# Modeling Greenhouse Gas Emissions from Sahelian Sylvo-pastoral Ecosystems

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AGU FALL MEETING
New Orleans, LA & Online Everywhere
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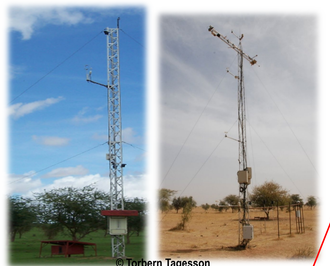
## BACKGROUND

- Pastoral farming in sylvo-pastoral systems remains a key activity for the local economy and food security in the Sahel. The impact of this type of farming on the carbon cycle and greenhouse gas (GHG) fluxes is not well documented.
- In these ecosystems, direct measurements of GHG emissions by soils are expensive, time-consuming and labor-intensive.
- Modelling studies can provide insights on the underlying processes as well as temporal and spatial variability of GHG fluxes allowing their quantification and estimation, from local-to-regional scales.

## STUDY AREA

### Location and site equipment



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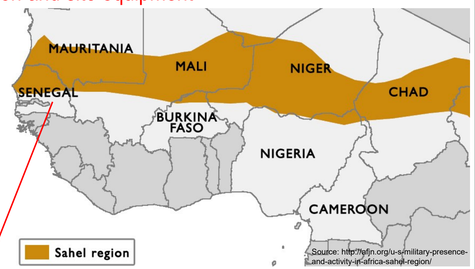
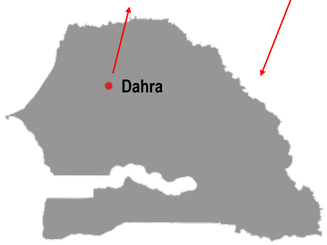



**Meteorological tower :**
- Wind speed sensors
- Air temperature and relative humidity sensors
- Rain gauges
- Radiometers (for incoming and reflected radiances)

**Land Surface Temperature tower:**
- Infrared temperature sensors (pointing at the sky, a tree crown, and a shaded grass patch.

**Flux tower:**
- Open-path $CO_2$/$H_2O$ infrared gas analyzer
- Anemometer
- Phenology cameras

### Climate and soil properties

| Date | Ann. Precipitation (mm) | Avg AirTemp 2m (°C) | Min AirTemp 2m (°C) | Max AirTemp 2m (°C) | Rainiest month | Wet season |
|---|---|---|---|---|---|---|
| 2012 | 514.83 | 28.39 | - | - | Aug. (173.90 mm) | Jun. – Oct. |
| 2013 | 355.15 | 28.69 | - | - | Sept. (115.25 mm) | Jun. – Oct. |
| 2014 | 331.75 | 28.57 | - | - | Aug. (150.80 mm) | Jul. – Oct. |
| 2015 | 270.60 | 28.80 | - | - | Aug. (131.60 mm) | Jul. – Oct. |
| 2016 | 367.55 | 29.15 | - | - | Jul. (165.64 mm) | Jul. – Sept. |
| 2017 | 399.55 | 29.06 | - | - | Aug. (173.35 mm) | Jul. – Oct. |
| 2018 | 295.32 | 28.44 | 22.26 | 35.18 | Sept. (162.60 mm) | Jul. – Oct. |
| 2019 | 355.20 | 28.76 | 22.36 | 35.67 | Aug. (163.45 mm) | Jul. – Oct. |
| 2020 | 529.25 | 29.93 | 23.20 | 36.15 | Jul. (209.28 mm) | Jul. – Oct. |

**Soil Properties:** % sand = 89, % Silt = 3.1, % Clay = 7.9, pH $H_2O$ = 6.4

## METHOD

### Simulation design

**Inputs**

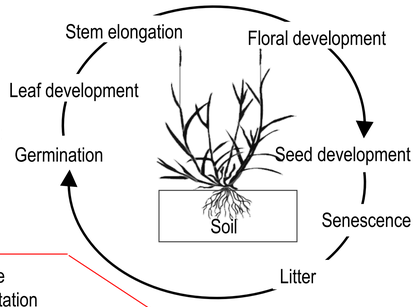
Weather :
- Precipitation
- Global radiation
- Air temperature
- Relative humidity
- Wind speed

Soil Parameters :
- Soil water content
- Soil pH
- Soil temperature
- Soil texture

Vegetation state:
- Initial values of state variables of the vegetation

Animal load :
- Livestock distribution
- Livestock service area
- Ingestion and degradation

**Forage grass growth cycle dynamic**




**Outputs**

Biomass variables e.g.
- Green biomass
- Dry biomass
- Litter biomass
- Root biomass
- Ground cover by biomass
- Microbial biomass …

Soil variables and fluxes e.g.
- Soil moisture
- Evapotranspiration
- Soil C, N
- $CO_2$ fluxes
- $N_2O$, NO fluxes…

Environmental variables
- List of variables under consideration

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Free grazing cattle

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Vegetation state in the wet season

### Coupled model STEP-GENDEC-$N_2O$

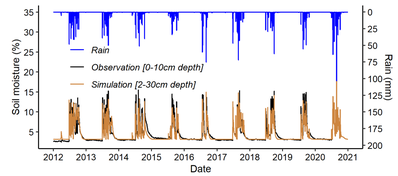
STEP (Mougin et al., 1995) → Biomasses, Soil moisture → GENDEC C/N (Moorhead & Reynolds, 1991) → Microbial biomass, $CO_2$ flux & Soil $NH_4^+$ → $N_2O$ flux (Bigaignon et al., 2020)

Acknowledgments: The projects CaSSECS- Carbon Sequestration and greenhouse gas emissions in (agro) Sylvopastoral Ecosystems in the Sahelian CILSS States (www.cassecs.org) and INSA- Integrated Nitrogen Studies in Africa (h2020-insa.aeris-data.fr)

References:
- Mougin et al.,: A Regional Sahelian Grassland Model To Be Coupled with Multispectral Satellite Data, I: Model Description and Validation, Remote Sens. Environ., 52, 181–193, 1995
- Moorhead & Reynolds,: A general model of litter decomposition in the northern Chihuahuan desert, Ecol. Modell., 56, 197–219, 1991.
- Bigaignon et al.,: Understanding $N_2O$ Emissions in African Ecosystems: Assessments from a Semi-Arid Savanna Grassland in Senegal and Sub-Tropical Agricultural Fields in Kenya , sustainability., 12, 21, 2020.

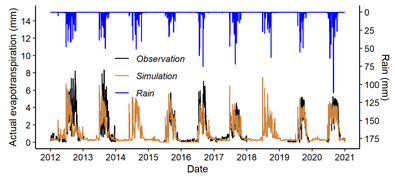
## FINDINGS

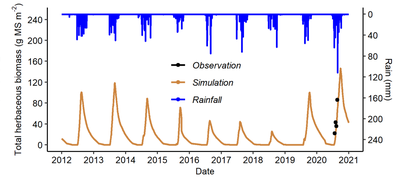
### Soil moisture




- The seasonal dynamics of soil moisture were quite well represented by the model.
- Simulated values were highly correlated to measured values ($R^2$ = 0.71 and RMSE=1.04%).
- The minimum and maximum thresholds correspond to the wilting point and the field capacity, respectively.

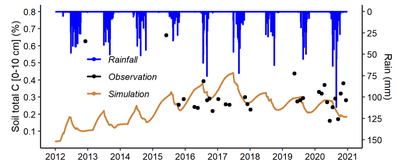
### Evapotranspiration and herbaceous biomass

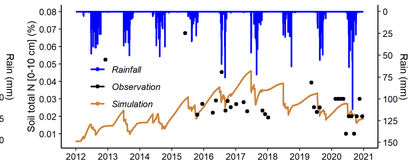



- Lower evapotranspiration simulated at the end of 2012 and 2013 wet seasons, can be explained by model calibration while simulating water balance. Soil evaporation has been reduced (by increasing ground cover) to keep water in the soil a bit longer at the end of the wet seasons in order to match the simulated soil moistures with measurements.
- In 2020, the four on-site measurements carried out during the season showed good agreement between the simulated and observed biomasses.
- In 2018, the amount of water needed by herbaceous plants for optimal leaf development and stem elongation was not available at the right time, resulting in a decline in total biomass production.

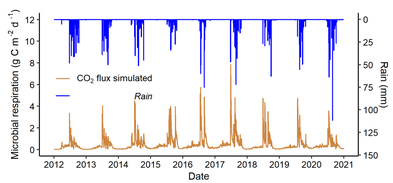
### Soil total C and N

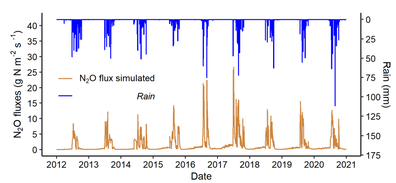



- The values obtained after soil analysis and the simulated values were consistent for both soil C and N.

### Microbial respiration and $N_2O$ fluxes




- Simulations show an impact of rainfall on the seasonal dynamics of $CO_2$ flux.
- Annual means range from 0.6 gC $m^{-2}$ $d^{-1}$ in 2012 to 1.11 gC $m^{-2}$ $d^{-1}$ in 2016.
- The temporal dynamics of the simulated $N_2O$ fluxes show a clear impact of precipitation on $N_2O$ emissions.
- Annual means range from 0.73 gN $m^{-2}$ $s^{-1}$ in 2012 to 2.58 gN $m^{-2}$ $s^{-1}$ in 2017.

## CONCLUSION

- Model outputs were consistent with in-situ validation data for soil moisture, evapotranspiration, soil mineral and organic N, soil C, and herbaceous biomass.
- The temporal dynamics of the simulated $N_2O$ and $CO_2$ fluxes clearly show a seasonal variation in fluxes due to precipitations.
- Simulations showed pulses of $CO_2$ and $N_2O$ emissions after the first rains as generally observed in dry ecosystems