Roles of Agroforestry in sustainable intensification of small farMs and food SEcurity for SocIetIes in West Africa

WP3 Coconstruction of agroforestry parkland intensification scenarios

Task 3.1. Simulations of parkland dynamics under innovative management scenarios (biophysical modelling)

D 3.1. Biophysical modelling (100% completed)

(by Sidy Sow, Yolande Senghor, Khardiatou Sadio, Rémi Vezy, Gatien Falconnier, Guerric le Maire, François Affholder, Diaminatou Sanogo, Saidou N. Sall, Cathy Clermont-Dauphin, Christophe Jourdan, Frédéric DO, Adama Tounkara, Moussa N'dienor, Djim Mouhamadou Lamine Diongue, Céline Blitz-Frayret, Yélognissè Agbohessou, Espoir Gaglo, Olivier Roupsard**)**

Introduction

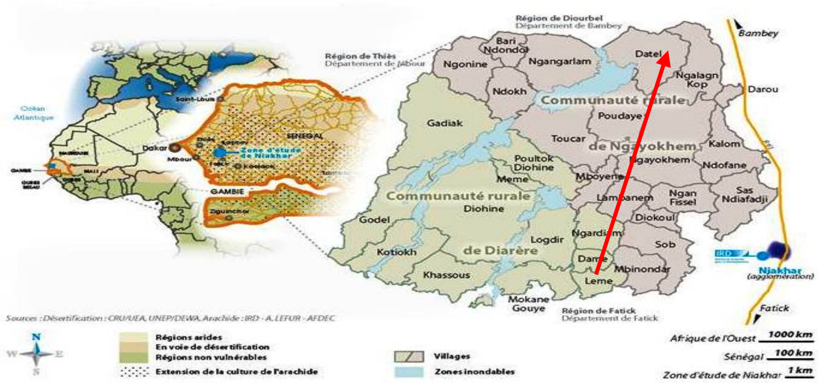
In West and Central Africa, food and nutritional security and poverty reduction remain the main challenges. In this context, agriculture makes a significant contribution as it employs nearly 70% of the active population. However, this agriculture is facing an increase in population correlated with a decrease in resources (land, energy, etc.) but also climate change. In a global context of rising input and fossil fuel costs on the one hand, and internalization of the cost of de-contamination on the other, it is becoming clear that conventional intensification with high input levels will no longer work economically speaking if its profit margin is cancelled out (Meadows & Meadows, 2007). Therefore, a globalization of the shift to more resilient agroecological practices must be considered. System resilience is thus a key but so far neglected issue in modern agriculture. To ensure the productivity and resilience of agrosystems in the long term, sustainable intensification of agriculture seems to be the most appropriate strategy. Even if among agroecological practices in general, several works have shown the interest of agroforestry as an adaptive practice, especially in the context of climate change, it remains to quantify the relationships between trees and crops to better cope with climate projections, marked by an increase in extreme events. It is urgent to find solutions for more resilient systems. This study proposed to use modeling to formalize the interactions at stake in agroforestry systems and, based on virtual experimentation, to propose more resilient and sustainable intensification scenarios.

This work is the subject of Sidy Sow's PhD thesis, which was funded by the Ramses II project.

Materials & Methods

Study Site

Fieldwork was conducted in Sob located in the Niakhar/Fatick area, in the heart of the groundnut basin of Senegal. The Population-Health-Environment Observatory of IRD and its partners (OPSE) is over 50 years old (Delaunay et al., 2018) and has housed much previous research in the field of demography, health and sustainable agriculture. It is located in the groundnut basin and consists of an agro-sylvo-pastoral park dominated by the multipurpose, phenologically reversed tree Faidherbia albida. The main crops grown are millet, groundnuts, cowpeas, sorghum and watermelon, either as pure crops or in combination with livestock.



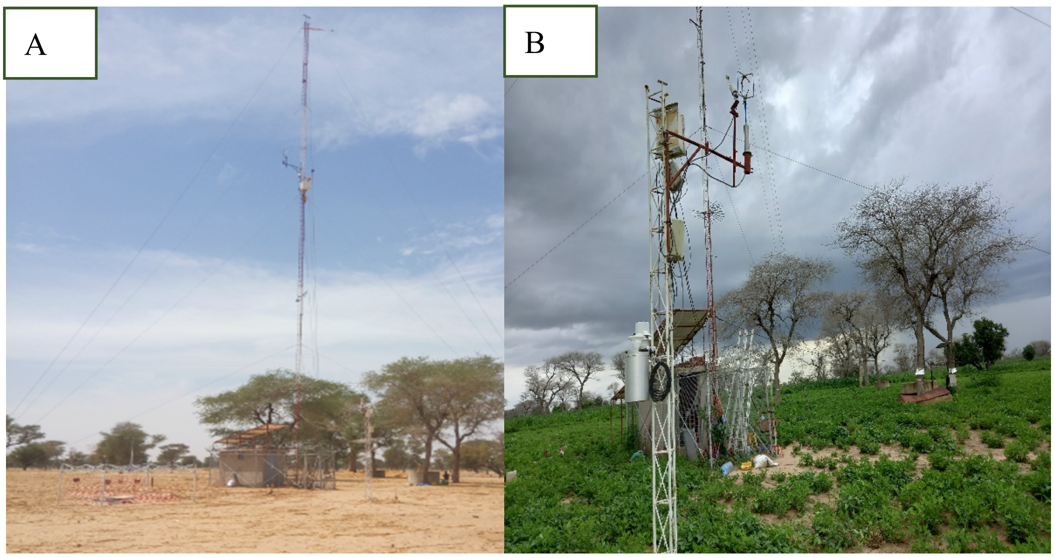
The Faidherbia-Flux site is located here in Sob

Figure 1 : Presentation of the study site

Experimental display

In order to parameterize the models in question, a set of installations and devices on site allowed the acquisition of data. Among these installations we have :

- 2 flow towers, Eddy-covariance: a large one ((30m height) and a small one (4.5m) above trees and above crops, respectively: meteorological variables as well as CO2, H2O and heat fluxes (see Deliverable 2.2.4).

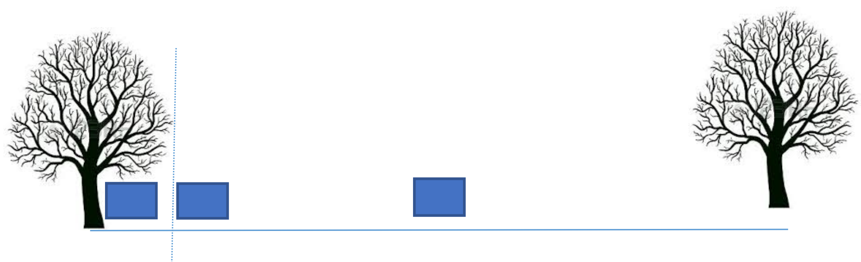


- Buried scanners for roots
- 7 trees equipped with sap flow measurement devices
- LAI2000 which allows the determination of the foliar indices of the trees (every 10 days) and the crops during the cycle
- TDR which determine the volume humidity every 10cm up to 200cm and every 30 minutes
- access tubes for Diviner that determine the volume moisture every 10cm up to 160cm.
- Multi-spectral drone: several flights during the growing season (about 5-6 per year and per crop), including one flight at emergence and one flight at harvest

Plots of 15 m2 were delimited, just after emergence, and several observations and measurements were made. These plots for millet and peanut, in rotation at our site, were installed each year between 2018 and 2021 to determine agronomic variables related to the crop. The plot design is composed of 3 treatments:

- Under Tree, Edge of Tree, and Far from Tree (>25m).
- 6 replicates: each replicate corresponds to a Faidherbia albida tree. The transects are chosen so that there is no double influence on the plots.

A total of 18 subplots de 15 m^2.



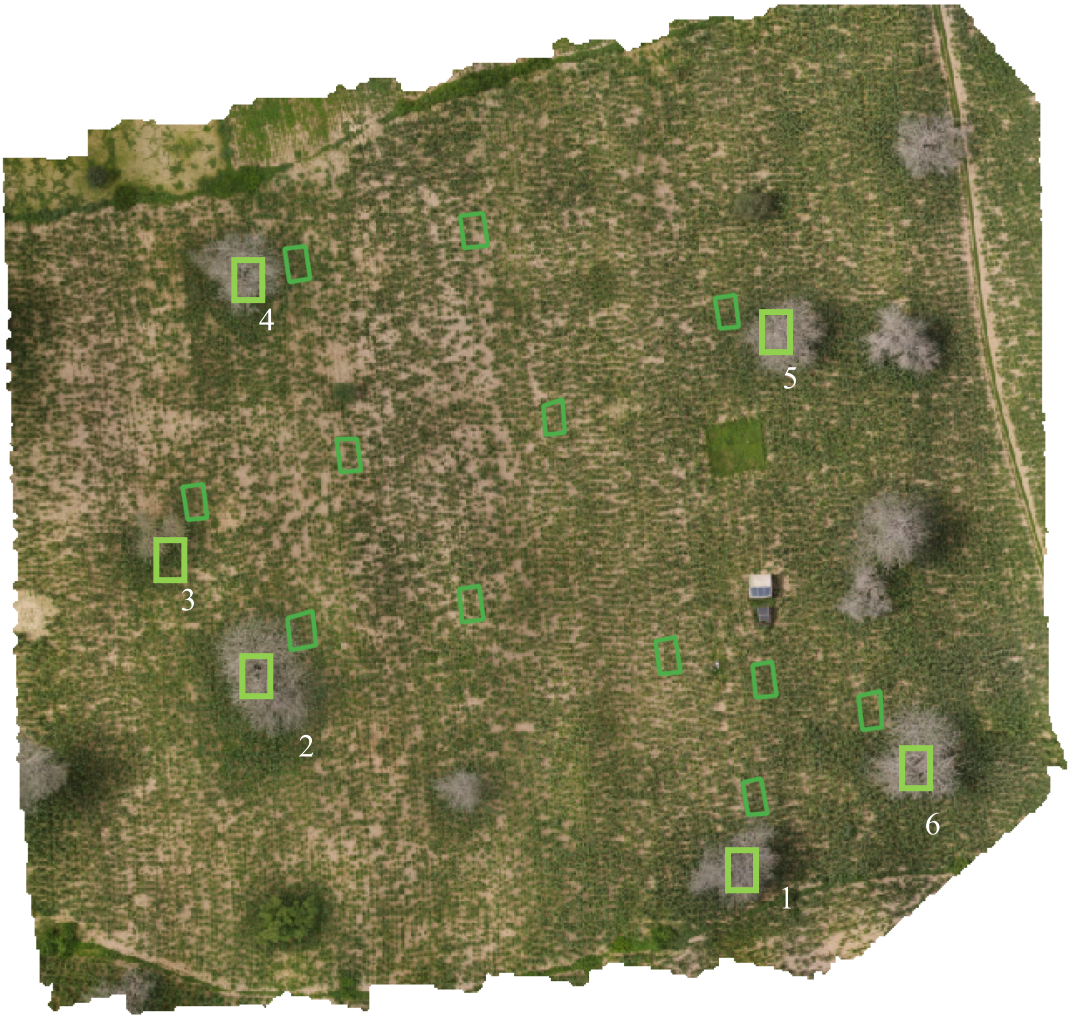


Figure 2: Millet experimental device in a whole plot. 6 *Faidherbia albida* trees (red numbers) with one subplot each below the crown (large green rectangles) and 2 subplots at the border and out of influence of trees (narrow green rectangles). Total = 18 subplots per whole plot. Drone orthoimage RGB.

Agronomical variables

The experimental plots were monitored throughout the crop cycle from emergence to harvest and post-harvest operations were also used to determine other quality variables needed to parameterize the models.

- ✓ During the cycle

The emergence rate was determined by counting the number of clusters on the plot and the phenological cycle was followed and the dates identified (emergence, beginning and 50% flowering, beginning and 50% grain filling, physiological maturity and harvest). Other measurements were made such as the count of the striga parasitized clusters, the sanitary state of the plot (qualitative note for each pest), passage of the LAI2200 every 10 days during the cycle to determine the leaf area index, count of the number of leaves per stem and per cluster, the height of the stems was also measured during the cycle. A soil sample was attached to each measurement to determine the evolution of the soil water content which is an important variable in the parameterization of STICS.

Figure 3: Flowering A and mature B millet spikes

- ✓ At harvest

For each plot, a team of 5 persons proceeded to the harvest. The ground surface was precisely measured by tape measure and confirmed later by drone, the number of living clusters on the theoretical number calculated, the rate of infestation by the hemiparasite Striga hermontica and the global sanitary state of the plot (diseases and pests) recorded. Then the harvesting was done by plant compartment: the compartments spikes (later subdivided into grains + rachis + hairs), leaves (without sheath), stems (with sheath), roots (0-20 cm) and weeds (aerial parts only) were taken and the fresh weights (MF) determined on site immediately with an electronic g scale and weighing machines for the largest samples. For the ears, the entire sample is kept for post-harvest measurements, but for the other compartments only subsamples (5 bunches) were brought back to the laboratory after measurement of their MF relative to the total MF of the compartment.

A subsample of leaf biomass was scanned on an A4 scanner and its leaf area measured. The specific leaf area (SLA) was calculated (ratio between the surface and the dry mass), in order to convert later the leaf DM in leaf area per plot.

- ✓ Post harvest

Samples were pre-dried in the sun for 5-10 days to stabilize them before steaming (to avoid rotting of fresh samples). Then they were sequentially oven dried at 65°C for 48h, weighed (MS) and the water content calculated. A fine grinding was performed on the samples and grindings for chemical analysis of C, N, P, K, Mg, Ca, ... and for VisNIR spectral analysis. VisNIR models were developed for each compartment and each crop

These operations allowed us to calculate variables such as grain yield, above-ground biomass, root biomass, leaf area, above-ground biomass of weeds, etc., but also to determine the organic and mineral quality and to compare situations under trees and full sun in our agroforestry system.

- ✓ Soil analysis

Gravimetric moisture measurements were also taken during wet and dry periods to determine dry bulk densities and to calibrate the moisture content of TDRs and Diviners.

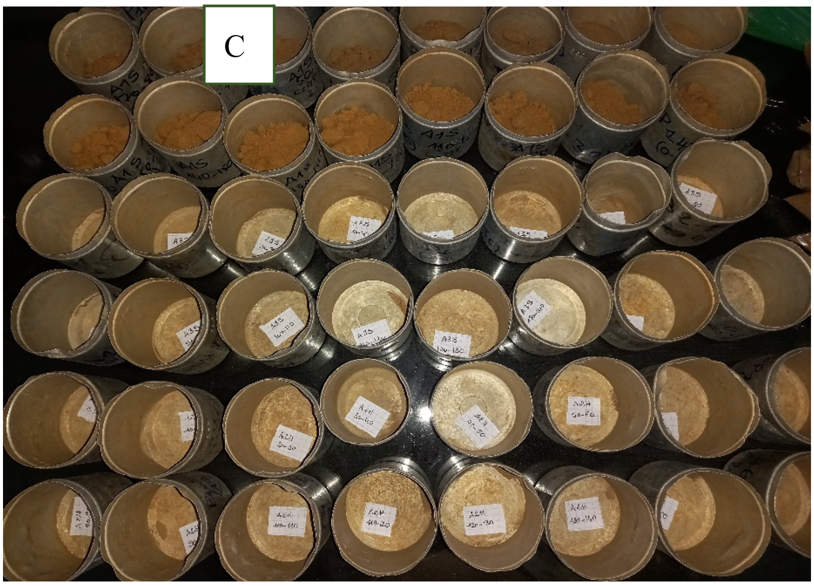


Fig 4: Soil sampling for water content and dry bulk density on peanut (A), on millet (B) and laboratory analysis (C)

The 0-10 and 10-30cm soil samples were analyzed for pH (H2O and KCl), assimilable nitrogen (nitrates and ammonium), N%, C%, C/N, assimilable P, exchangeable bases (Ca, Mg, Na, K) and cation exchange capacity (CEC).

Other observations made in the field such as the rate of foliage of the trees were also used in the calibration of MAESPA.

Parameterizing STICS

STICS overview

STICS is a dynamic model that simulates, on a daily time step, the behavior of the soil-crop system over a one-year period. It is organized in modules, each module simulates one or more specific ecophysiological or physical processes or groups of processes. A first set of modules deals with the ecophysiology of the aerial parts of the plants, i.e. the phenological development, the growth of the aerial biomass, the leaf growth on the surface, the elaboration of the yield but also the quality and the distribution of the biomass between the different organs. A second set of modules simulates the functioning of the soil in interaction with the underground parts of the plants. It deals with root growth, water and nitrogen balance and water and nitrogen transfers. At the interface, there is a module for managing the interactions between cultivation techniques and the soil-crop system, whether it is a question of water, fertilizer or microclimate inputs. Between these modules there are exchanges of information and variables (Brisson et al., 1998; 2002 ; 2003 ; 2004; Godard, 2005 ; Launay et al. 2008).

STICS is also a generic model and its adaptation to a new crop is based on its double modular and generic characteristic. As inputs to the model, we have climate variables (minimum and maximum daily temperature, radiation, cumulative daily precipitation, etc.); these data must be filled in every day of the crop cycle, from sowing to harvest. We also have soil variables (useful water reserve, organic matter content which determines the amount of nitrogen that can be mineralized, etc.) and finally the cultivation practices: sowing dates and densities, varieties, fertilization level, irrigation, rotations, harvesting methods (harvesting, picking, mowing, etc.) The model calculates agricultural outputs (yield, water or nitrogen content of organs, irrigation and fertilization levels) as well as environmental outputs such as water consumption by the plant, N2O emissions, water and nitrate losses by leaching, etc.

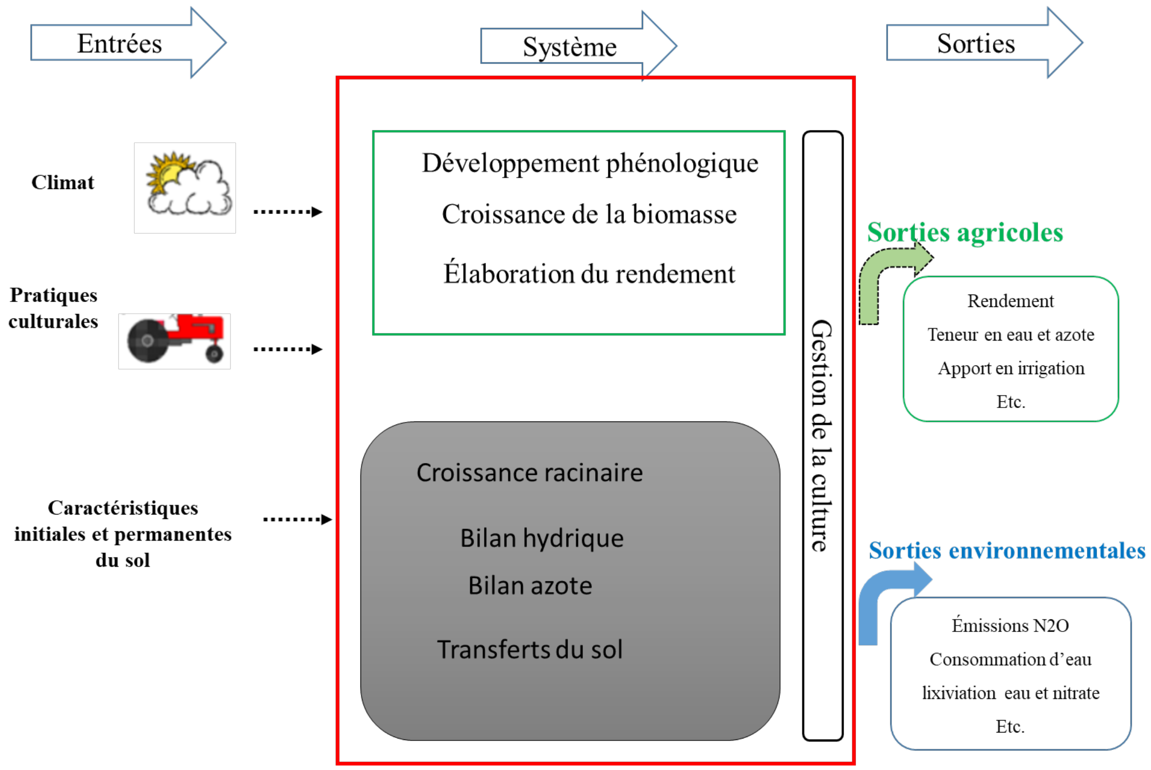


Figure 5: Overview of the STICS model

Database of parameters

The calibration of the STICS model required the pooling of data from 3 different sites, namely Bambey, Diohine and Sob/Niakhar, for greater variability and therefore greater robustness. Table 1 below presents in detail the experiments in the 3 sites. Each experiment generates simulation units, called USMs in Stics.

Table 1: Site, year, crop management and available measurements for calibration and validation datasets. USM = "Unité de Simulation"; LAI = Leaf Area Index; AB = above-ground biomass; SWC = soil water content; GY = Grain Yield; PN = Plant Nitrogen

			Crop management					Available measurements during experiments						
Use	site	Year	Species	variety	density	irrigation	mineral fertilization	Phenology	LAI	AB	SWC	GY	PN	code_usm
Calibration	Bambey	2018	Millet	souna3	1.23	yes	No	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F0A_2018
			Millet	souna3	1.23	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F1B_2018
			Millet	souna3	1.23	yes	No	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F0E_2019
			Millet	souna3	1.23	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F1E_2019
			Millet	souna3	1.56	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_dens3_2018
			Millet	souna3	3.12	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_dens4_2018
			Millet	souna3	6.25	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_dens5_2018
			Millet	souna3	4.94	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_dens6_2018

			Millet	souna3	1.23	yes	No	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F1A_2018
		2019	Millet	souna3	1.23	No	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_IR_F1F_2019
			Millet	souna3	2.47	yes	yes	yes	yes	yes	Yes	yes	yes	Bby_Millet_dens2_2018
	Niakhar	2018	Millet	souna	1.25	No	No	No	yes	yes	Yes	yes	yes	Nkr_Millet_2018_Mean_sun
		2019	Millet	souna	1.25	No	No	No	yes	yes	Yes	yes	yes	Nkr_Millet_2019_Mean_sun
	Diohine	2015	Millet	souna	2.4	No	No	yes	yes	yes	Yes	yes	No	Dhn_Millet_2015_CC_F0N0
			Millet	souna	2.4	No	No	yes	yes	yes	Yes	yes	No	Dhn_Millet_2015_CB_F0N0
			Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CC_F0N1
			Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CB_F0N1
			Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CC_F0N2
			Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CB_F0N2
Evaluation	Bambey	2017	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F0A_2018

	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F0B_2018
	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F0C_2018
	Millet	souna3	1.23	yes	yes	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F1A_2018
	Millet	souna3	1.23	yes	yes	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F1B_2018
	Millet	souna3	1.23	yes	yes	yes	yes	yes	No	yes	yes	Bby_Millet_CS_F1C_2018
2018	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F0B_2018
	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F1C_2018
	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F0D_2019
	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F0F_2019
2019	Millet	souna3	1.23	yes	No	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F0C_2018
	Millet	souna3	1.23	yes	yes	yes	yes	yes	No	yes	yes	Bby_Millet_dens1_2018
	Millet	souna3	1.23	No	yes	yes	yes	yes	No	yes	yes	Bby_Millet_IR_F1D_2019

Niakhar	2020	Millet	souna	1.25	No	No	No	yes	yes	Yes	yes	yes	Nkr_Millet_2020_Mean_sun
	2021	Millet	souna	1.25	No	No	yes	yes	yes	Yes	yes	yes	Nkr_Millet_2021_Mean_sun
Diohine	2016	Millet	souna	2.4	No	No	yes	yes	yes	Yes	yes	No	Dhn_Millet_2015_CC_F0N0
		Millet	souna	2.4	No	No	yes	yes	yes	Yes	yes	No	Dhn_Millet_2015_CB_F0N0
		Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CC_F0N1
		Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CB_F0N1
		Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CC_F0N2
		Millet	souna	2.4	No	yes	yes	yes	yes	No	yes	No	Dhn_Millet_2015_CB_F0N2

Calibration

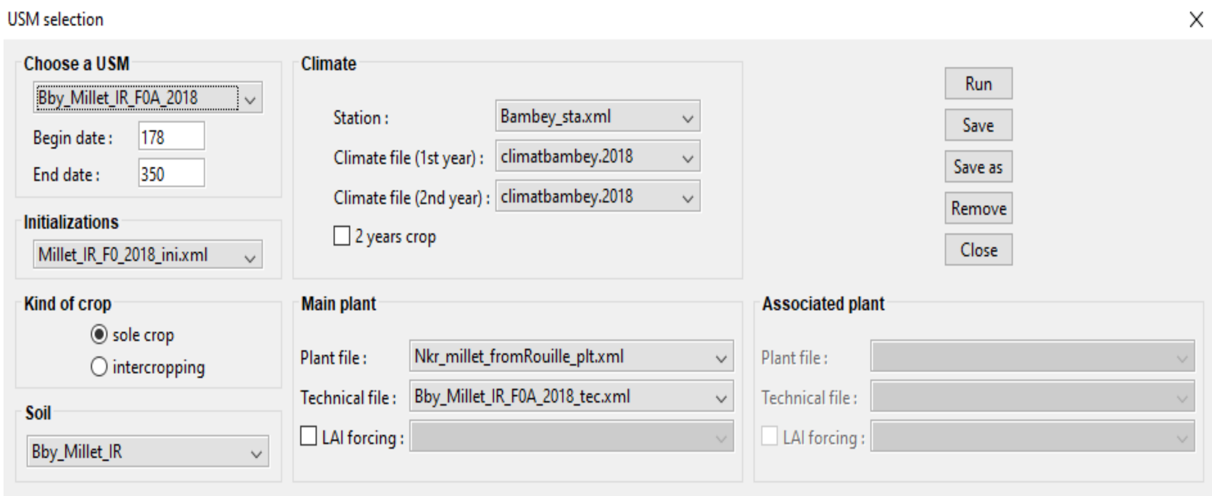
Calibration started on Javastics with the manufacturing of USMs (simulation unit). A USM is characterized by a homogeneous agronomic situation. The data required to run the model are those that characterize a supposedly homogeneous agronomic situation, corresponding to the millet plot or to a portion of this plot if it is heterogeneous. These data include:

- the permanent characteristics of the soil ;

- daily climatic variables;

- cultural practices (fertilization, irrigation, tillage, trimming, etc.);

- data that characterize the initial state of the soil-plant system, i.e. the soil's water and nitrogen status, as well as the growth and development status of the millet, at the beginning of the simulation.



The simulation units were built on Javastics and from R the calibration and validation of the parameters are performed in several steps:

- Step 1: Phenology

- Step 2: Soil water content

- Step 3: LAI (leaf area index)

- Step 4: Above-ground biomass

- Step 5: Millet grain yield

During each step a set of parameters influencing the variable were calibrated. We started from a plant file that was initiated (Ruillé, 2020) and we re-calibrated the parameters**.**

Validation (or Evaluation)

The model was first evaluated graphically and then statistically by calculating the efficiency of the FE model and the nRMSE (Normalised Root Mean Square Error)**.**

$$EF = 1 - \left(\Sigma^{ni}_{i=1}(Oi - Pi)^2 \,/\, \Sigma^{ni}_{i=1}(Oi - \bar{O})^2\right)$$

$$nRMSE = (RMSE/\bar{O}) \times 100,$$

Where Oi and Pi are the observed and simulated values for the ith measurement, n is the number of observations and $\bar{O}$ is the mean of the observed values**.**

Parameterizing MAESPA

MAESPA overview

The MAESPA model Duursma and Medlyn. (2012) is the product of the aerial components of the MAESTRA model (Wang and Jarvis, 1990; Medlyn et al., 2007) and the water balance components of the SPA model (Williams et al., 2001a, b), with several modifications and additions (see Table 1). It is a process-based ecophysiological model simulating energy, water, and carbon fluxes in forest ecosystems at the tree and stand scales. The MAESTRA sub-model simulates light absorption by foliage, photosynthesis, soil evaporation, transpiration, and water and energy balances. It shows how H2O and CO2 exchanges are estimated. The water balance sub-model is based on soil, root, leaf and air water potential and hydraulic conductivity. The MAESPA model, as well as the 2 sub-models MAESTRA and SPA, typically runs at a half-hour time step, although it can also be run at shorter hourly or arbitrary time steps (up to every minute.

Table 2: Summary of the origin of the different components of the MAESPA model

Composantes du modèle	Source
Radiative transfer	MAESTRA
Energy balance of leaves	;;
Photosynthesis	;;
Stomatal conductance (gs) leaf and canopy transpiration	;;
Additional models for gs	Tuzet et al. (2003), Medlyn et al. (2011)
Canopy interception	SPA
Soil drainage	;;
Soil evaporation	;;
Soil surface energy balance	;;
Soil temperature profile	;;
Soil water balance	;;
Infiltration	BROOK90, Federer et al. (2003)
Water absorption by roots	Modified from SPA, Taylor et Keppler (1975)
Water retention and soil hydraulic conductivity	Campbell (1974)

The MAESPA Model has undergone several modifications and developments as well as applications for many types of agrosystems (Wang and Jarvis, 1990; Medlyn, 2004; Duursma and Medlyn, 2012; Christina et al., 2017), including agroforestry ecosystems: (Charbonnier et al., 2013);(Charbonnier et al., 2017);(Vezy et al., 2018);(Vezy et al., 2020). This is a single-tree based 3D model that calculates light interception and distribution in tree crowns. Modifications are made on the soil water balance see in Christina et al. (2017). In (Vezy et al., 2018) improvements were made on the simulation of leaf temperatures and leaf evaporation after rain events.

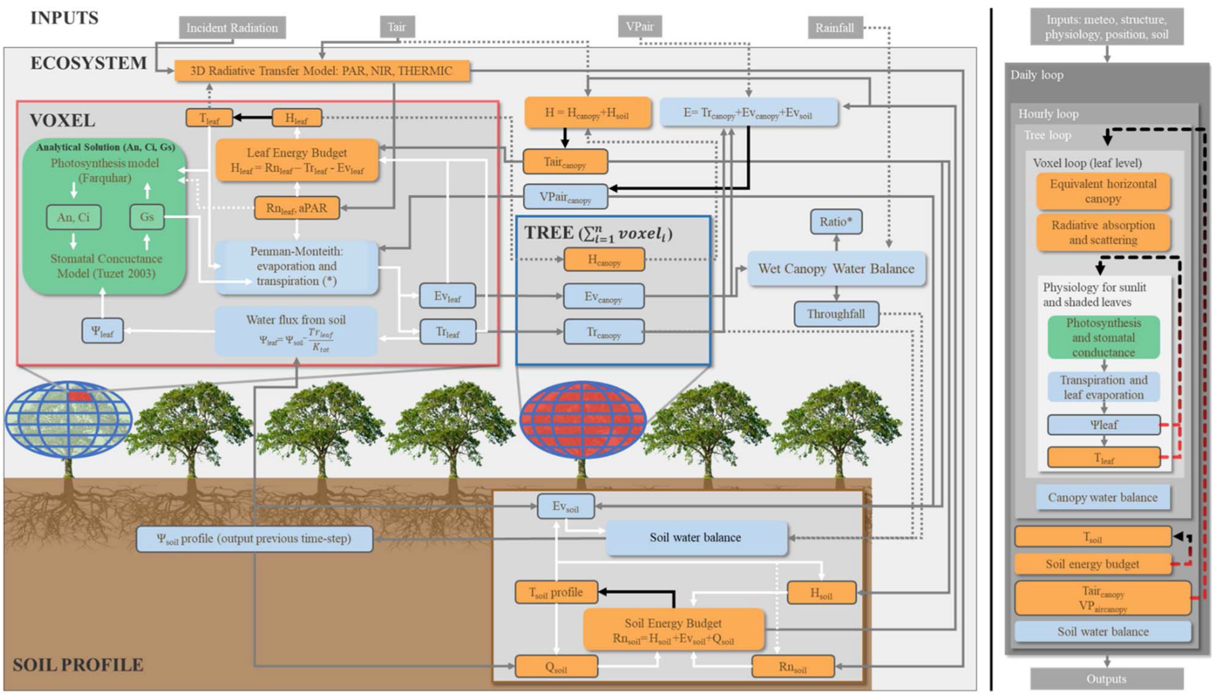


Figure 10: Detailed MAESPA model workflow. Some calculations are made at the voxel scale (VOXEL, in red) before being summed for upscaling to tree level (TREE). Other

calculations are made directly at ecosystem level (ECOSYSTEM) such as the soil energy budget and the water balance. Voxel-scale photosynthetic module is represented in green, energy modules (or variables) in orange and water-related modules (or variables) in blue. Black arrows emphasize the variables that are optimized. Linear workflow is shown on the right-side, showing the three iterative computations with arrows. (*): A ratio of dry/wet canopy is used at voxel scale for evaporation and transpiration partitioning. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of Vezy et al.,2018)

Input files

trees.dat	Tree size and location information	Mandatory
str.dat	Stand structure information	Mandatory
confile.dat	Simulation control parameters	Mandatory
phy.dat	Leaf physiology model parameters	Mandatory
met.dat	Meteorological drivers, site location	Mandatory
watpars.dat	Water balance, soil and plant hydraulics. If omitted, model is run in Maestra mode	Optional
points.dat	Coordinates of test points	Optional
ustorey.dat	Understorey parameters	Optional

Output files

Output files		
hrflux.dat	Hourly flux files, contains all flux estimates for each target tree for each timestep	Optional (recommended)
dayflx.dat	Daily flux files, contains totals per tree for all flux estimates	Always
Maeserr.dat	Maespa error messages and warnings	Always
watbal.dat	Water balance calculations for each timestep	If run in Maespa mode
watbalday.dat	Daily summaries of water balance calculations	If run in Maespa mode
tutd.dat	Input / output file with diffuse transmittances	Optional
Other water balance output	watballay.dat, watupt.dat, watsoilt.dat	If run in Maespa mode
testflx.dat	Output for test grid points	Optional
layflx.dat	Output by canopy layer	Optional

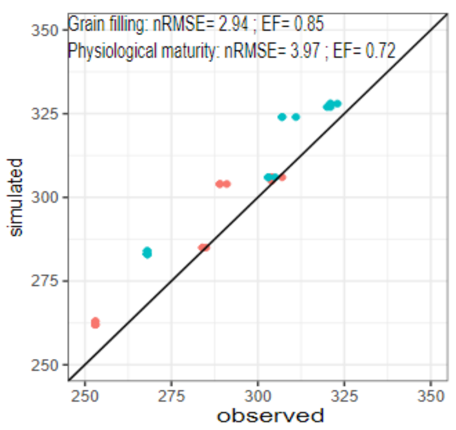
Results

STICS

Pearl Millet phenology

The model satisfactorily predicted the dates of grain filling and physiological maturity both during calibration and validation. This justifies the relevance of the non-photoperiodism formalisms for millet souna. The nRMSE is relatively low with EF> 0.7 in calibration and validation.

Calibration



Validation

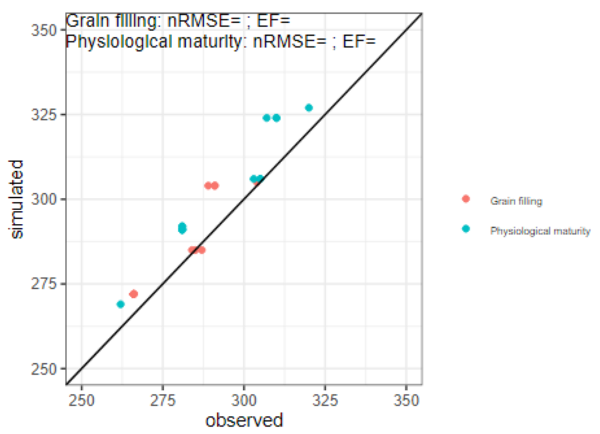


***Figure 6**: Comparison between observations and STICS simulations of grain filling and physiological maturity of millet during calibration and validation. Units = day of year (DOY).*

Soil water content

Soil water content was simulated from 1 month before sowing to harvest on a 160 cm deep profile. It is correctly simulated on the whole profile both in calibration and validation with a FE > 0.8 for both and a rather low nRMSE < 22% (Figure 7). The model simulates well the soil water content over the whole millet growing period.

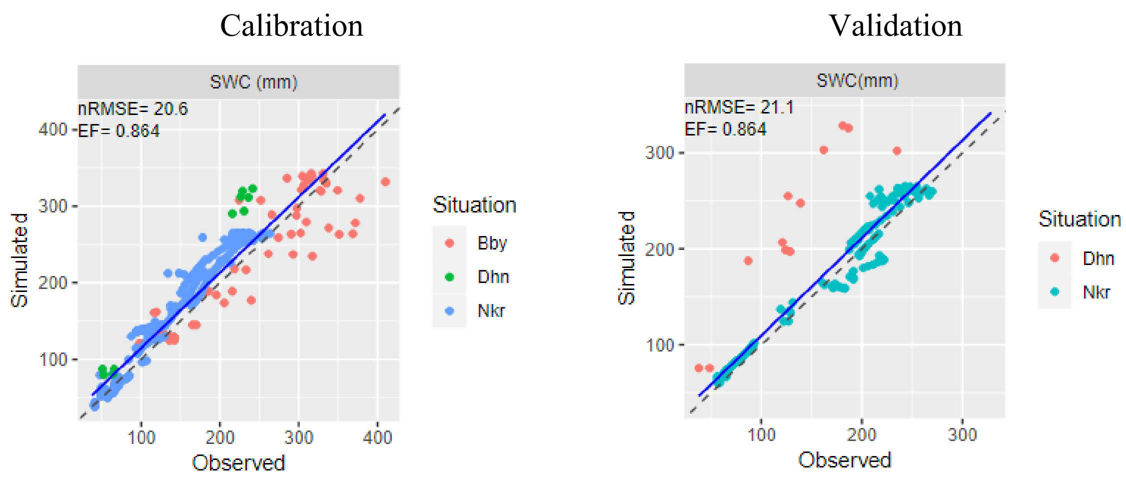


Figure 7: Comparison between observations and STICS simulations of SWC under millet cultivation during calibration and validation. SWC= Soil Water Content (mm H2O on the 0-160 cm layer).

The following table 2 presents the synthesis of the values used for the calibration of the soil water content.

Table 3: Summary of values used for the calibration of soil water content. HCCF: gravimetric water content at field capacity, HMINF: gravimetric water content at wilting point. Zesx: maximal soil depth affected by soil evaporation, q0: cumulative soil evaporation above which evaporation rate is decreased and cfes: soil contribution to evaporation.

Site	Situation	layers	Thickness (cm)	HCCF (%W)	HMINF (%W)	Zesx (cm)	q0 (mm)	Cfes
Bambey								
	Irrigated	1	30	19	5.5	160	7	4
		2	40	14.6	4			
		3	20	16	4.2			
		4	40	12	5.4			
		5	30	11	6.4			
Diohine								
	Rainfall	1	30	17	6.99	150	2	7
		2	40	13	7.06			
		3	20	17	7.53			
		4	30	12.71	8.06			
		5	40	11.54	8.16			
Niakhar								
	Rainfall	1	30	10.57	2		1.25	4
		2	40	11.22	3			
		3	20	11.33	3			
		4	30	11.37	6	160		

5	40	10.63	7.5

Leaf area index and aerial biomass

For the calibration data set, the simulated LAI values were close to the observed values. The statistics show it with an nRMSE of 35.2% with a satisfactory EF of 0.66. However, on the validation data set, the model efficiency is low (0.16), even if it is higher than the average. The prediction error is also important (nRMSE=61.1%).

Above-ground biomass is well simulated by the model. The observations correspond to the predictions in both calibration and validation with a satisfactory EF of 0.85 and 0.61 respectively. The prediction error is satisfactory for the calibration nRMSE=27.9. However, it is important on the validation data set (nRMSE=45.7). These strong variations between predictions and measurements on LAI and aerial biomass could be due to the dynamics of leaf senescence which amplified the deviations on the validation data set.

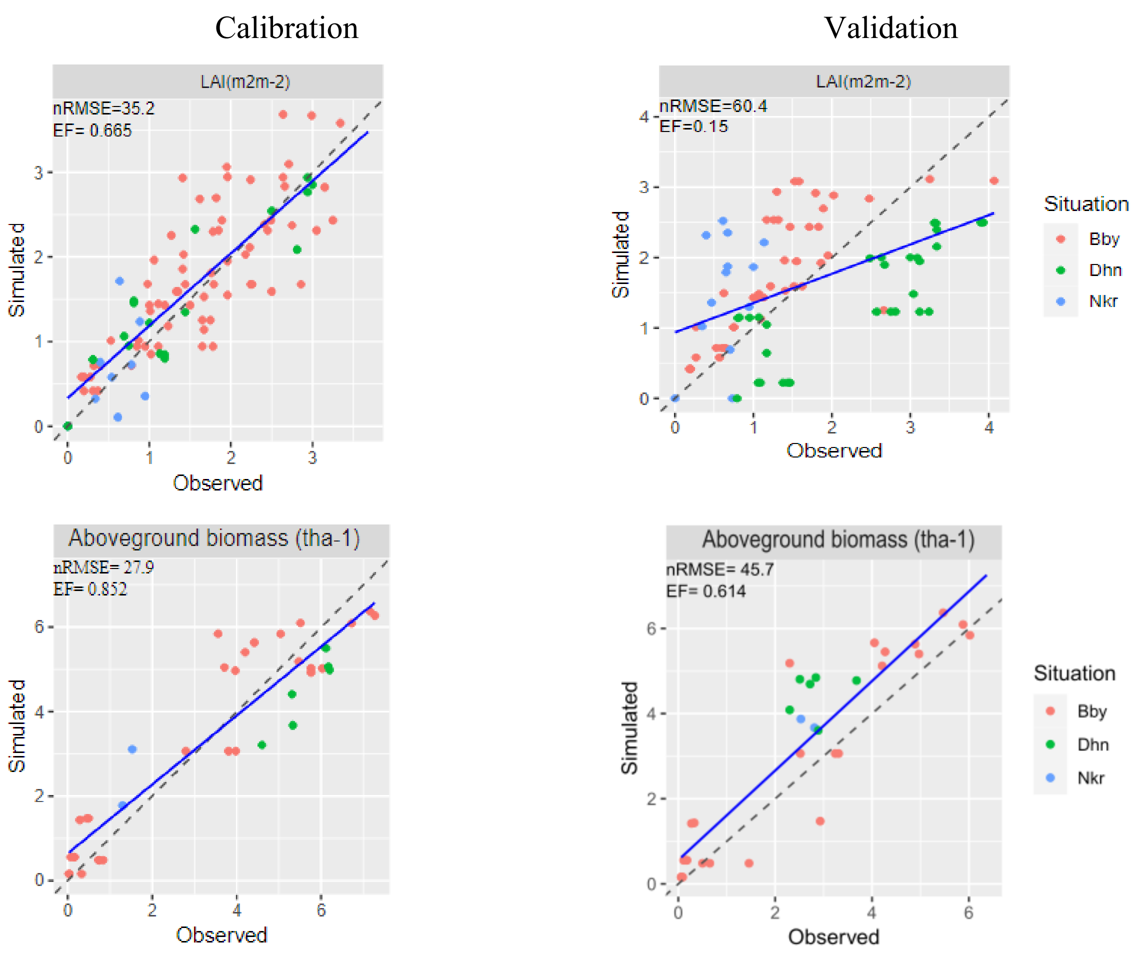


Figure 8: Comparison between observations and STICS simulations of Leaf Area Index (LAI) and aboveground biomass of millet during calibration and validation.

Amount of grain per square meter and grain yield

The model simulated the number of grains (EF=0.31) and yield with an EF=0.51 in calibration. However, the prediction error is satisfactory 23.8 and 26.4 respectively for the calibration data set. The performance of the model remained satisfactory during the evaluation, with an EF value>0.2 and a prediction error nRMSE<35%

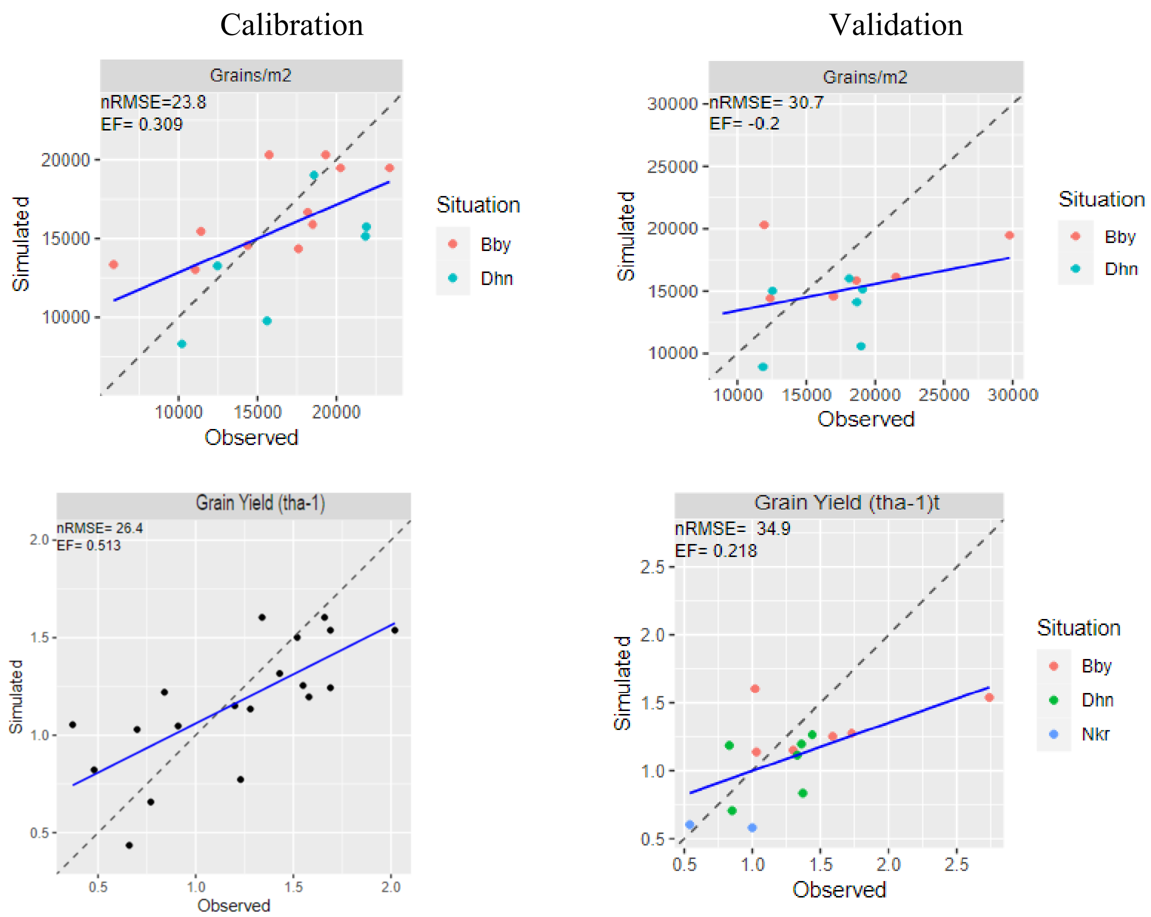


Figure 9: Comparison between observations and STICS simulations of number of grains and grain yield of millet during calibration and validation.

MAESPA

Tree choice and database of parameters

In green **(Fig. 11)** we have the plot to be simulated, which corresponds to the footprint of the Flow Tower in the dry and rainy seasons. In red we have delimited a perimeter characterized by the trees that can have an influence on the variables of the trees of the plot to be simulated.

In total we have 72 trees, 39 of which are in the area to be simulated and 33 in the perimeter area

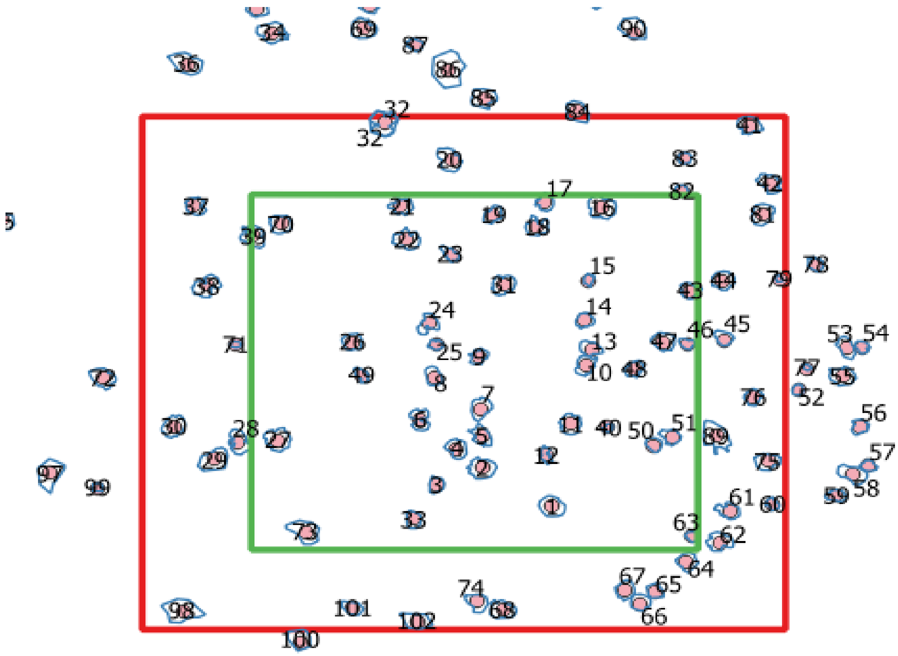


Figure 11: MAESPA simulation plan, each symbol is a *Faidherbia albida* tree canopy. Scale 1/2491. Plot simulated in greed 40726m^2; large surrounding plot in red 84823m^2

Database of parameters

- Climatic and evapotranspiration data from the 2 flow towers (High minus Low = transpiration of the trees in principle)

- Phenology data: leafing rate, flowering, fruiting (visual observations of leafing rate of 15 trees)

- Tree growth data: diameter circumference

- Sap flow on 7 trees,

- Soil moisture to water table

- LAI2000, tree leaf area

Calibration

In the wet season (A), simulated evapotranspiration is equal to crop evapotranspiration because the trees are leafless.

To simulate this process, evapotranspiration is forced during the cropping period from emergence to harvest of millet in 2018 and peanut in 2019.

In the dry season (B), the simulated transpiration effectively matches that of Faidherbia albida trees**.**

Simulating tree transpiration

In green (Fig. 12) we have the observations of transpiration and in blue the simulation of transpiration by the model. On average the model overestimates transpiration. It is worth noting here that the approach of estimating tree transpiration by double flux tower (Top-Bottom) also indicates that transpiratory fluxes could be higher than measurements by sap flow (data not shown). However, we observe on some trees like Tree 5 and Tree 48 that transpirations are not overestimated but well simulated and even underestimated towards the end. A closer look at the results and the field observations has suspected inconsistencies on the leaf surfaces of the trees, verifications are underway and responses for improvements are underway**.**

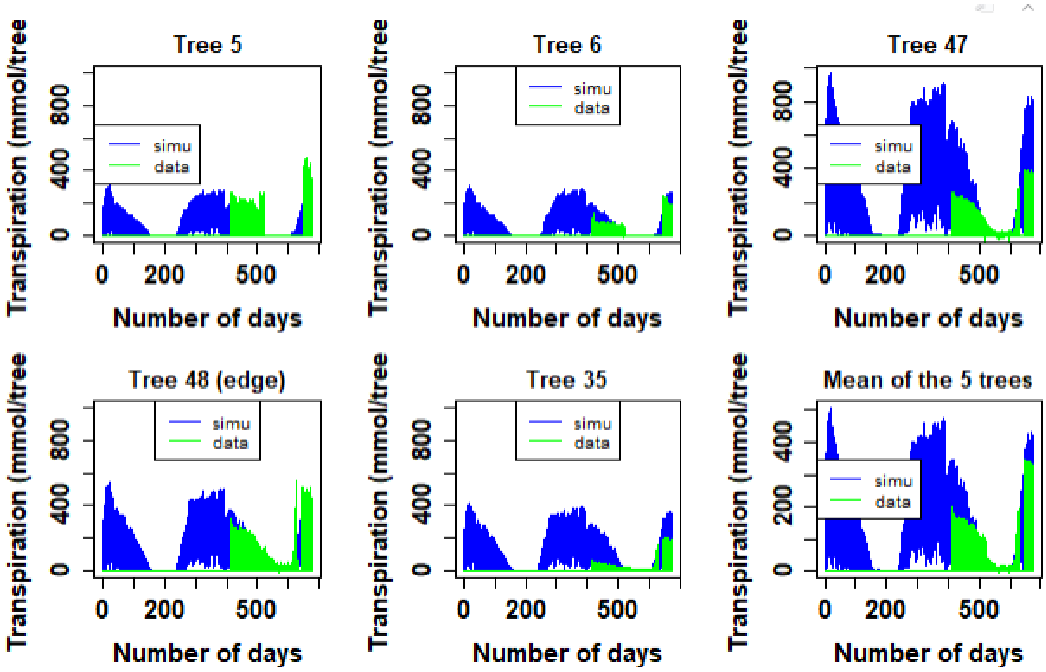


Figure 12: Tree transpiration simulation and observation by sapflow

Simulating water balance

Black corresponds to the periods of the rainy season during which the Faidherbia albida trees are leafless, and thus no photosynthesis or transpiration is taking place. The red curve represents the evapotranspiration simulated by the model and the green curve represents the observations by high flux tower, during the period when the trees are leafed out. We see that over the whole study period the model underestimates the evapotranspiration.

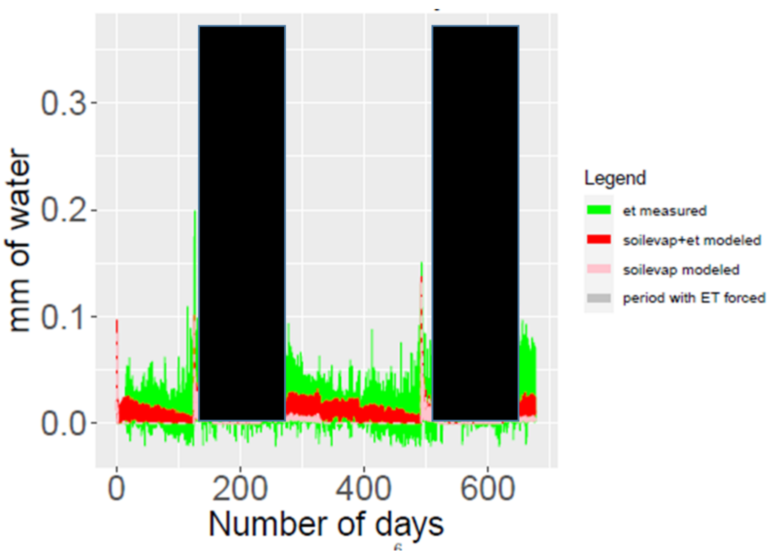


Figure 13: Water balance simulation

Simulating water content on the profile

The soil profile was cut into 18 layers. Layers of 20cm down to 2m and layers of 50cm from 2m to 6m. The simulation of the water content shows up to layer 10 that the patters are identical but in quantitative terms, the model does not simulate root uptake in the surface layers. The removal is largely in the water table (a lot of water and roots); several questions how to force the removal of trees? Which layers to remove? Or should the soil parameters be recalibrated? Answers are being developed**.**

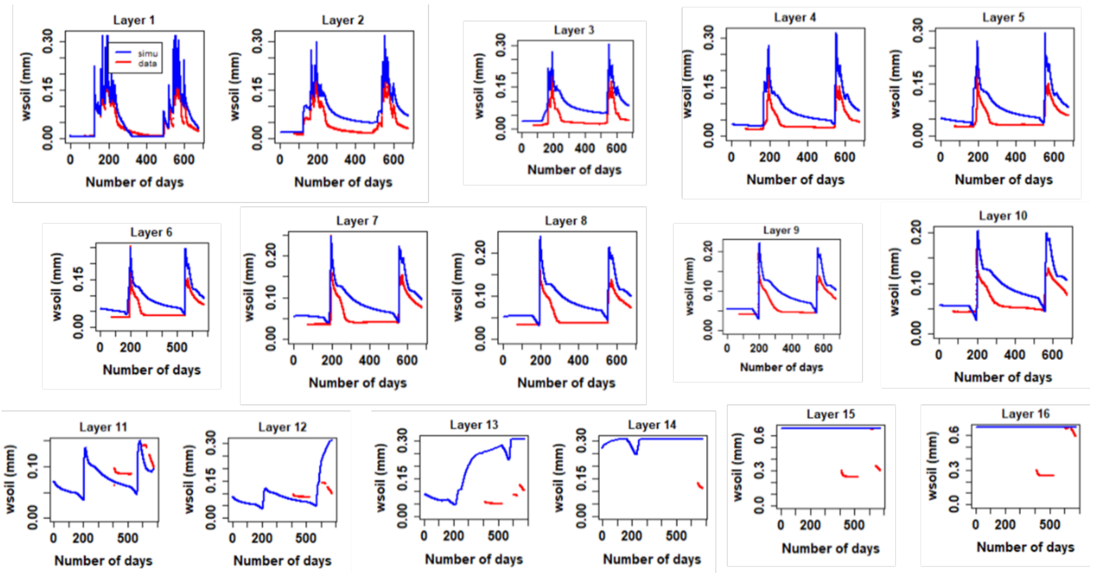


Figure 14: Soil Water Content simulation

Simulating photosynthesis

The black curve (Fig. 15) corresponds to the periods of the rainy season during which the Faidherbia albida trees are leafless and therefore not photosynthetic. The blue curve represents the model simulation and the green curve the observations from the high flux tower. We see that over the entire study period the model underestimates photosynthesis**.**

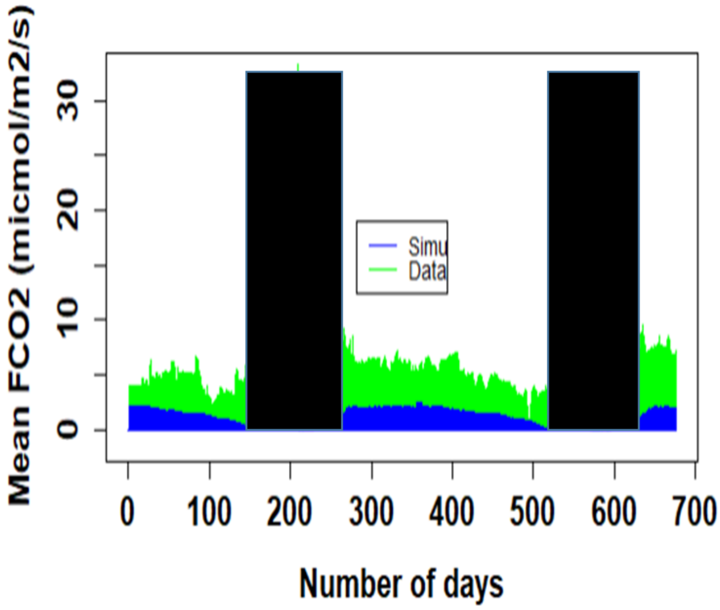


Figure 15: Photosynthesis (GPP) simulation. Measurements from the tall tower.

Conclusions and Perspectives

The work presented here is the core of Sidy Sow's PhD thesis that will be defended in early 2023. This first work on the calibration of Stics for millet (biomass production and yield) under full sun conditions will be the subject of a joint publication by the several laboratories that shared their data, to be submitted in May 2022. Then, millet plots located under trees will be simulated by changing the initial conditions and the microclimate under trees, using a coupling between the MAESPA model and the Stics model (meta-modeling). These models, once ready to simulate millet under agroforestry conditions, will lead to development work, by simulation and comparison of contrasting situations: various tree or millet densities, various microclimates. Other applications are expected from Stics, notably the simulation of GHG balances (CO_2, N_2O)**.**

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