STICS ability to simulate long-term soil organic matter dynamics in crop-grassland rotations

Anne-Isabelle Graux, Alice Cadero, Samuel Buis, Eric Casellas, Marie-Laure Decau, Patrice Lecharpentier, Frédérique Louault, Strullu Loïc, Francoise Vertès, Fabien Ferchaud

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CarSolEl - Construction of a methodology and a reference system for carbon flows in agricultural soils in cattle farming areas

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INRAE

INSTITUT DE L'ELEVAGE idele

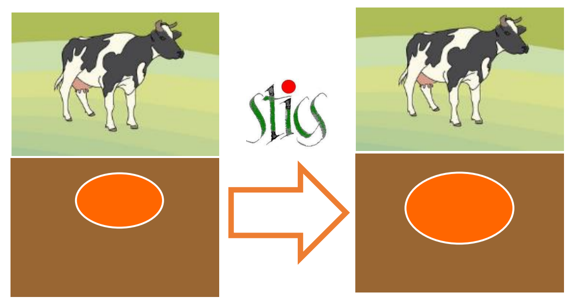
ADEME
Agence de l'Environnement et de la Maîtrise de l'Energie

Background

Many environmental and agronomical factors

- Soil and climate conditions
- (current and past) Management
- Species composition of grasslands

C inputs & soil C mineralization



Grasslands ability to store C well recognized

difficult to quantify

=> often modelled

Modelling the evolution of soil organic carbon (SOC) requires that models are sufficiently robust and accurate in their prediction

Background

STICS ability to simulate SOC

- **Evaluated in arable crop systems**, with satisfactory results (Autret et al., 2020; Yin et al., 2020; Clivot et al., 2020)

- **Not yet** in **rotations** including **temporary grasslands**, nor in **permanent grassland** soils

=> CarSolEl’s objective

How good is the simulation of long-term soil C evolution in these situations? Are the C inputs linked to the roots well simulated? Can simulation be improved through parameterization?

Approach: model calibration & assessment

Used a research version derived from v10.0 Oct 2023

Fixes bugs regarding senescence & return to the soil of the residual shoot biomass after removal

Initial (standard grass file)

Revision of grassland parameters

based on **previous works** (Graux et al., 2020; Launay et al. 2020)

Activated options to simulate roots

“**True density**” to simulate root emission and senescence versus time and depth	“**Continuous trophic link**” to drive root length expansion by shoot growth	“**Root deposition**” to simulate a daily recycling of dead root biomass within the soil profile

10 new root parameters (5 parameterized according to literature)

Used data from 3 long-term trials to calibrate STICS/assess SOC simulation

Revision of the value of **6 shoot parameters** to better represent the productive **grassland functional groups** (A, B) present in the experimental trials

Before optimisation

1 trial	2 trials
Optimization of **5 root parameters**	**Assessment** of the **final grassland parameterization**

After optimisation = final

3 long-term French trials: contrasting conditions

Kerbernez
Oceanic climate
3 Rotations: 1 with 3-year TG, **1 PG**
SOM: 4.7%; COS: 81 t C/ha (0-25cm); WHC:190 mm
27 years (1978-2004)
7 obs. of SOC&SON + yield, %N (grassland, corn)

Lusignan
Degraded oceanic climate
4 rotations with 3 or 6-year TG, **2 PG**
SOM: 1.9%; SOC: 48 t C/ha (0-30cm); WHC:180 mm
16 years (2005-2020);
6 obs. of SOC&SON + yield, %N (grassland, corn, wheat, barley); root BM %N %C (grassland); soil water and Nmin

Theix
Semi-continental climate on **mountain margins**
4 PG
SOM: 7%; COS 69 t C/ha (0-20cm); WHC: 80 mm
14 years (2004-2017);
3 obs. of SOC&SON + yield, %N (grassland)

Root parameter optimisation

- **5 parameters** involved in **root simulation**
  - **Allocation of assimilates between shoot and root parts** (krepracperm, repracpermin, repracpermax)
  - **Root lifespan** (debsenrac)
  - **Root nitrogen demand** (parazorac)
- **Nelder-Meade simplex** method (CroptimizR package)
- Data from **Lusignan trial**
  - The most **numerous** and **reliable**, with **root observations**
  - 4 rotations and 2 permanent grasslands
    - **T1**: a rotation of **maize – wheat – barley**
    - **T2**: T1 + **3 yrs.** of grassland, **highly fertilized** and **cut** N+
    - **T3**: T1 + **6 yrs.** of grassland , **highly fertilized** and **cut** N+
    - **T4**: T1 + **6 yrs.** of grassland , **low fertilized** and **cut** N-
    - **T5**: **permanent** grassland, **fertilized** and **cut** N+
    - **T7**: **permanent** grassland, **fertilized** and **grazed** N-

Root parameter optimisation

- Adjustment on **several sets of variables**

opti.	SOC	Cutting yield	Grass N content	Root C	Root N
opti1	x	x			
opti2	x	x	x		
opti3	x	x		x	x
opti4	x	x	x	x	x

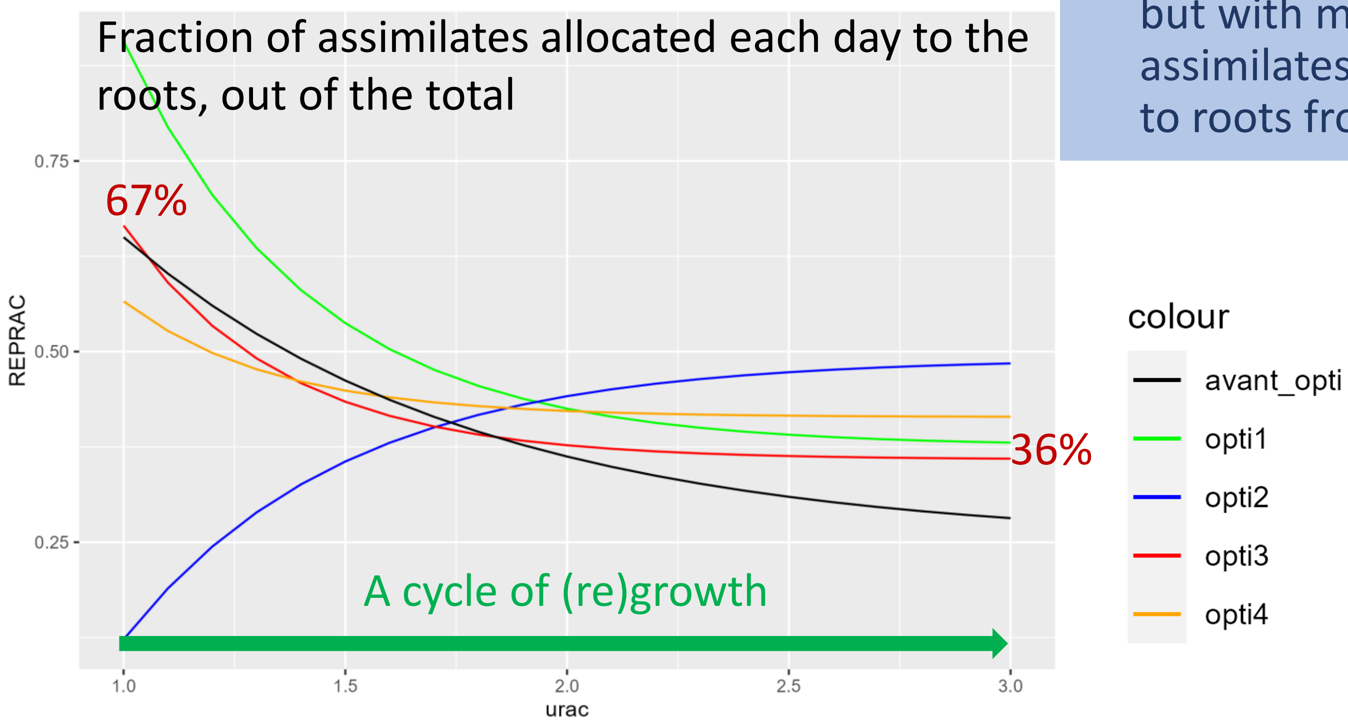
- Root mean square errors (Lusignan)

X	SOC (kg C ha^{-1})	Cutting yield (t DM ha^{-1})	Grass N content (% or 10gN kg^{-1})	Root C (kg C ha^{-1})	Root N (kg C ha^{-1})
initial	1912	1.37	1.07	NA	NA
before opti	1886 😐	1.02 🙂	0.76 🙂	2628	81
after opti1	1731 🙂	1.02 😐	0.85 ☹️	2828 😐	93 ☹️
after opti2	1959 😐	1.07 😐	0.64 🙂	3127 ☹️	93 ☹️
after opti3	2048 😐	1.01 😐	0.75 😐	1110 🙂	36 🙂
after opti4	2004 😐	1.04 😐	0.70 🙂	1115 🙂	38 🙂

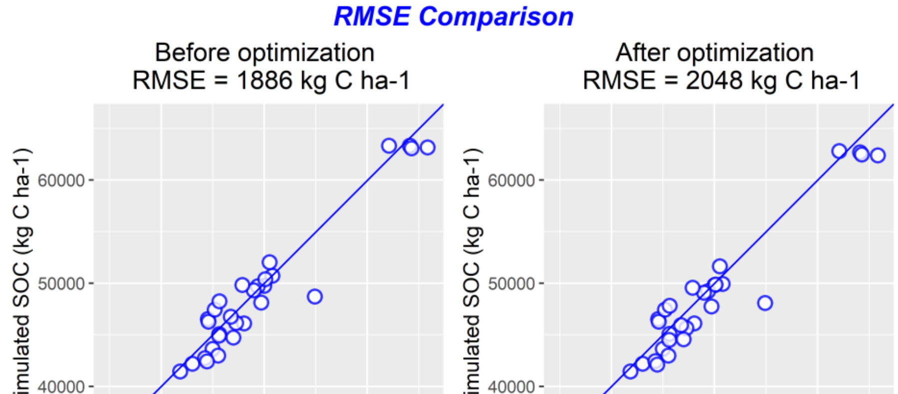
Root parameter optimisation

Parameter	Before optimisation	opti1	opti2	opti3	opti4
krepracperm	1.27	2.38	2.00	2.80	2.95
debsenrac	1200	358	247	3594	2987
parazorac	NA	56.3	20.7	22.6	21.3
repracpermin	0.25	0.38	0.49	0.36	0.41
repracpermax	0.65	0.91	0.12	0.67	0.57

- ↗ in root lifespan
- parazorac = root C/N for INN=1
- dynamics of assimilate allocation between shoot and roots close to those before optimization, but with more assimilates allocated to roots from urac=2



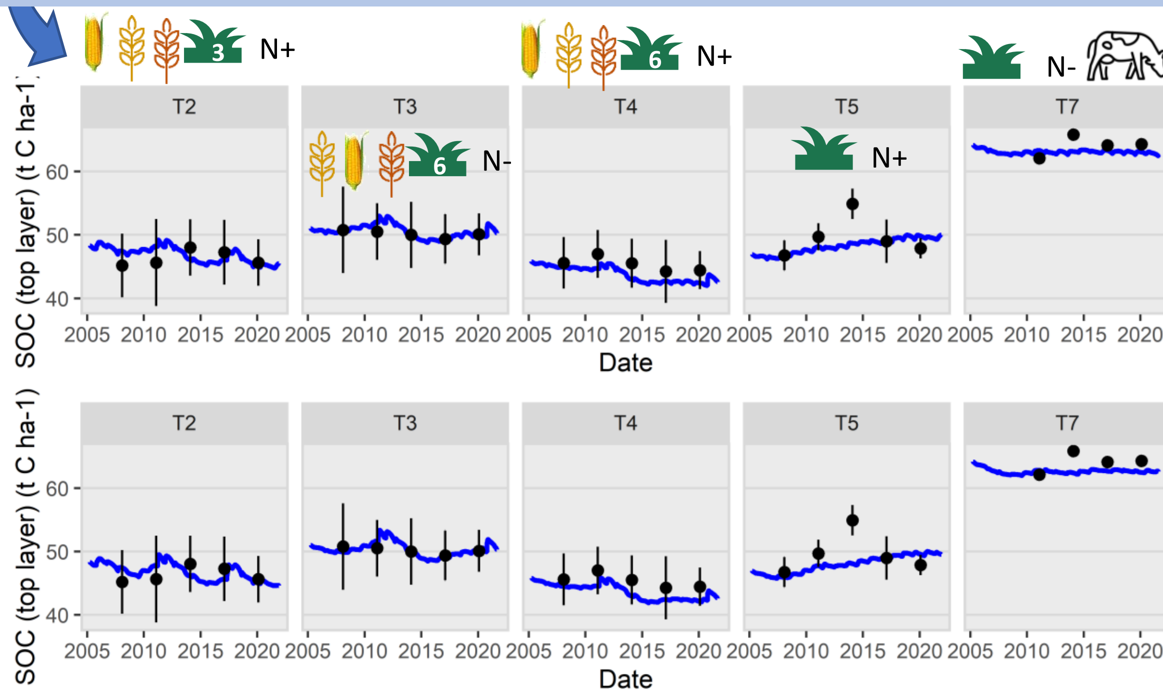
Comparison of SOC (opti. N°3)



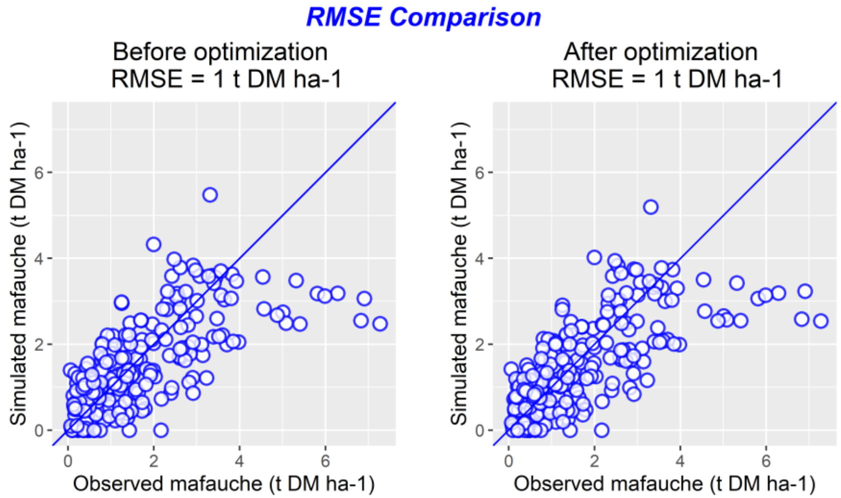
- SOC of all rotations and permanent grasslands within the range of observations
- Slight increase in RMSE after optimization

Before optimization

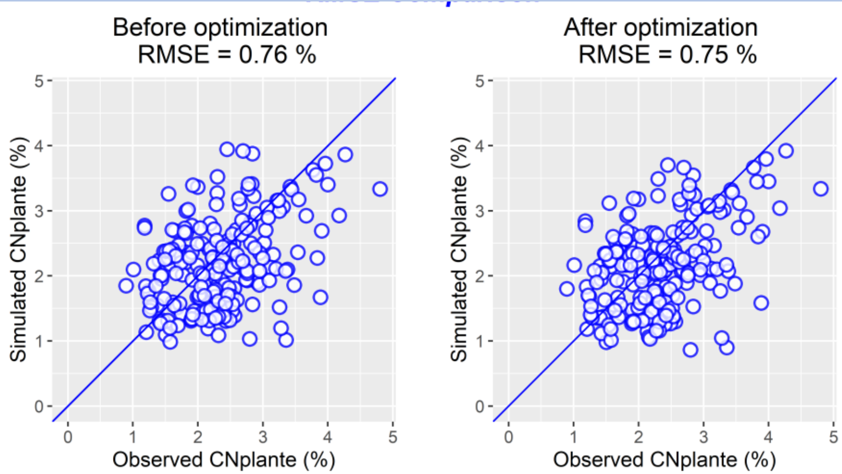
After optimization



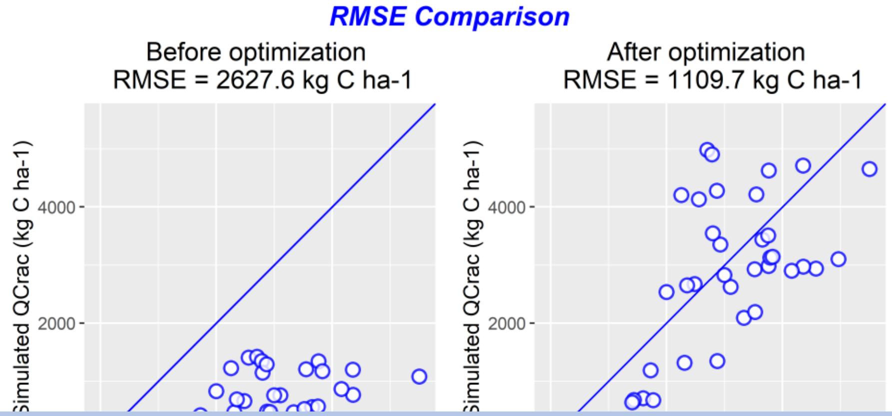
Comparison of grassland yields and grass N contents (opti. N°3)



No change in simulated cutting yield and grass nitrogen content

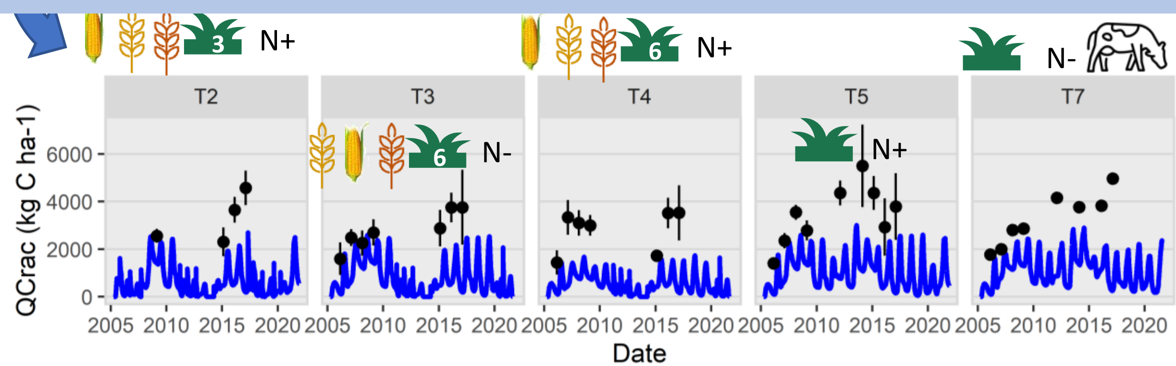


Comparison of root C (opti N°3)

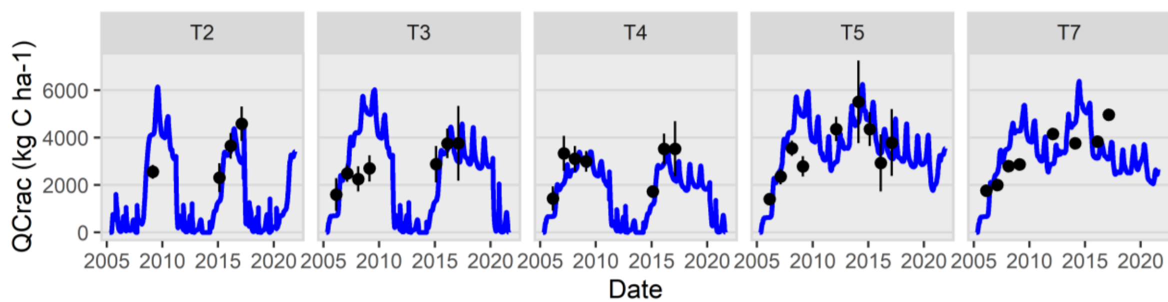


- Root C dynamics clearly better simulated after optimization (RMSE divided by 2.3)
- Same for root N

Before optimization

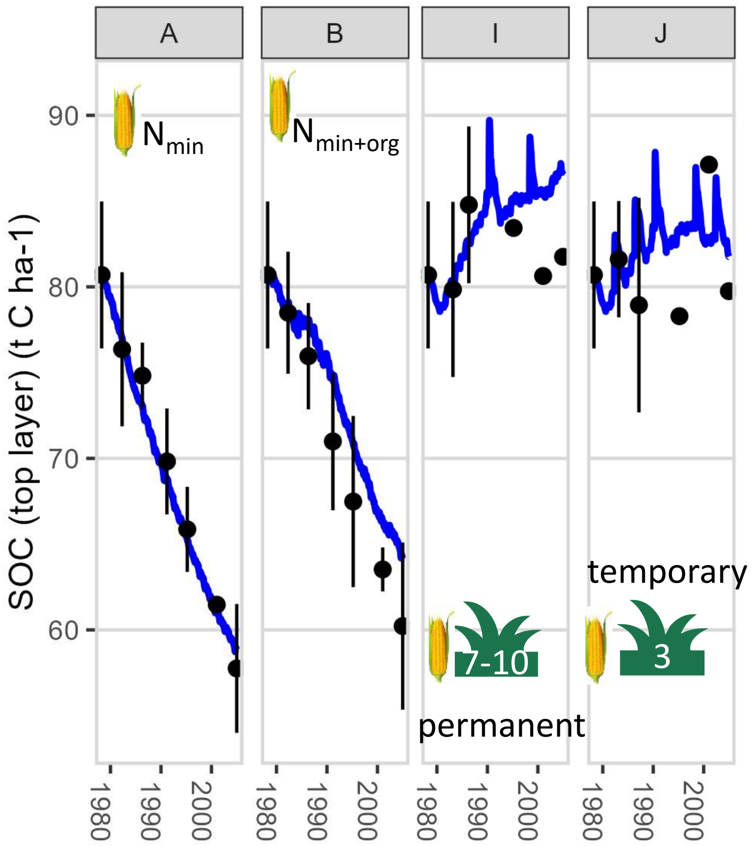


After optimization



Model assessment - Kerbernez site simulation

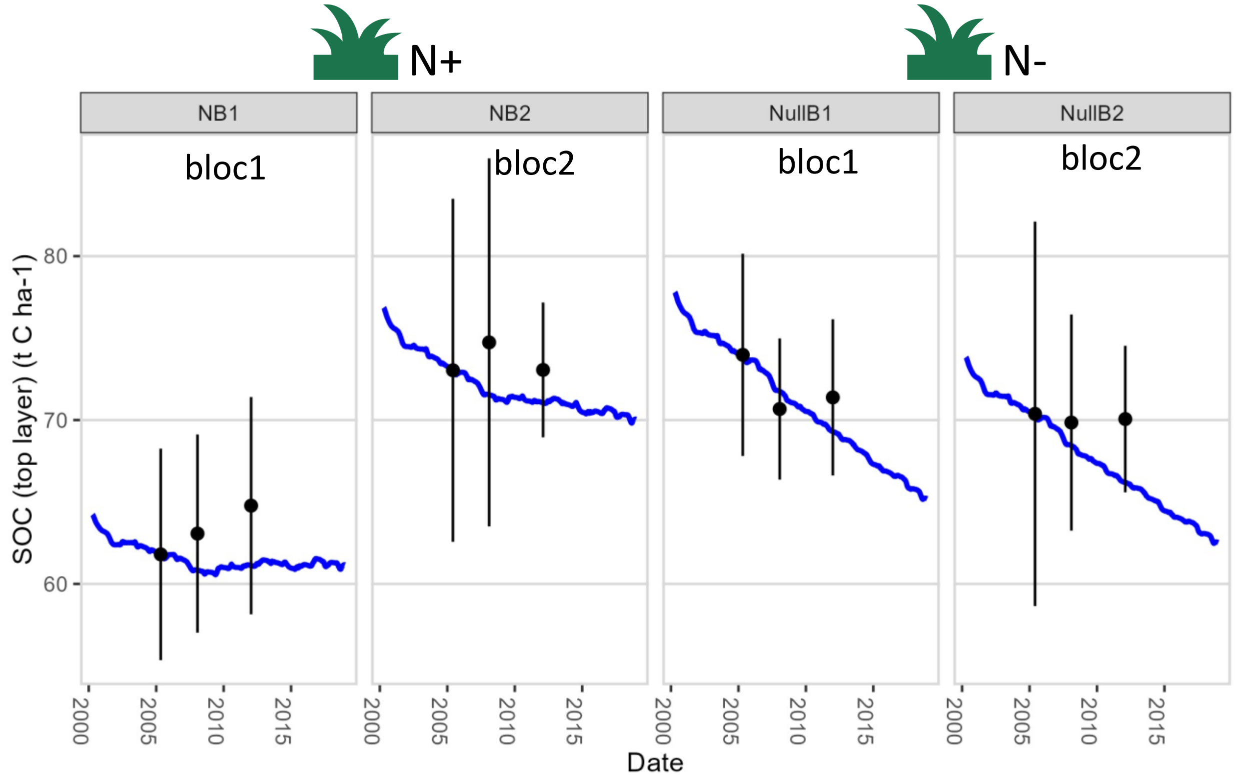
- 2 silage maize monocultures: A with only ammonitrate, B with both ammonitrate and cattle or pig manure
- 2 grasslands alternating with corn, cut 5 times/year, with ≈ 250 kg N/ha/year



- Uncertainty surrounding observations in the 2nd half of the trial
- SOC dynamics under temporary and permanent grassland quite well represented, as well as grass DM yields and N content

Model assessment - Theix site simulation

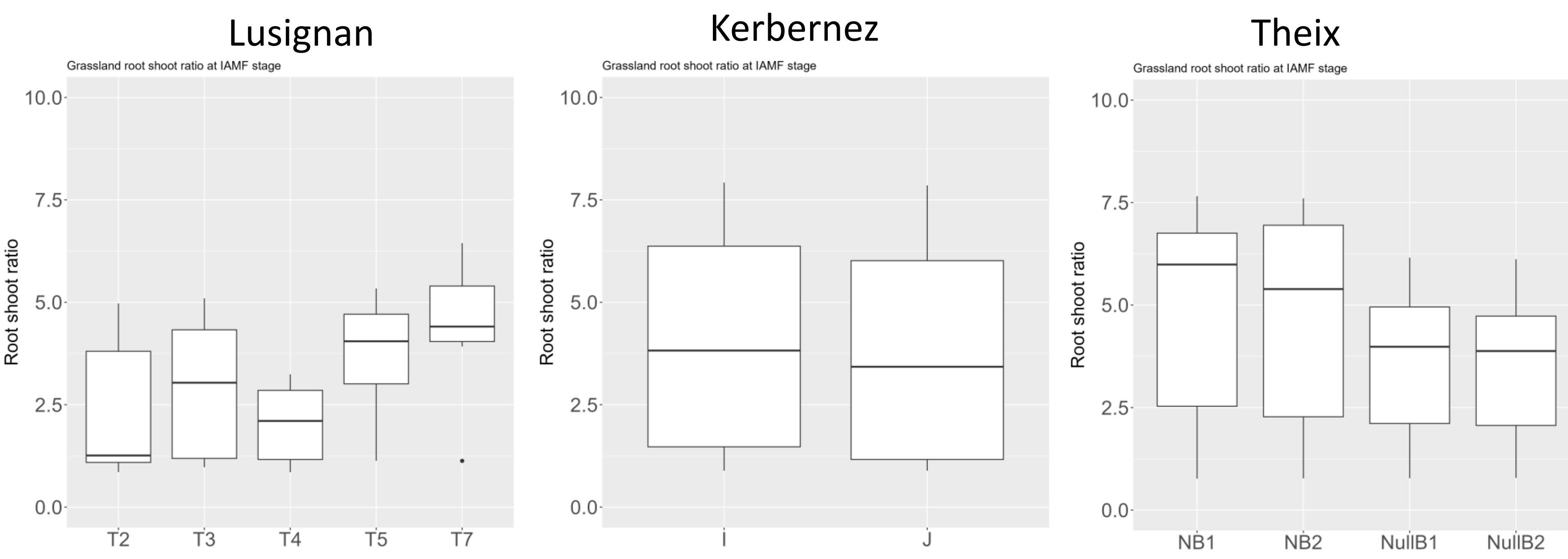
- 4 permanent grasslands, cut 3 times a year, with 250 kg N/ha/year (N+) or no N fertilizer (N-), with soil heterogeneity between blocks



- A few observations with very high variability, 2016 samples not yet analyzed
- SOC dynamics quite well represented (N+: maintained SOC; N-: ↘ SOC, perhaps too large in relation to the trend observed)

Model assessment - orders of magnitude

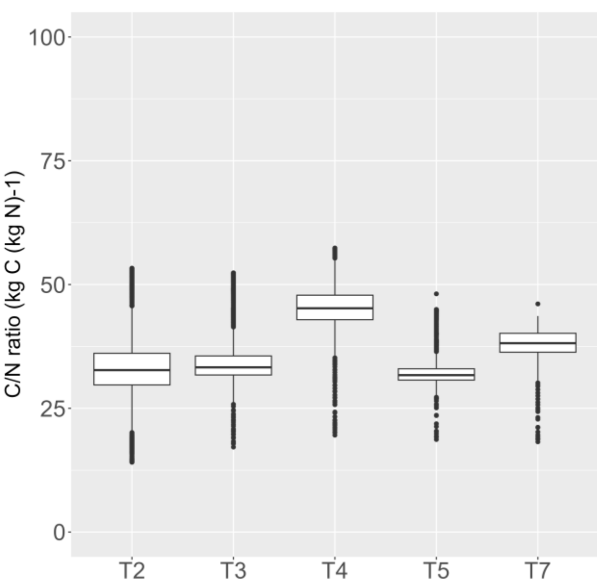
- Simulated grass root/shoot ratio at IAMF stage
  - **within the expected range** from **0.8 to 26** (Poeplau, 2016) ; Median ≈ 4.2 – 4.5 (Mokany et al. 2006)
  - **But ratio is not higher in fertilized treatments** (higher investment of plants in roots for N acquisition under N deficiency according to Poeplau, 2016)



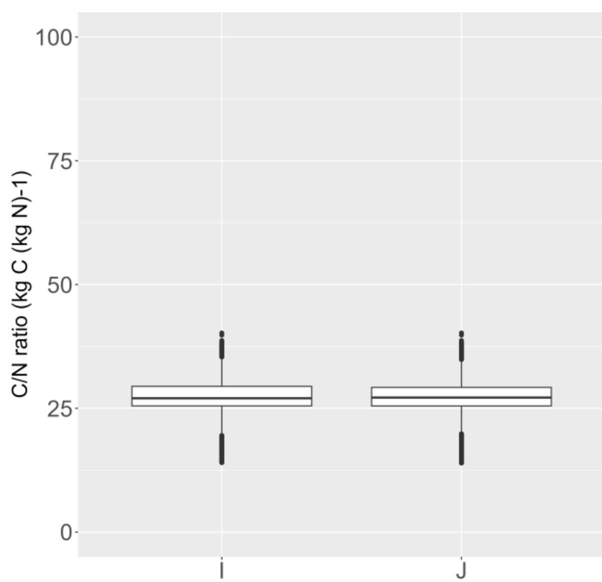
Model assessment - orders of magnitude

- Simulated grass root C/N ratio
  - Simulated values **within the expected range from 36 to 118 kg C (kg N)$^{-1}$** (Legay et al., 2016)
  - **Higher** C/N ratio **in unfertilized** or **lightly fertilized** treatments

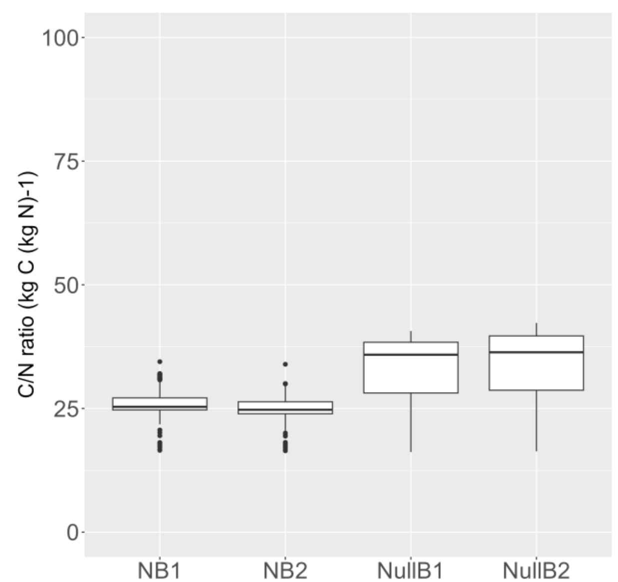
Lusignan



Kerbernez



Theix



Conclusions

- Encouraging results
  - Without revising the formalisms, **satisfactory simulation of SOC under** temporary and permanent **grasslands**
  - A **more realistic representation of roots** with a parameterization that improves root C and N simulation
  - **Consistent orders of magnitude** for root biomass, root/shoot ratio, N content and root C/N ratio
- A parameterization reserved for productive grasslands
  - Composed of **species with a resource capture/rapid organ recycling strategy** (groups A, B, b after Cruz et al. 2010)

Thank you for your attention