry. , 20-22 of May 2019. Le Corum Conference Centre, Montpellier, France. Oral presentation. Session 2: Agroforestry and adaptation to climate change.
- 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.

Projects, networks, partners

- Ongoing projects: SIIL-SIMCO (USAID, U. Kansas, UC Davis), LeapAgri-RAMSESII (EU), DSCATT (Agropolis+Total Found.), GLDC (CGIAR), CASSECS(EU-DESIRA), ENCAS (EC2CO); SOCA (Agropolis)
- Targeted networks: FLUXNET 2015 (Sn-Nkr), AMMA-CATCH, SEACRIFOG, SOERE-ANAEE, ICOS, ECOSTRESS (NASA)…
- Some partners: GET, HSM, LSTM, INRA-Bordeaux, U. Copenhagen, U. Lund, UC DAVIS, IPGP, IEES
- …

PhD Students

- ISRA/UCAD/CNRF: W. Faye (hydrology); E. Gaglo (Crop 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))

MSc & Fellowships

- U. Montpellier: G. Demarchi; Y. Agbohessou; S. Diatta; N. Crequy

Scientists

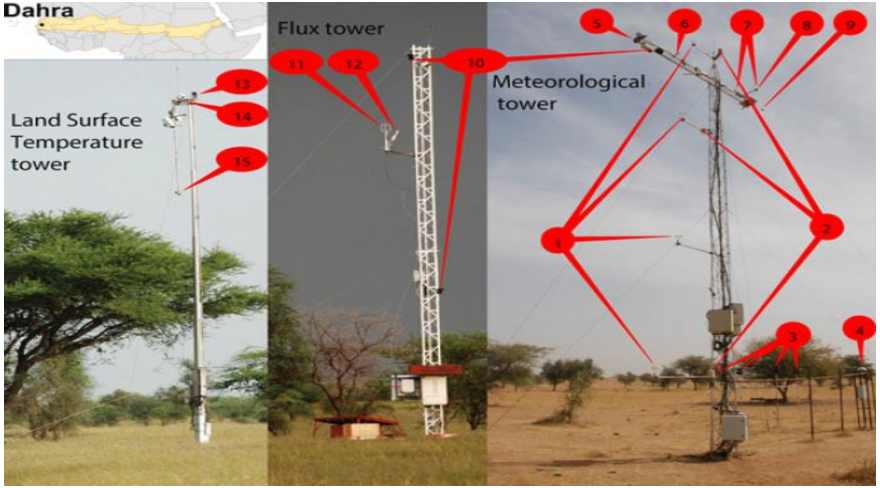
- ISRA (LNRPV, CNRF, CRZ), UCAD (EDEQUE): Y. Ndour; L. Tall; D. Sanogo; Mame Sokhna Sarr; C.O. Samb; Prof. S. Faye; O. Ndiaye
- INERA: J. Koala, J. Sanou; B. Bastide
- CIRAD , IRD, CNRS, CNAP, AgroParisTech , U. Montpellier, IEES: O. Roupsard; C. Jourdan; G. le Maire; J.P. Laclau; M. Duthoit; K. Van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

Complementarity with our Dahra colleagues (meeting in January 2018)

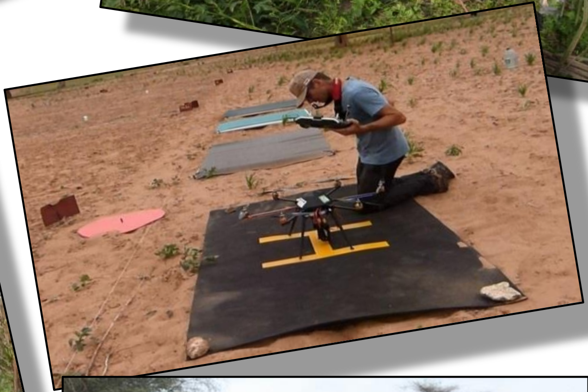
Faidherbia-Flux (agro-silvo-pastoral)

Dahra (silvo-pastoral): Tagesson et al., GCB, 2015

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



Thank you !!!



Web site: AGRAF / Faidherbia-Flux: http://agraf.msem.univ-montp2.fr/Senegal.html