Modeling agroecological intensification in the tropics with the STICS model – lessons learned and way forward

Séminaire STICS - 15/11/2023

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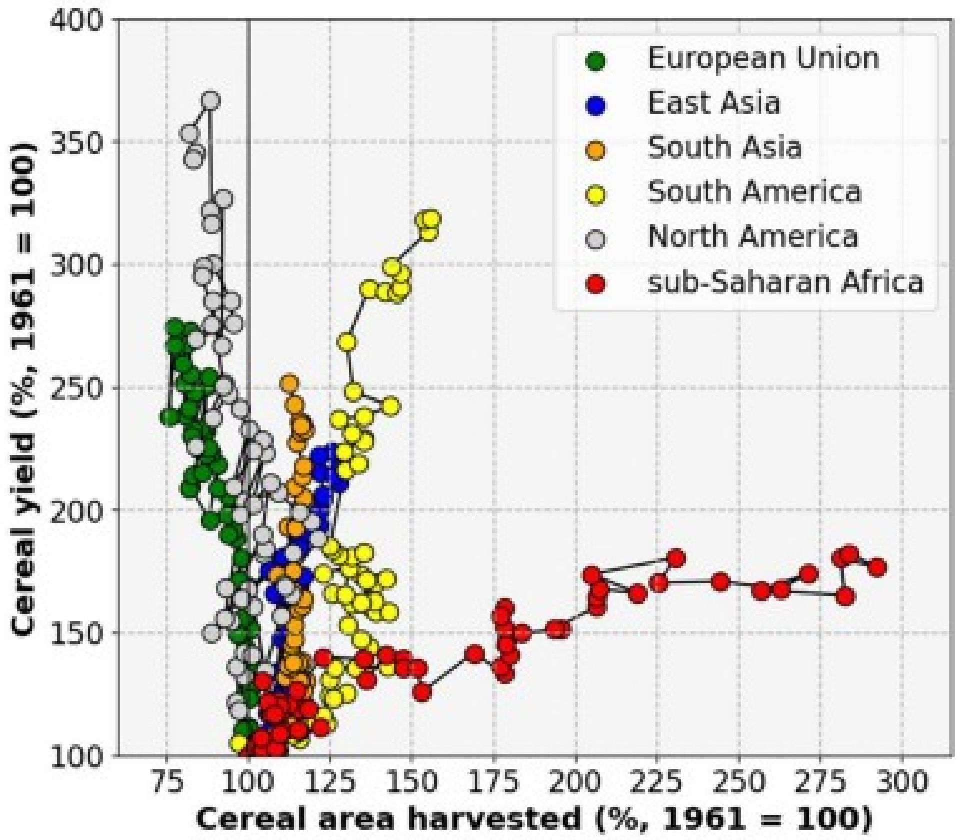
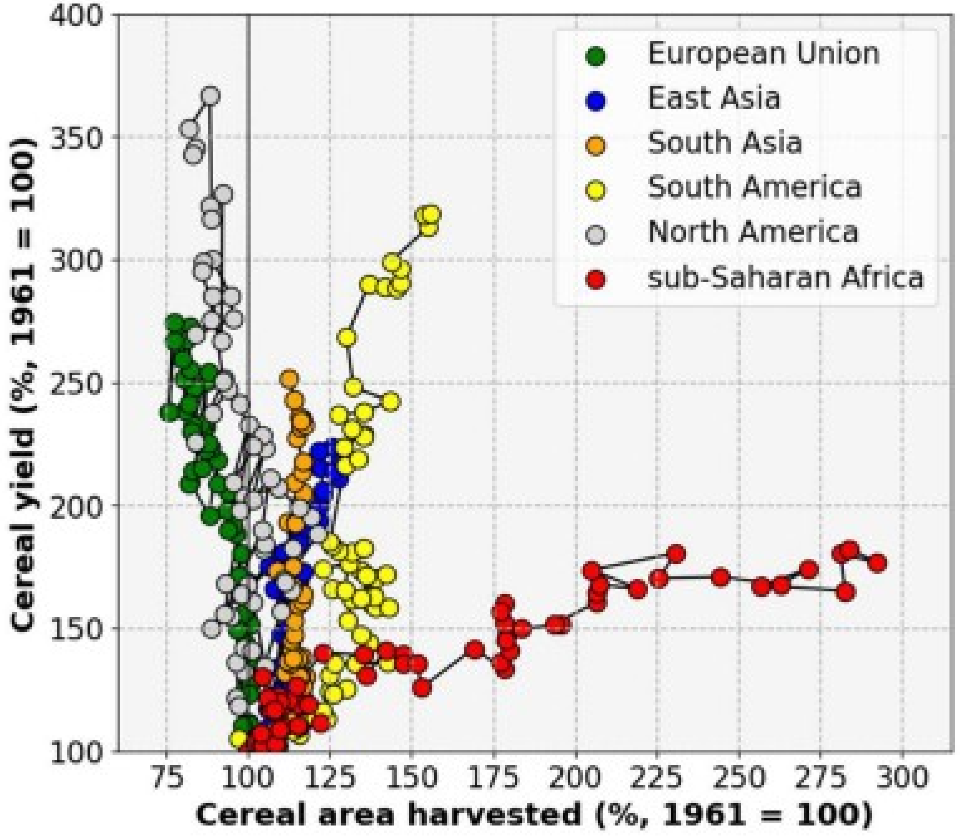
Room for agroecological intensification in Sub-Saharan Africa



Vanlauwe et al 2023

Room for agroecological intensification in Sub-Saharan Africa



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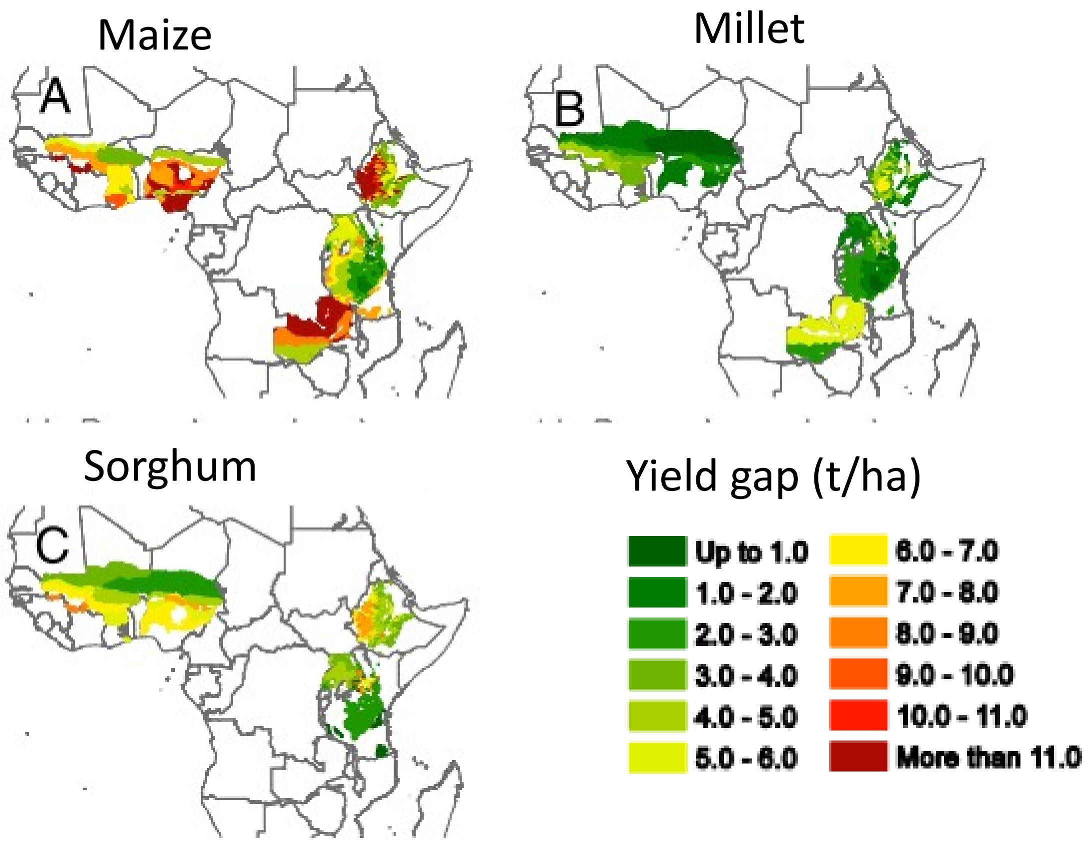


Van Ittersum et al 2016

Climate change adapation

- **Agricultural adaptations that have deserved great attention:**
  - Varietal choice
  - Mineral fertilizer use
- **Agroecological practices less accounted for:**
  - Residue mulching
  - Legume integration (rotation and intercropping) with cereals
  - Application of organic amendments

Rik Schuiling - TropCrop /TCS

Collective research effort

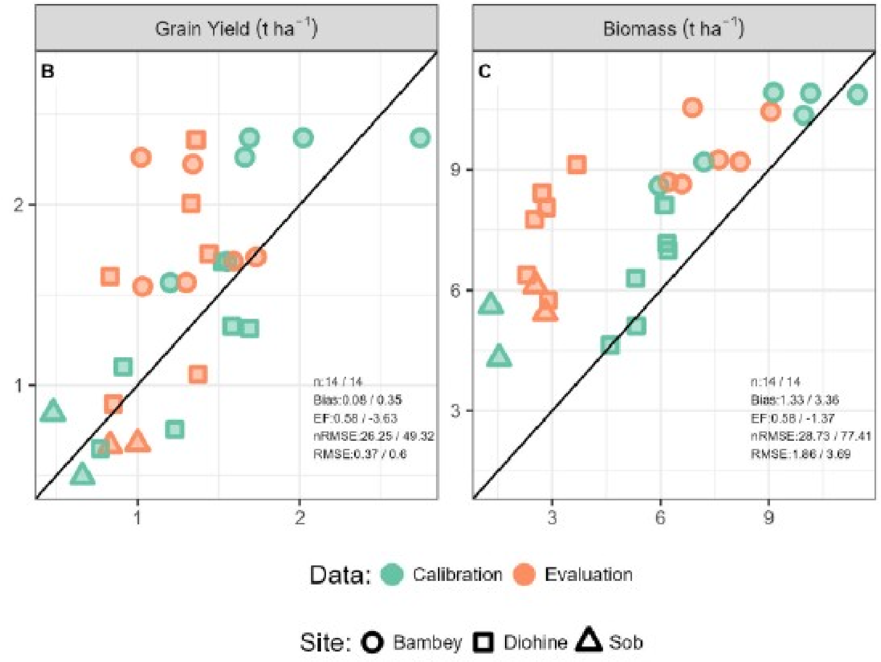
- To update and test STICS to account for the **impact of agroecological practices** on cropping system performance in the tropics.
- **Calibration and evaluation** on multiple years of measurements in contrasting experimental sites:
  - from cool to warm,
  - from semi-arid to sub-humid subtropical environments
  - in Senegal, Zimbabwe, Mali, Burkina Faso, Kenya, Brazil and Madagascar.
- **Virtual experiments to** assessment performances in face of climate variability (long-term simulations)

Table of content

i) new cereal and legume crops (1/3)

- Over-estimation of low yields (underestimation of water stress)

Millet - Senegal



Sow et al, in revision

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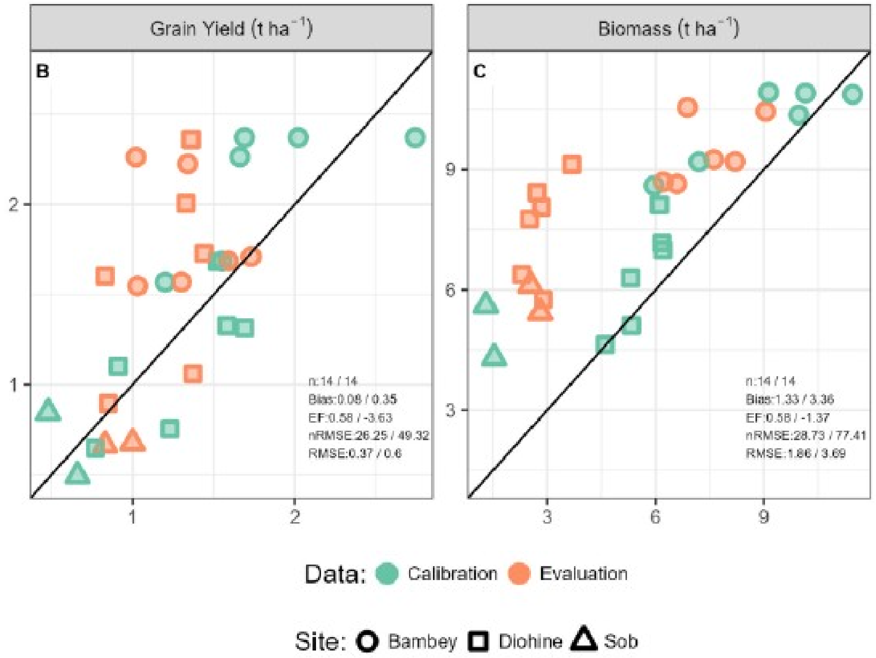

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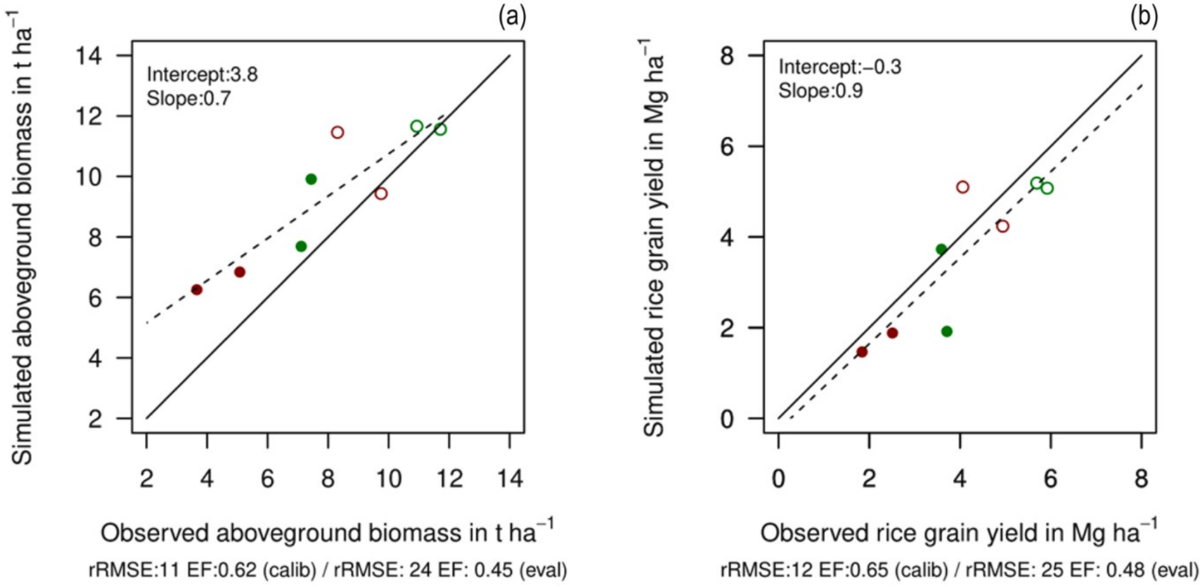

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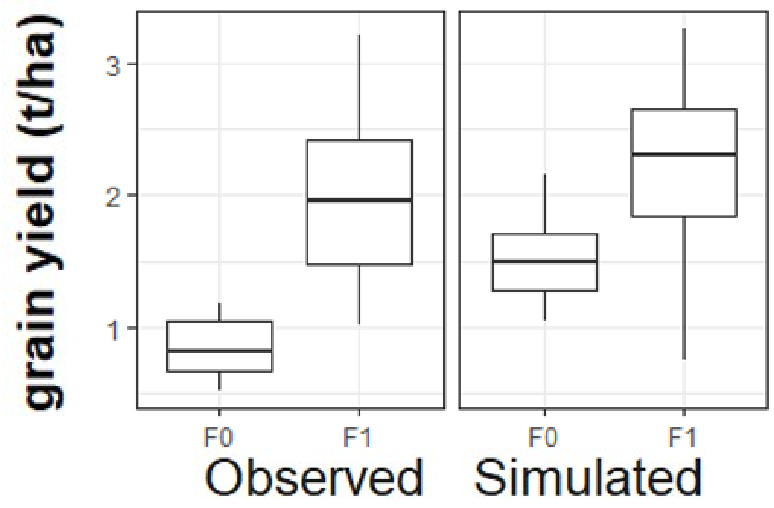
i) new cereal and legume crops (2/3)

- Over-estimation of yield under unfertilized conditions (in season N mineralisation over-estimated)

Sorghum - Mali



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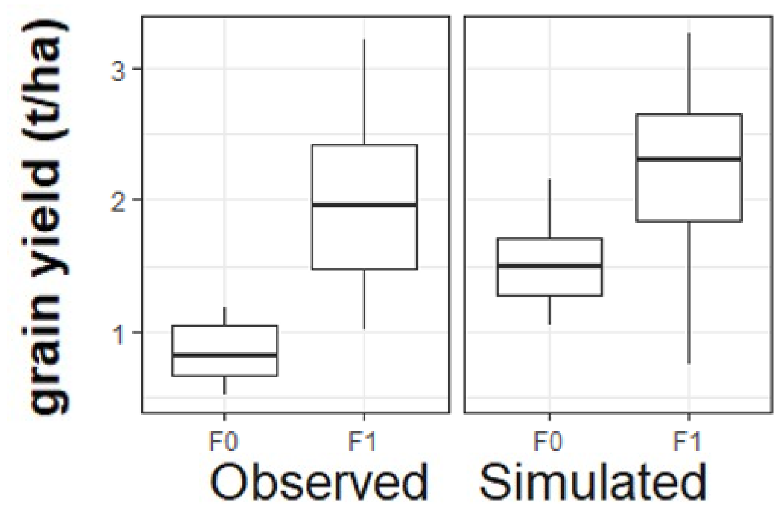

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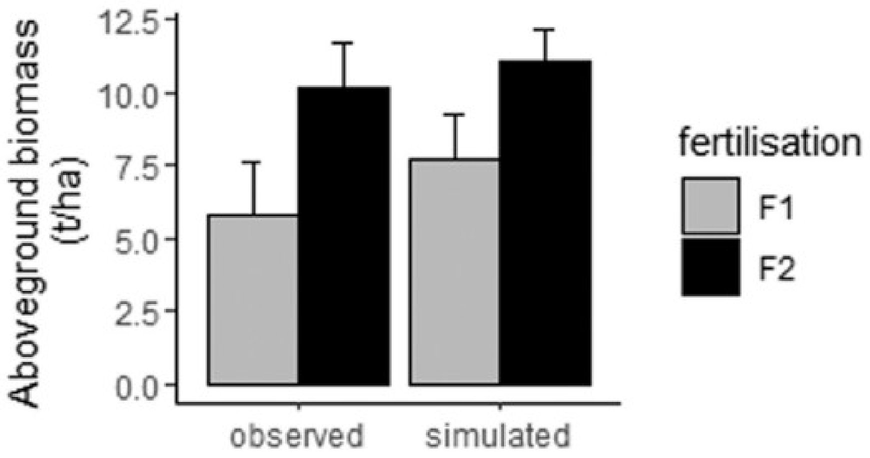

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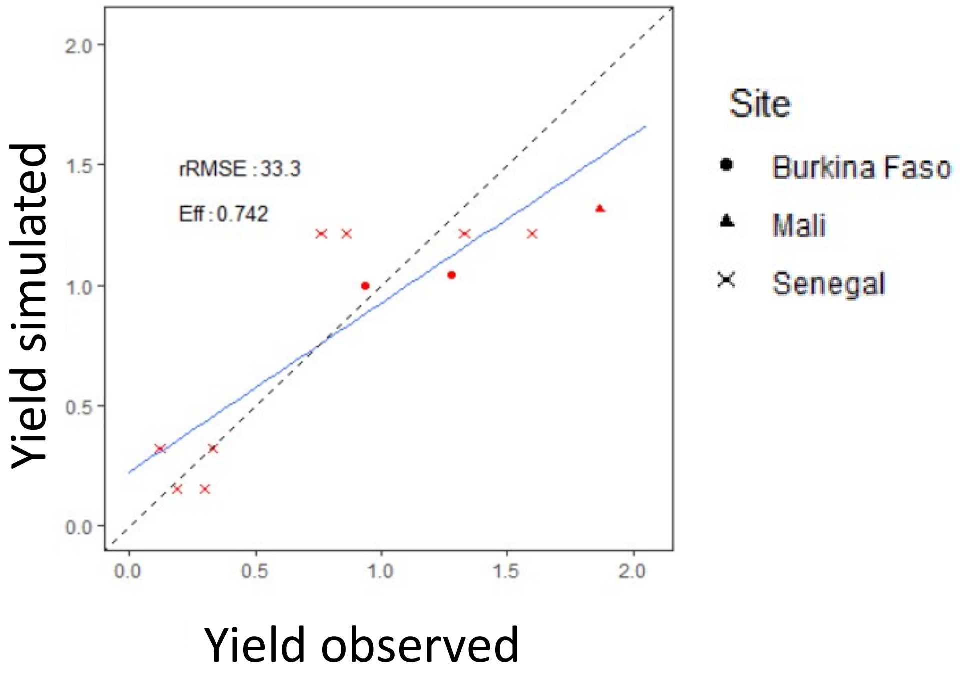
Cowpea – 3 sites in West Africa



de Freitas, 2022

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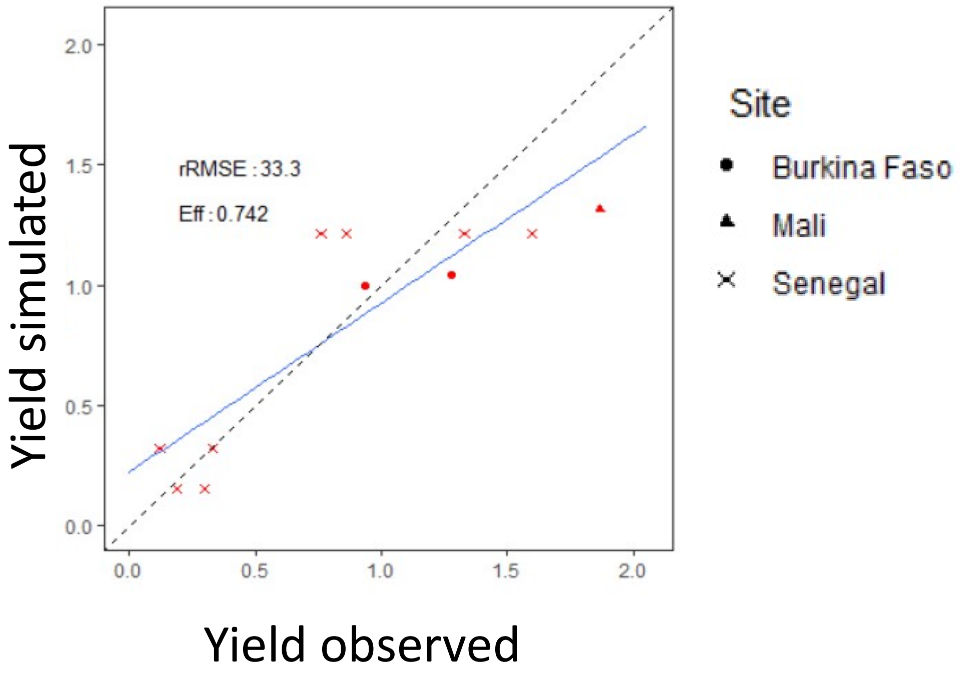

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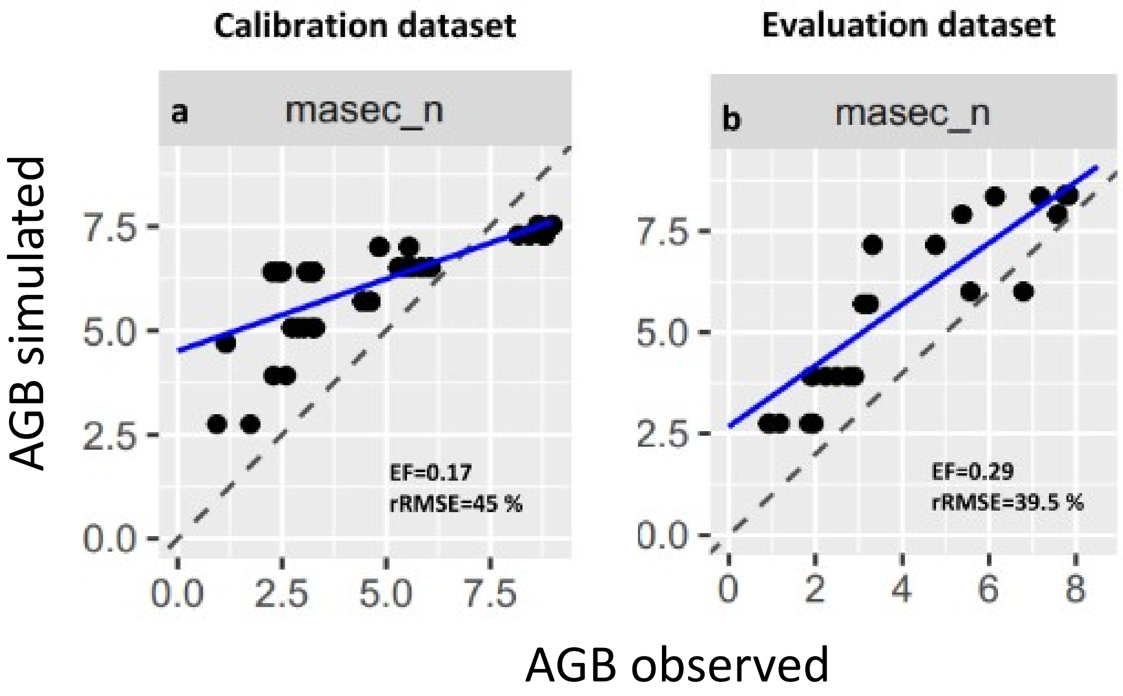
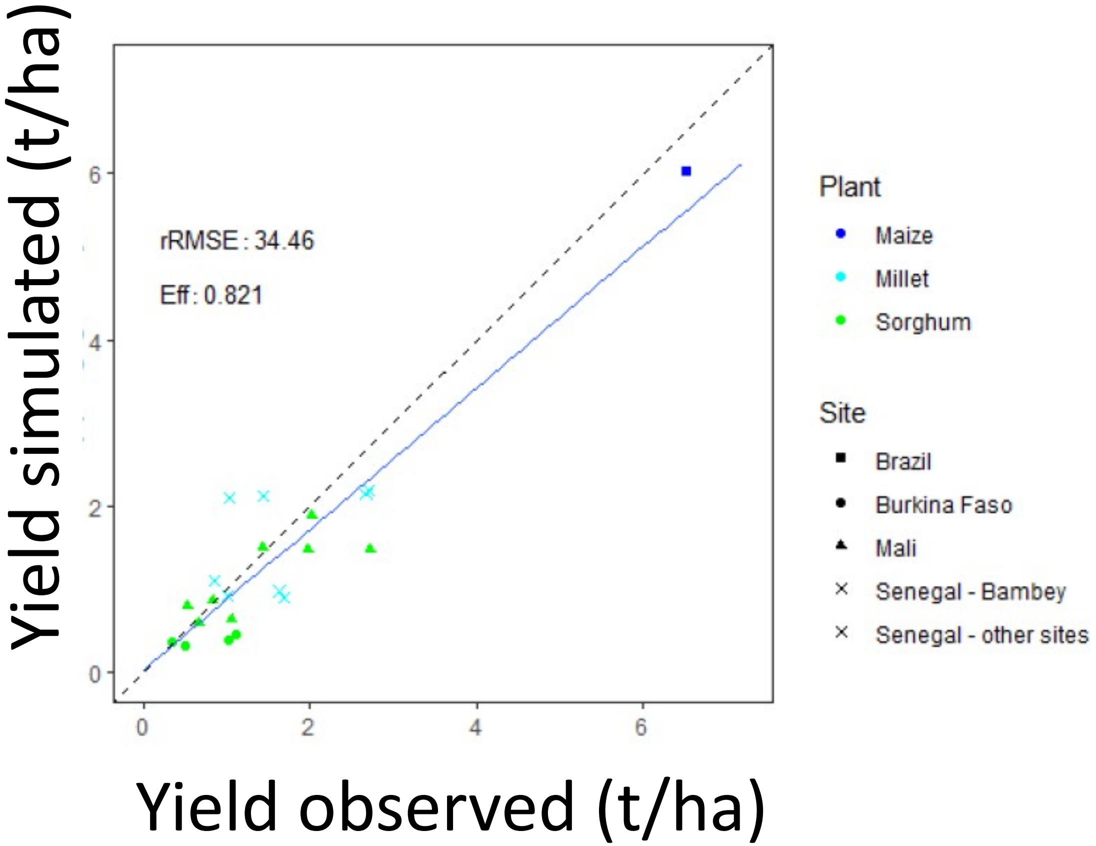
Groundnut - Senegal



Civil, 2022

ii) cereal-legume intercropping (1/2)

- **Cereal and legume calibration** in inter-cropping (de Freitas 2023)



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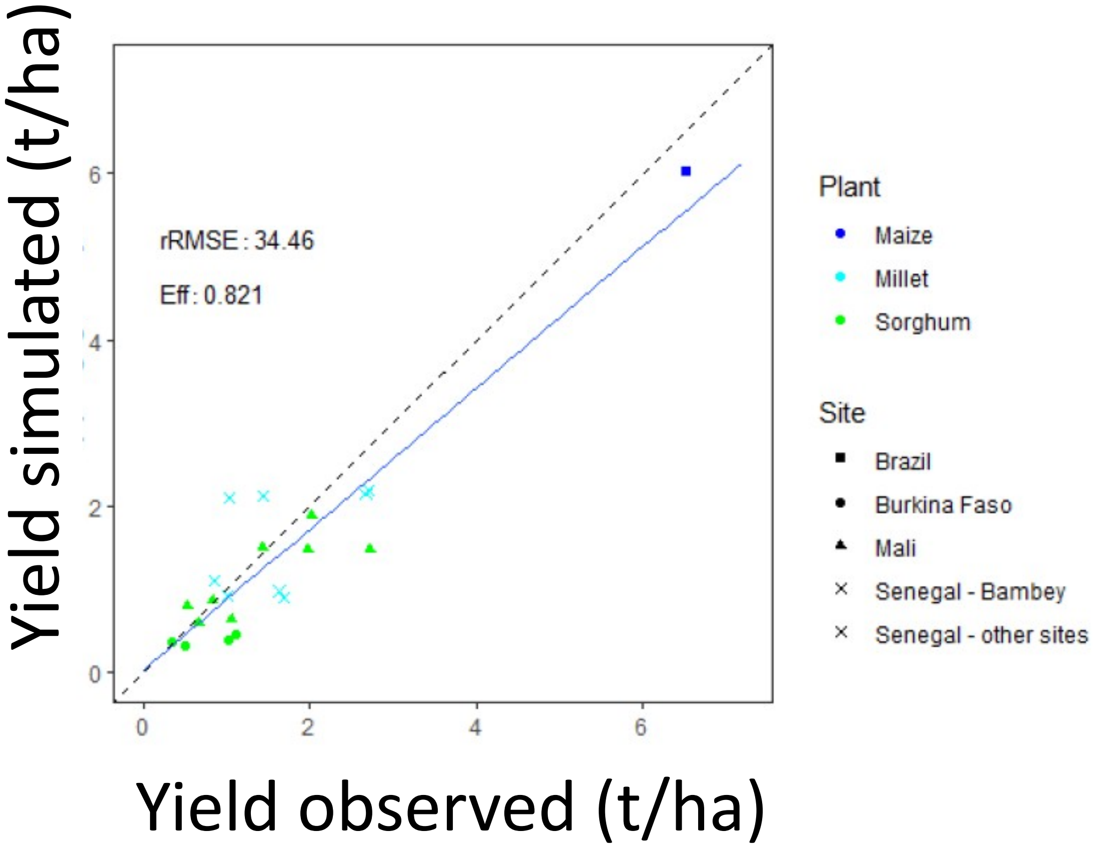
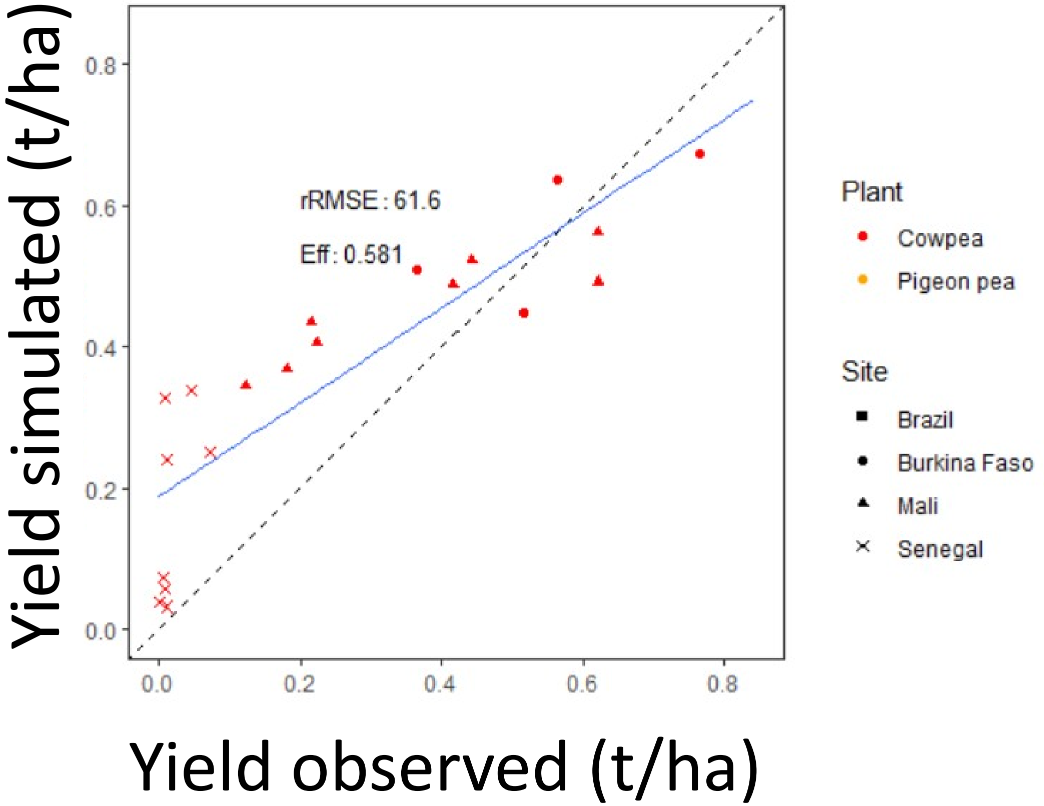
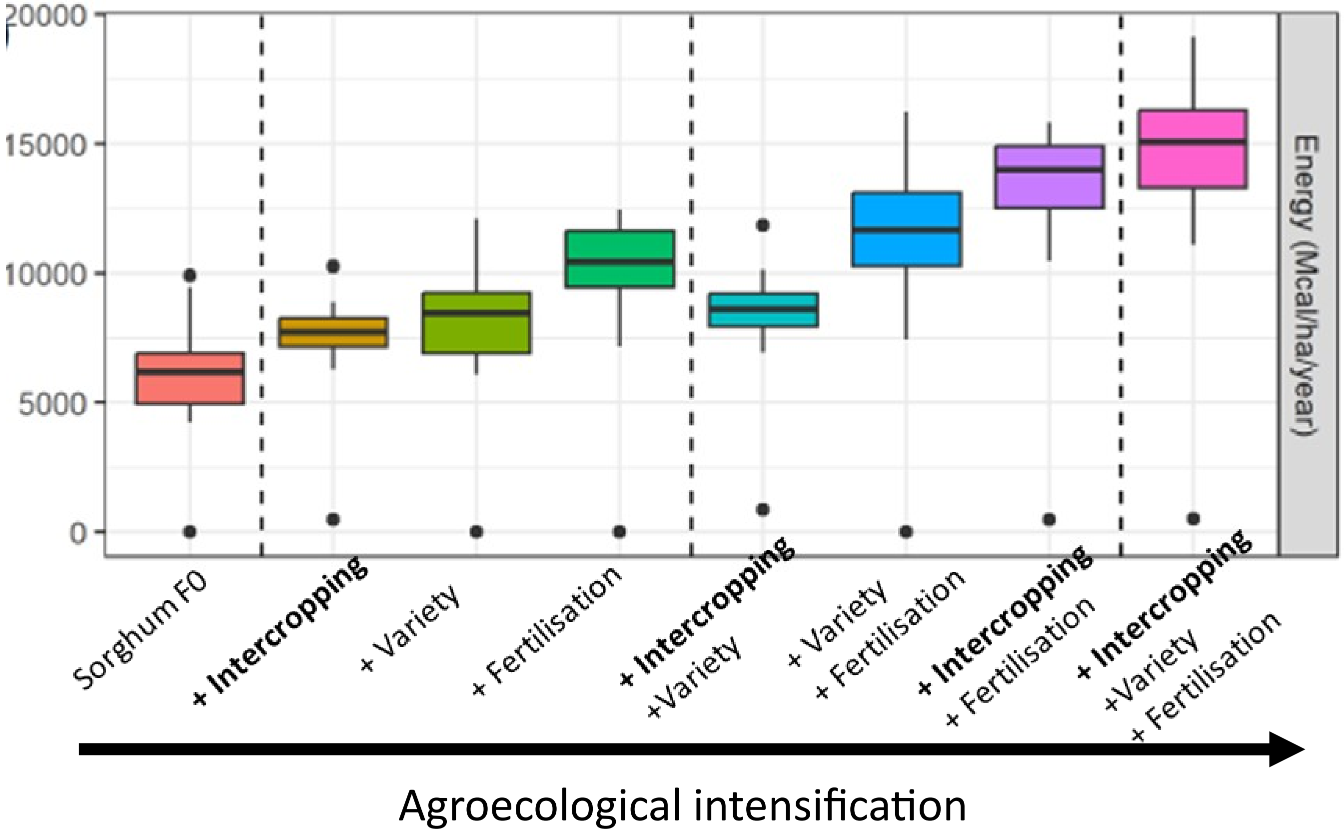




de Freitas, 2023 → Presentation tomorrow at 9:20am

ii) cereal-legume intercropping (2/2)

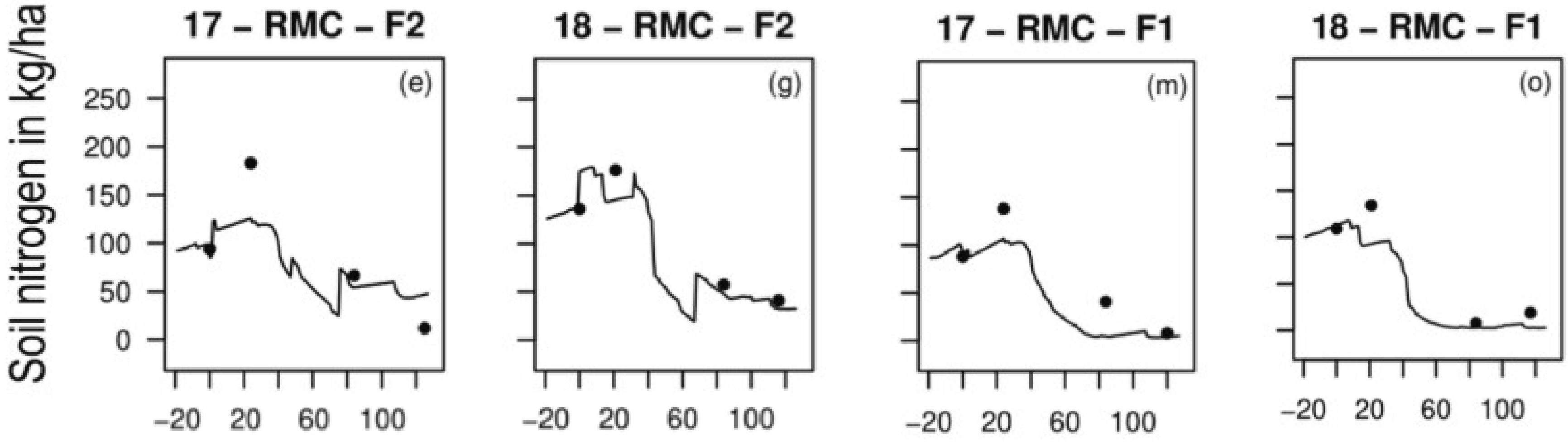
- **Virtual experiment** to assess the interest of intercropping vs sole cropping in Mali (Traoré et al 2023)



Traoré et al, 2023

iii) Crop/manure residue decomposition and feedback on crop growth (1/3)

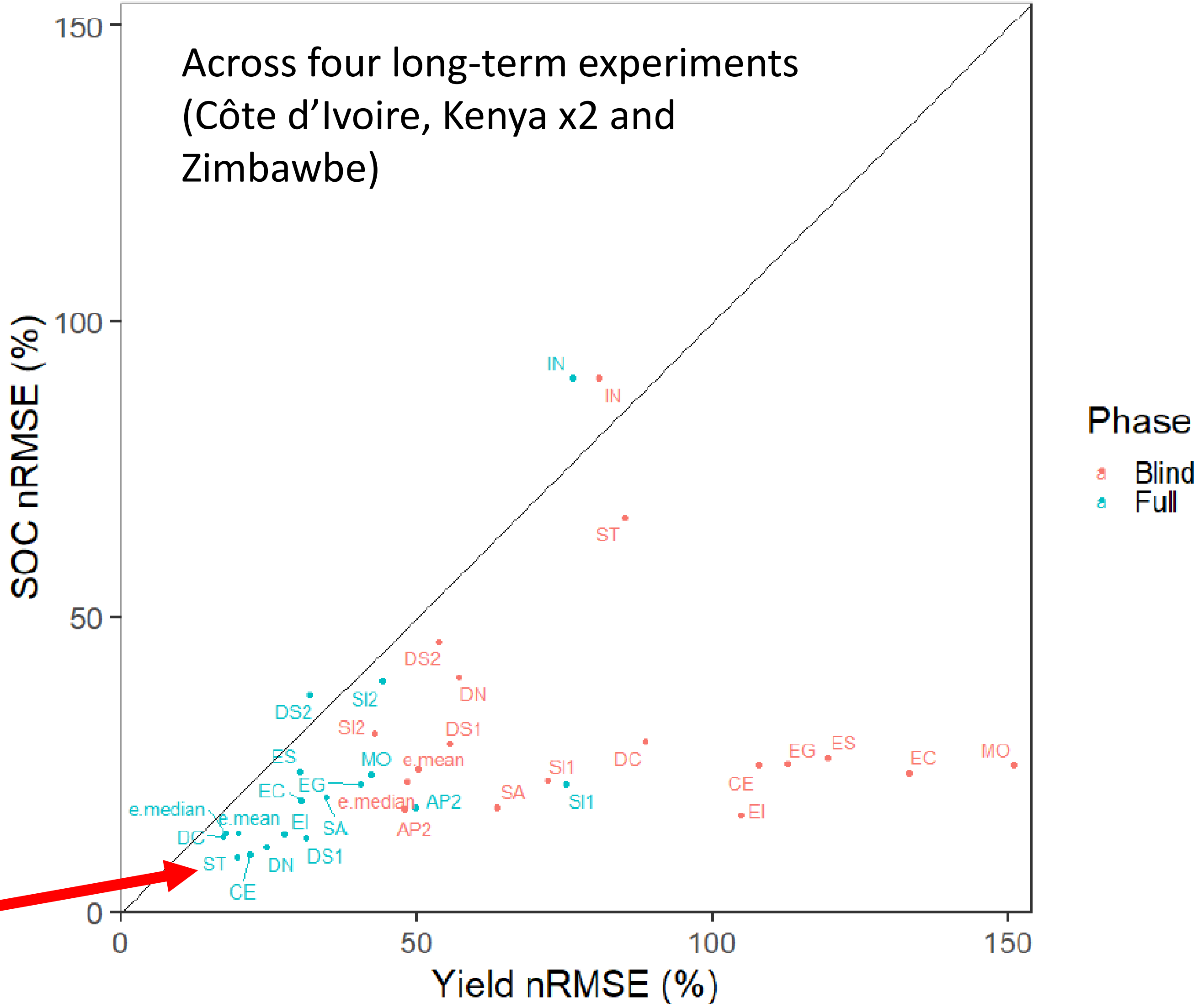
- mucuna + crotalaria green manures effect on soil N during rice cropping season (Ranaivoson et al 2022)



Ranaivoson et al., 2022

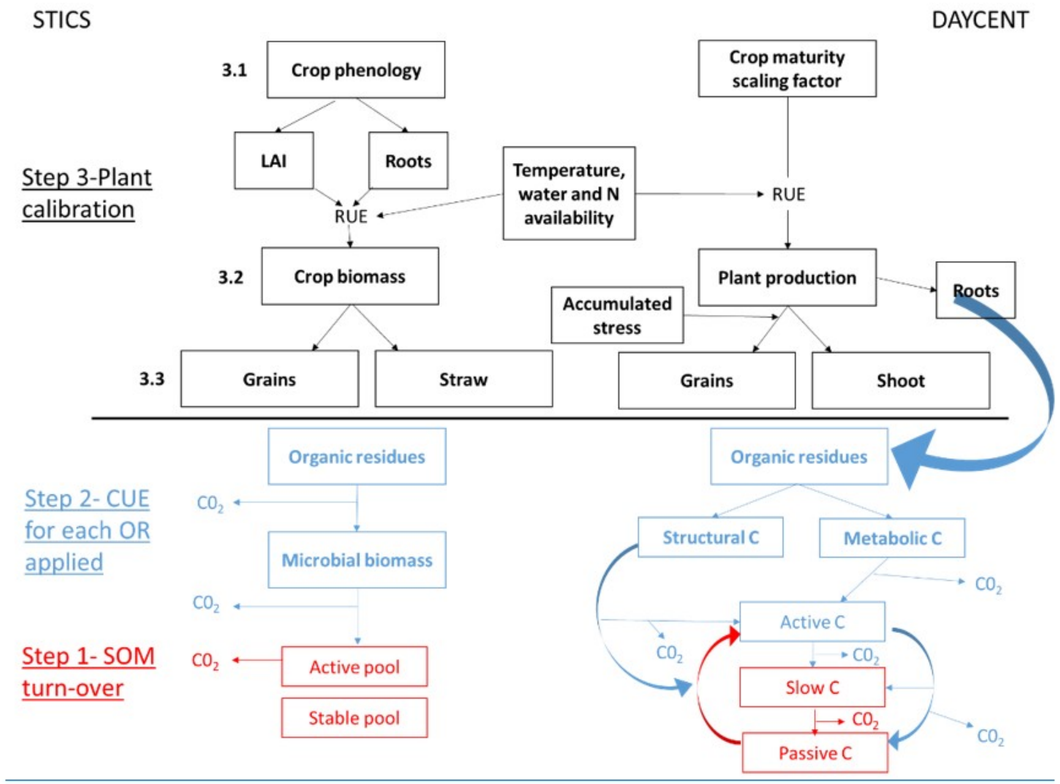
iii) Crop/manure residue decomposition and feedback on crop growth (2/3)

- **STICS reproduced well the observed feedback** between declining soil organic carbon and declining yield (Couëdel et al. under review)



iii) Crop/manure residue decomposition and feedback on crop growth (3/3)

- **Soil organic carbon calibration** on long term trials for different organic residues (Couëdel et al. in prep)



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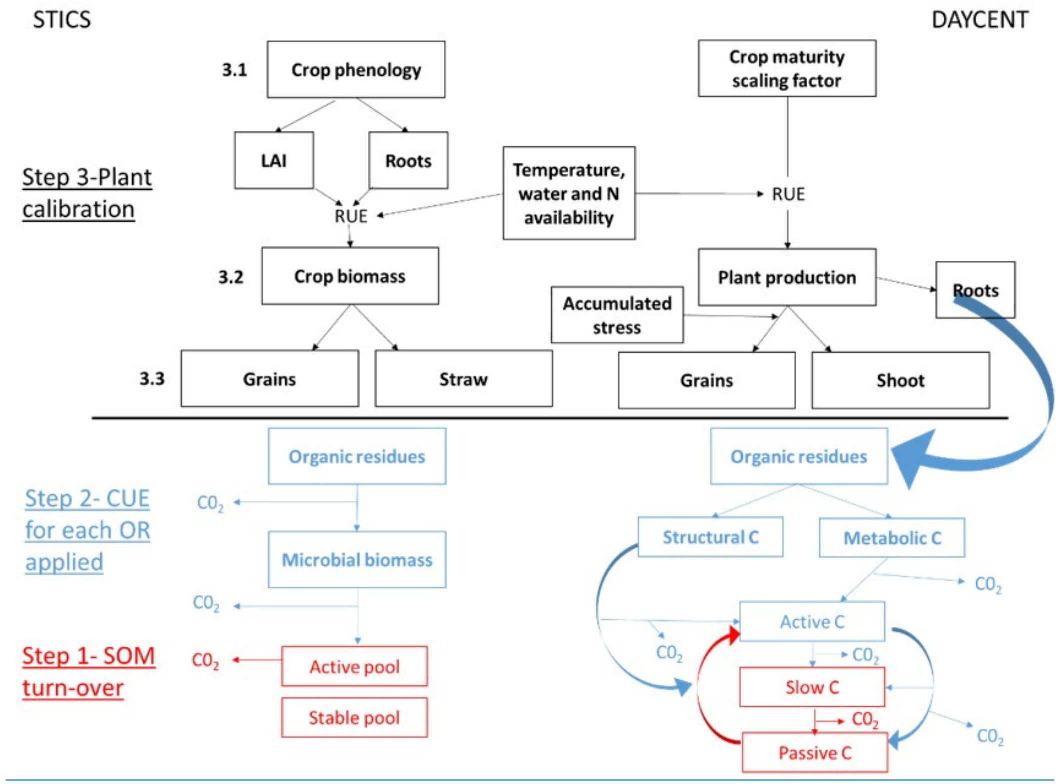
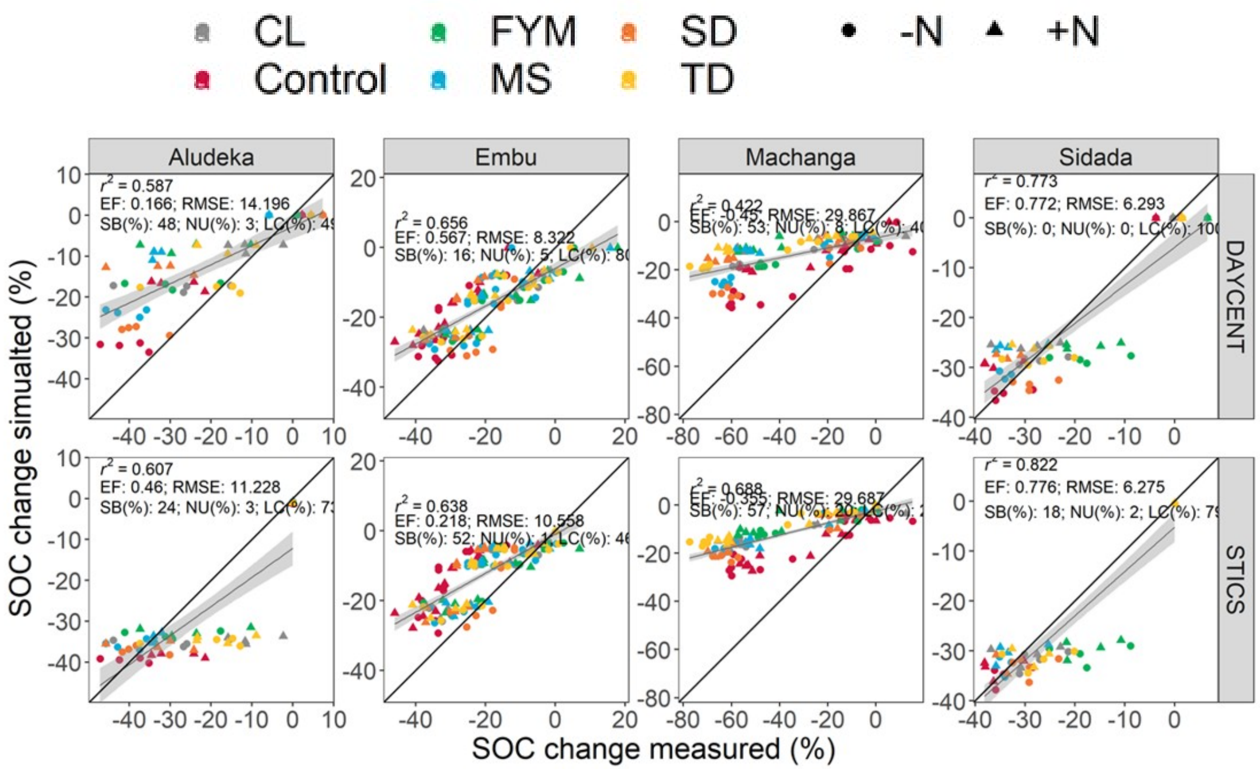


Kenya – 4 sites



CL= Calliandra, FYM = farmyard manure, MS= maize stover, SD = sawdust, TD= Tithonia diversifolia

iv) crop residue mulching

- Crop residue mulching helps reduce evaporation and can be a key adaptation strategy.
- Earlier simulation study showed that **soil temperature under mulch (Balde, 2011) was not adequately represented**, leading to poor simulation of soil organic matter mineralization.
- This issue is currently being investigated **with new data collected in sub-humid Zimbabwe** so that new formalisms can be implemented into the model (new Stics modelling branch, Souleymane Diop).

Plans to move forward

- **New evaporation function** to be developed to account for the specificities of warm tropical environments (Souleymane Diop)
  - i.e. topsoil does not necessarily reach field capacity after a rainfall event
  - i.e no more evaporation after long dry periods (wilting point not reached)

- **New mineralization function** specific to the tropical context
  - Better simulation of in-season soil organic matter mineralization and long-term soil organic carbon trends

- **New data on nitrogen fixation** will be used to test the accuracy of model simulation with the current set of calibrated plant parameters.

Thank you for your attention!

References

Balde, A.B., 2011. Analyse intégrée du partage des ressources (eau , azote et rayonnement) et des performances dans les systèmes de culture en relais sous semis direct en zone tropicale subhumide. Thèse. SUPAGRO Montpellier.

Civil, J.-A., 2022. Modélisation de la croissance et du rendement de l'arachide (Arachis hypogaea L.) en milieu tropical : cas du bassin arachidier du Sénégal. Institut de Recherche pour le Développement (IRD), CNRS IRD – UMR-242.

Couëdel, A., Falconnier, G., Corbeels, M., Adam, M., Cardinael, R., Boote, K., Justes, E., Smith, W., et al. Long term soil organic carbon and crop yield feedbacks differ between 16 soil-crop models in sub-Saharan Africa (under review in European Journal of Agronomy).

de Freitas, M., 2023. Intercropping cereals and legumes to stabilise yield in the tropics : evaluation of the STICS soil-crop model to simulate bi-specific intercrops. AgroParisTech.

Ranaivoson, L., Falconnier, G.N., Affholder, F., Leroux, L., Autfray, P., Muller, B., Auzoux, S., Ripoche, A., 2022. Can green manure contribute to sustainable intensification of rainfed rice production in Madagascar? F. Crop. Res. 289, 108711.

Traoré, A., Falconnier, G.N., Ba, A., Sissoko, F., Sultan, B., Affholder, F., 2022. Modeling sorghum-cowpea intercropping for a site in the savannah zone of Mali : Strengths and weaknesses of the Stics model. F. Crop. Res. 285.

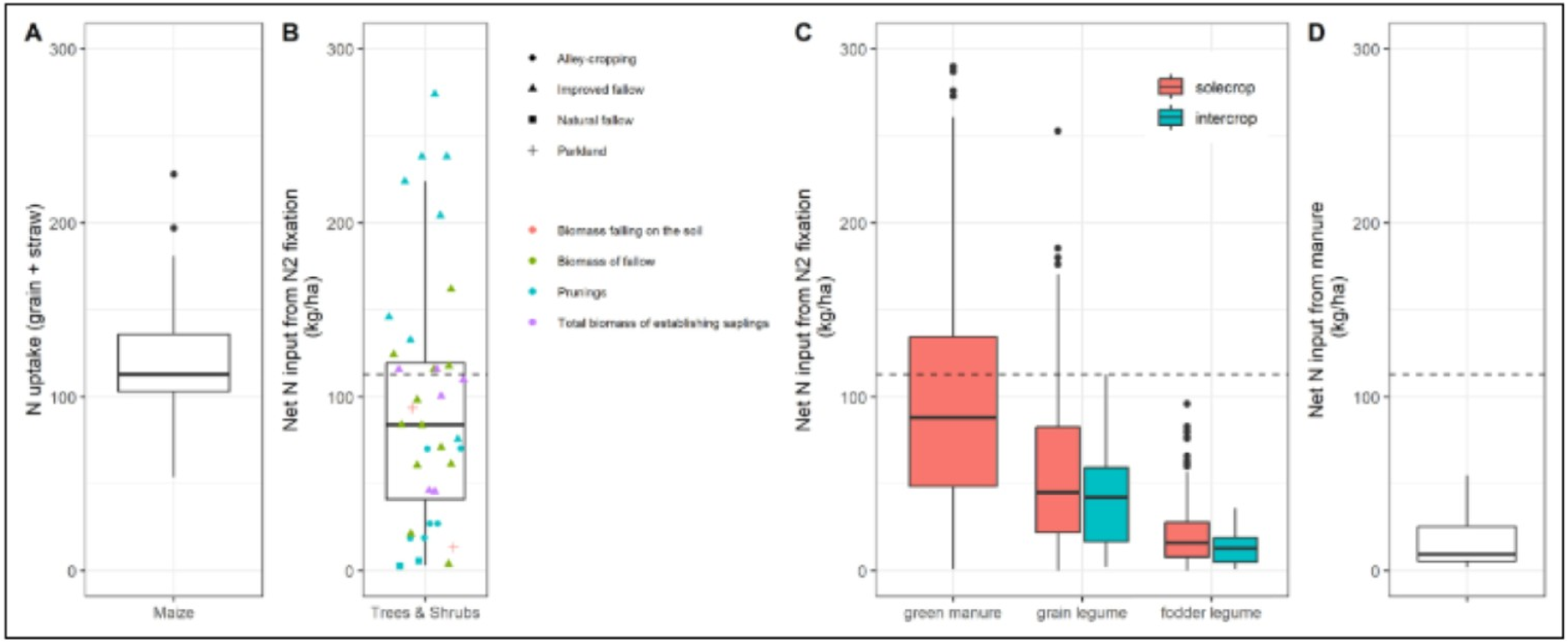
Traore, A., Falconnier, G.N., Couëdel, A., Sultan, B., Chimonyo, V.G.P., Adam, M., Affholder, F., 2023. Sustainable intensification of sorghum-based cropping systems in semi-arid sub-Saharan Africa : The role of improved varieties , mineral fertilizer , and legume integration. F. Crop. Res. 304.

Sow, S., Senghor, Y., Sadio, K., Vezy, R., Roupsard, O., Affholder, F., N'dienor, M., Clermont-Dauphin, C., Gaglo, E., Ba, S., Tounkara, A., Balde, A., Agbohessou, Y., Seghieri, J., Nourou Sall, S., Couedel, A., Leroux, L., Diate, D., Falconnier, G. Calibrating the STICS soil-crop model to explore the impact of agroforestry parklands on millet growth (under review in F. Crop. Res.)

Table 3
Values of sorghum parameter as calibrated in the STICS crop model for experiments at N'Tarla in Mali.

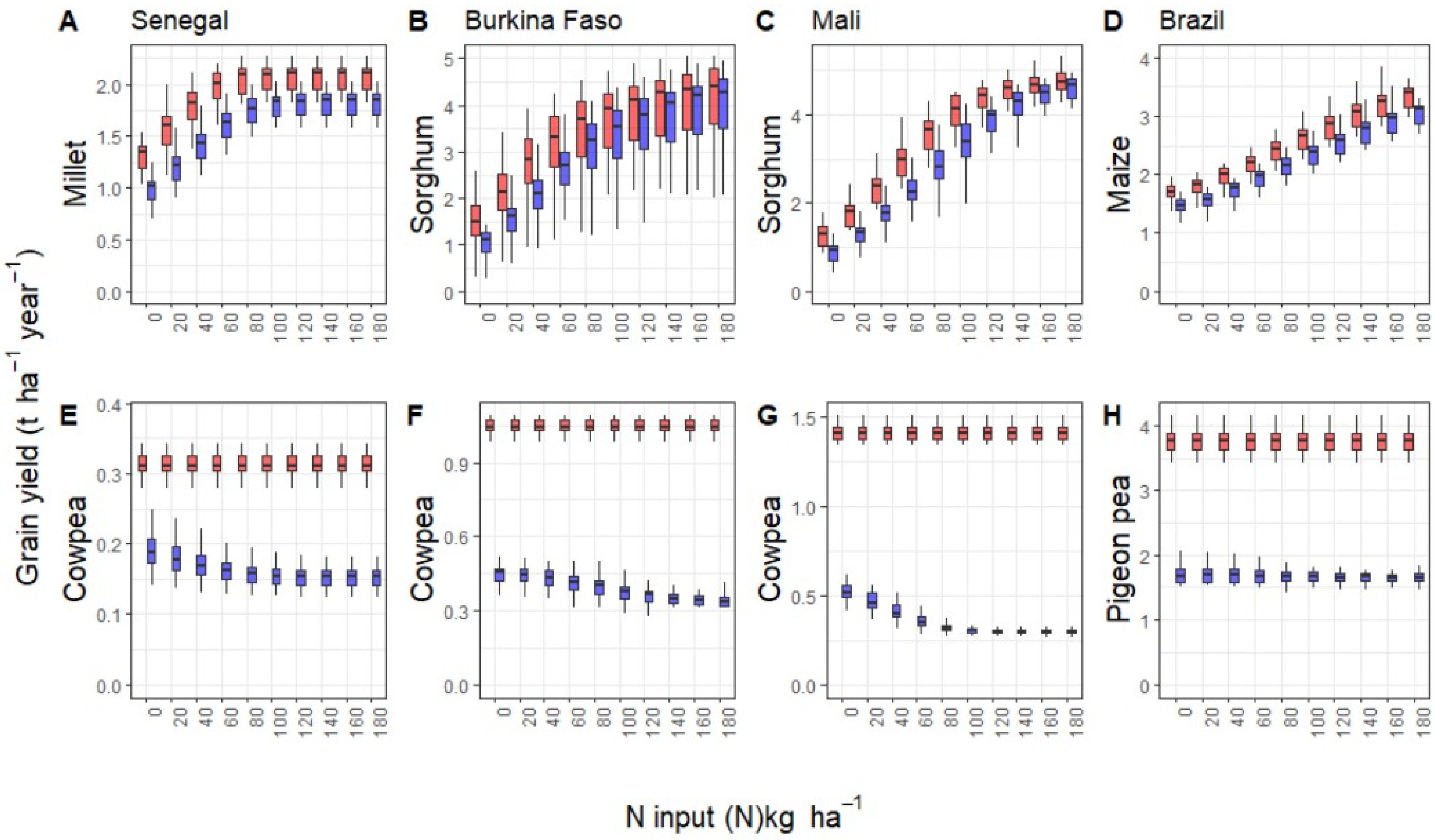
Parameter				Value			
Process	acronym	Description	Target variable	V1	V2	Cowpea	Source
Emergence	tdmin	basal temperature for crop development	Leaf area index	8	8	6.2	Folliard et al. (2004), Luo (2011)
Crop development	sensiphot	index of photoperiod sensitivity (1 =insensitive)		0.4	0.6	–	Trial and error calibration
	phobase	basal photoperiod controlling photoperiod slowing effect		14	14	–	Traore (2015)
	phosat	saturating photoperiod controlling photoperiod slowing effect		12,75	12.75	–	Traore (2015)
	stlevamf	cumulative thermal time between emergence and end of juvenile phase		180	718	881	Test of a range of values
	stamflax	cumulative thermal time between end of juvenile phase and maximum LAI		305	314	687	Trial and error calibration
	stlevdrp	cumulative thermal time between emergence and beginning of grain filling		685	1077	1609	Trial and error calibration
Leaves	dlaimaxbrut	maximum rate of the setting up of LAI		0,0015200	0.01	0.0035	Trial and error calibration
	durvieF	maximal lifespan of an adult leaf		480	280	240	Trial and error calibration
Shoot growth	efcroijuv	maximum radiation use efficiency during the juvenile phase	Aboveground biomass	2.1836	2.1877	1.2	Trial and error calibration
	efcroirepro	maximum radiation use efficiency during the grain filling phase	Aboveground biomass	3.8572	2.8372	1.3559	Trial and error calibration
	efcroiveg	maximum radiation use efficiency during the vegetative stage	Aboveground biomass	3.8049	2.8414	1.7465	Trial and error calibration
	temin	basal temperature for photosynthesis	–	11	11	7.2	Folliard et al. (2004), Luo (2011)
	teopt	optimal temperature for photosynthesis	–	25	25	27	Folliard et al. (2004), Luo (2011)
	temax	maximal temperature for photosynthesis	–	45	45	40	Folliard et al. (2004), Luo (2011)
Nitrogen fixation	fixmaxgr	maximal N symbiotic fixation rate per unit of grain growth rate	N_2 fixed[a]	–	–	9.5	Trial and error calibration
	fixmaxveg	maximal N symbiotic fixation rate per unit of vegetative growth rate	N_2 fixed[a]	–	–	30	Trial and error calibration
Nitrogen uptake	Kmabs2	affinity constant of N uptake by roots for the low uptake system	N uptake	40,000	37,672.32	25,000	numerical optimization
	Vmax2	maximum specific N uptake rate with the high affinity transport system	N Uptake	0.1	0.00878	0.06	numerical optimization
Yield formation	cgrain	slope of the relationship between grain number and growth rate	Number of grains	0.06	0.07	0.084	Trial and error calibration
	nbjgrain	Duration in days of the period during which the number of grains can be reduced by stresses	Number of grains	15	15	15	Traore (2015)
	cgrainv0	number of grains produced during the nbjgrains before beginning of grain filling	Number of grains	0	0	0.069	Trial and error calibration
Yield formation	vitircarbe	rate of increase of the C harvest index vs time	grain yield	0.009	0.015	0.01462	Trial and error calibration
	nbgrmax	maximum number of grains	grain yield	25,000	60,000	1200	Measurement
	pgrainmaxi	maximum weight of one grain	grain yield	0.027	0.0247	0.25	Measurement
	Irmax	maximum harvest index	grain yield	0.3	0.51	0.42	Measurement

[a] N_2 fixed by the legume was not measured, but estimated for sole cowpea as the difference between the N uptake of sole sorghum without fertilizer and N uptake of sole cowpea.


A
N uptake (grain + straw)
Maize
B
Net N input from N2 fixation (kg/ha)
Trees & Shrubs
Alley-cropping
Improved fallow
Natural fallow
Parkland
Biomass falling on the soil
Biomass of fallow
Prunings
Total biomass of establishing saplings
C
Net N input from N2 fixation (kg/ha)
solecrop
intercrop
green manure
grain legume
fodder legume
D
Net N input from manure (kg/ha)
0
100
200
300

ii) cereal-legume intercropping (5/5)

- **Virtual experiment** to assess the interest of intercropping vs sole cropping (de Freitas 2023)



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